Feb. 2, 1960 P. U. REUSSER 2,923,106

GRINDING MACHINE

Filed Aug. 14, 1958 4 Sheets-Sheet 1

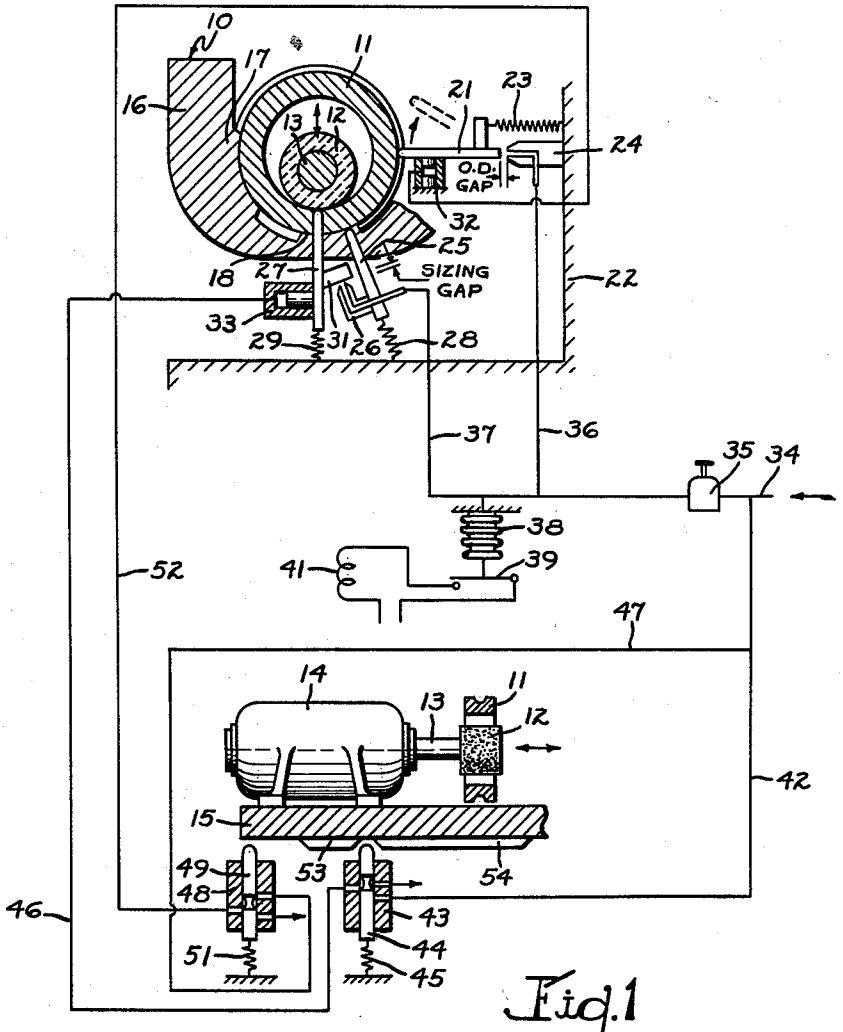


Fig. 1

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GRINDING MACHINE

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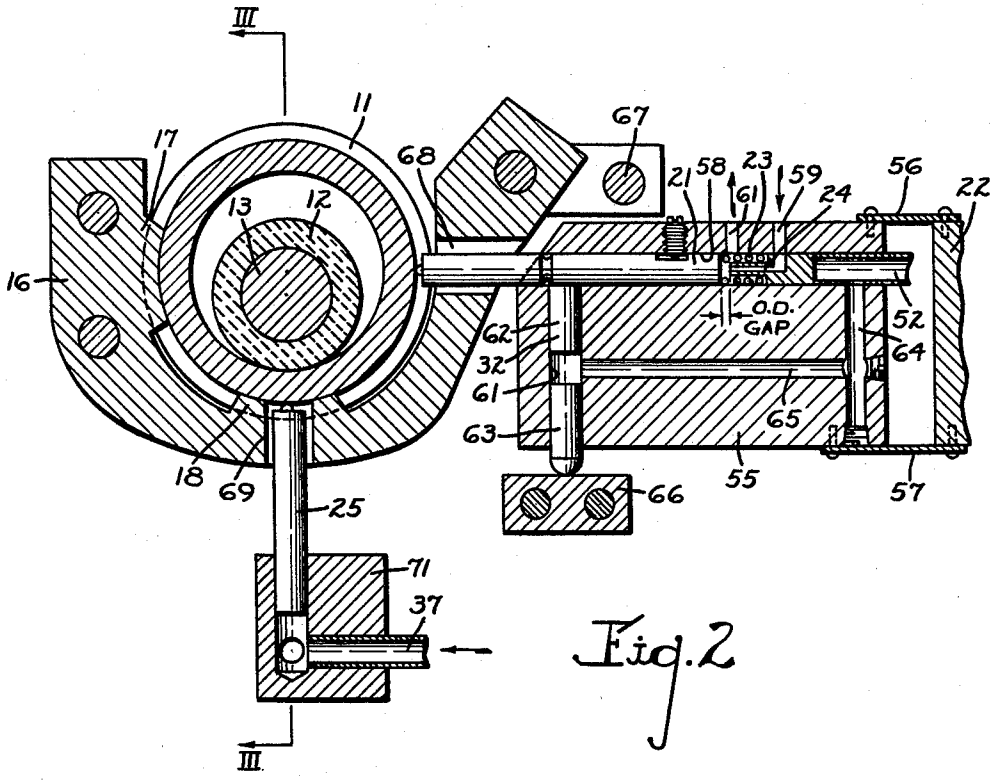


Fig. 2

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GRINDING MACHINE

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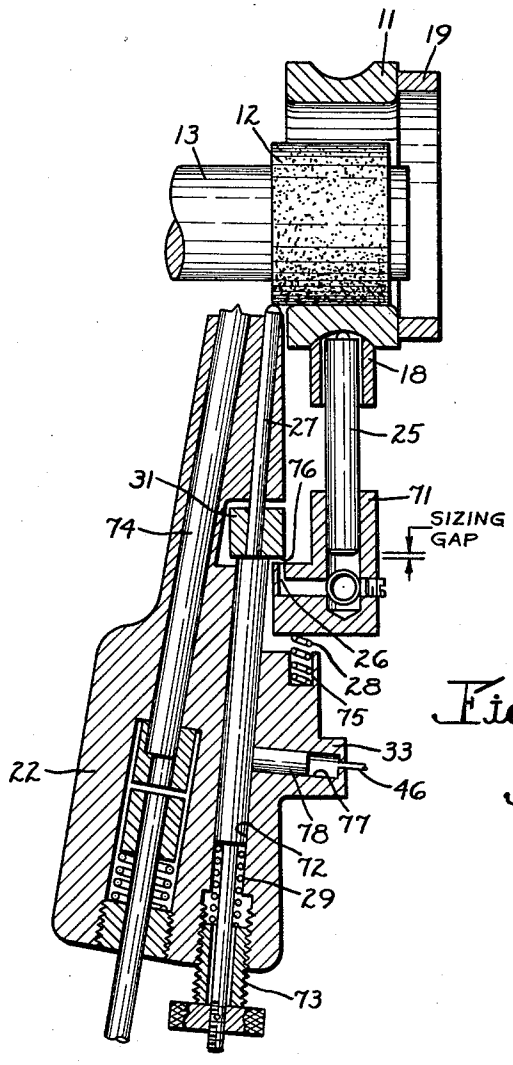


Fig. 3

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GRINDING MACHINE

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	WHEEL	WORKPIECE	O.D. COMP. FEELER	O.D. REF. FEELER	I.D. FEELER
1	RETRACTED	INSERTED IN SHOE	UNCLAMPED + IN OPERATIVE POSITION	FLOATING	CLAMPED
2	ADVANCE + DRESS	IN SHOE	UNCLAMPED + IN OPERATIVE POSITION	ENGAGES WORKPIECE	CLAMPED
3	IN BORE	IN SHOE	CLAMPED + IN INOPERATIVE POSITION	ENGAGES WORKPIECE	CLAMPED
4	EXTENDS FROM END OF BORE	IN SHOE	CLAMPED + IN INOPERATIVE POSITION	ENGAGES WORKPIECE	UNCLAMPED + ENGAGES WHEEL
5	STEPS 3+4 REPEATED UNTIL FINISH SIZE REACHED				
6	WHEEL STARTS TO RETRACT	IN SHOE	CLAMPED + INOPERATIVE POSITION	ENGAGES WORKPIECE	CLAMPED
7	RETRACTED	REMOVED FROM SHOE	UNCLAMPED + IN OPERATIVE POSITION	FLOATING	CLAMPED

Fig. 4

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United States Patent Office 2,923,106 Patented Feb. 2, 1960

2,923,106

GRINDING MACHINE

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Application August 14, 1958, Serial No. 755,075

16 Claims. (Cl. 51—165)

This invention relates to a grinding machine and more particularly to apparatus arranged accurately to grind an internal bore in a workpiece.

In the finished grinding of internal bores, it has been the practice in the past to remove the abrasive wheel from the bore while a gauge is inserted to determine whether the bore has reached a predetermined size or not. One difficulty experienced with the practice of removing the wheel from the work is that, as the wheel moves out of the bore, a taper remains and when the wheel is inserted again, the wheel climbs up the narrow taper and builds up very high forces over the length of the taper, thus crushing the wheel. In order to eliminate this, the force has to be kept low enough so that the ends of the wheel are not crushed. The ideal way to take care of this problem is to use a long wheel which extends from both ends of the bore and to use oscillations which are very short so that the ends of the wheel never enter the bore. However, in order to gauge size accurately it is necessary that a gauge reading be taken at the end of each oscillation of the wheel. None of the previously known gauging systems will permit this type of operation. These and other difficulties experienced with the prior art devices have been obviated in a novel manner by the present invention.

It is, therefore, an outstanding object of the invention to provide a grinding machine having a gauging system which permits the wheel to stay within the workpiece during the entire grinding cycle.

Another object of this invention is the provision of a gauging apparatus in which entrance of the gauge into the workpiece bore is not necessary.

A still further object of the present invention is the provision of a novel compensation for variation of outside diameters of successive workpieces.

It is a still further object of this invention to provide a grinding machine containing a gauging apparatus for use with bearing races or the like in which means is provided for compensating for variations in the outside diameters of workpieces and for gauging the internal diameter of the workpiece during an internal grinding operation without removing the wheel from the bore.

It is another object of the instant invention to provide apparatus for compensating for varying outside diameters of workpieces having internal bores to be ground on a shoe-type grinding machine.

Another object of the invention is a provision of means for compensating for variation in outside diameter of a circular workpiece in which changes in size due to thermal effects during grinding have no effect on the final size.

It is another object of this invention to provide a gauging means for internal grinding wherein compensation is automatically made for wheel wear at every stroke of the machine.

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:

Figure 1 is a schematic view of an internal grinding machine embodying the principles of the present invention,

Figure 2 is an enlarged detailed view of a portion of the apparatus,

Figure 3 is a sectional view of the apparatus taken on the line III—III of Figure 2, and

Figure 4 is a chart showing the condition of the various elements of the invention at selected times during the grinding cycle.

Referring first to Figure 1, wherein are best shown the general features of the invention, the grinding machine, indicated generally by the reference numeral **10**, is shown being used in grinding an internal bore in a workpiece **11**, which workpiece in this case is shown as being the inner race of a ball bearing. It will be noted that in Figure 1 several of the elements are repeated for ease in understanding the invention. An abrasive wheel **12** having a drive shaft **13** is shown within the bore of the workpiece **11**. The grinding machine is constructed so that feeding motion of the wheel **12** toward the surface of the bore of the workpiece takes place in a vertical direction, as shown by the arrow.

The wheel **12** and the shaft **13** are driven by a wheelhead **14** mounted on a table **15**. The workpiece **11** is mounted in a support **16** having shoes **17** and **18** which engage the workpiece **11** on its outer surface. In the present case, contact is made in the semicircular groove usually formed on the outside periphery of the inner races of ball bearings. One end of the workpiece **11** is held against a drive platen **19** (see Figure 3) which is driven and which is slightly eccentric with the axis of the workpiece so that the friction forces tend to force the workpiece down into the shoes **17** and **18** so that the workpiece does not jump out of the machine. A conventional clamping means, not shown, is provided at the other end of the workpiece to hold it against the drive platen **19**.

An O.D. compensation feeler **21** is slidably mounted in a fixed base **22** of the machine and is resiliently biased by a spring **23** into engagement with the outside surface of the workpiece **11** at a point opposite the shoe **17**. An O.D. nozzle **24** is also mounted on the base **22** in alignment with the outer end of the feeler **21** to detect axial movement of the feeler. An O.D. reference feeler **25** is slidably mounted relative to the base **22** to engage the outside diameter of the workpiece **11** in the vicinity of the shoe **18** and this feeler is also provided with a sizing nozzle **26** which is directed parallel to the feeler and toward the workpiece. An I.D. feeler **27** is slidably mounted in the base **22** to contact the wheel **12** on occasion. A spring **28** biases the feeler **25** toward the workpiece and a spring **29** biases the feeler **27** toward the wheel **12**. The I.D. feeler **27** is provided with a laterally extending block **31** which extends in front of the nozzle **26** defining therewith a "sizing gap."

The feeler **21** is provided with a clamping and swinging means **32** while the feeler **27** is provided with a clamp **33**.

A source of air under pressure, not shown, is connected through a line **34** to one side of a pressure regulating valve **35**, the other side of which is connected through a line **36** to the nozzle **24** and also through a line **37** to the nozzle **26**. The lines **36** and **37** are also connected to a pressure bellows **38** whose outer end is connected to an electrical switch **39**. The switch lies in a power line leading from an electrical power source, not shown, to a coil **41** which, when energized, terminates the feed mechanism, not shown, of the grinding machine. A feed

mechanism of the type which may desirably be used in the present grinding machine is shown in the patent to Schmidt et al. No. 2,771,714, wherein the solenoid **96** is the equivalent of the coil **41** shown in the present invention.

The pressure air line **34** is also connected by a line **42** to one side of a plunger-type valve **43** having a plunger **44** which is biased by a spring **45** in such a manner that the valve is closed under normal circumstances. The other side of the valve **43** is connected by means of a line **46** to the clamp **33** associated with the I.D. feeler **27**. The pressure air line **34** is also connected by means of a line **47** to one side of a plunger-type valve **48** having a plunger **49** which is biased by a spring **51** in such a manner that the valve is normally opened when the valve is in its normal position. The other side of the valve **48** is connected by means of a line **52** to the clamping and swinging means **32** associated with the O.D. compensation feeler **21**. The valves **43** and **48** are located under the table **15** which carries the wheelhead **14** in such a manner that their plungers may be contacted by cams **53** and **54** formed on the underside of the table. The particular location, arrangement, and shape of the cams and plungers will be more completely described in connection with the operation of the apparatus.

Referring next to Figures 2 and 3, wherein are best shown the details of the control apparatus, it can be seen that the O.D. compensation feeler **21** is slidably mounted in a block **55** which, in turn, is mounted for swinging movement by means of reeds **56** and **57** which connect it to a portion of the base **22**. The feeler is mounted in a bore **58** and in this same bore is mounted the nozzle **24** which has a long nose and is surrounded by the spring **23**. A port **59** extends through the block **55** and has access to the nozzle **24** and an exit port **61** passes through the block **55** into the bore **58** to provide an exit for any air which passes out of the nozzle between the end of the nozzle and the end of the feeler **21**. The clamping and swinging means **32** consist of a bore **61** formed in the block **55** and carrying therein two plungers **62** and **63**. The line **52** carrying air under pressure enters the bore **58** outboard of the nozzle **24** and gains access to the space between the plungers **62** and **63** by means of passages **64** and **65** extending through the block **55**. A stop **66** is fastened to the base **22** in line with the plunger **63** and closely adjacent thereto, while a stop **67** is attached to the support **16** some distance above the block **55**. An enlarged passage **68** is formed in the support member **16** to permit free swinging of the feeler **21**.

A passage **69** is formed in the support **16** to permit the entrance of the feeler **25** and to permit its engagement with the outer surface of the workpiece **11**. The lower end of the feeler **25** is fixed in a block **71** having formed therein the passages leading to the nozzle **26**; the line **37** is suitably attached to the block and to these passages. The I.D. feeler **27** is slidably mounted in a bore **72** formed in a portion of the base **22** and the spring **29** lies in the bore at the outer end of the feeler, thus providing a compressive force between the end of the feeler and a plug **73** threaded into the end of the bore **72**. A suitable diamond dressing tool **74** is also mounted in the base **22** beside the I.D. feeler **27**, but this construction forms no direct part of the present invention. A suitable recess **75** is formed in the portion of the base **22** containing the feeler **27** properly to seat the spring **28** which presses against the block **71** and in turn presses the feeler **25** continually against the outside diameter of the workpiece **11**. The axis of the feeler **27** is somewhat inclined to a line at right angles to the axis of the wheel **12** so that the feeler may more easily engage a small portion of the wheel as it emerges from the bore. A surface **76** of the block **31** is arranged so as to be parallel to the axis of the wheel and to cooperate with the nozzle **26** to form the sizing gap. The clamp **33** consists of a bore **77** formed in the portion of the base **22** which contains the feeler **27**, and a plunger **78** situated in the bore. Access to the bore **77** is provided for the line **46** so that pressure air may be admitted thereto.

The cross-sectional area of the O.D. nozzle **24** is selected to be one-half that of the sizing nozzle **26**; the apparatus is arranged so that, when a workpiece **11** of exactly the proper O.D. is used in the machine, the O.D. gap and the sizing gap will be equal at the moment that the proper I.D. is reached in the grinding cycle. The selection of these relationships will be explained more fully hereinafter.

The operation of the apparatus of the invention will now be readily understood in view of the above description. Referring to Figure 4, it can be seen that at the beginning of the grinding cycle the wheel **12** is in retracted position and is outside of the bore of the workpiece away from the support **16**. The workpiece is inserted in the support **16** so that its outside diameter lies against the shoes **17** and **18**. At that time the O.D. compensation feeler **21** is in the position shown in Figure 2 and is free to slide in its bore **58** under the impetus of the spring **23**. At the same time the O.D. reference feeler **25** is free to move vertically and is pressed upwardly by the spring **28**. At this time the I.D. feeler **27** is clamped by the plunger **78**. This is because the valve **43** is in the condition in which the plunger **44** is contacted by the cam **54** and is depressed, so that the valve is open and air passes from a line **42** to the line **46** into the bore **77**. The feeler **27**, therefore, is not free to move in its bore **72** under the impetus of the spring **29**. At the second stage of the grinding cycle the wheel **12** advances axially toward the workpiece and toward the support **16**. It is, of course, being rotated at a high rate of speed by the wheelhead **14**. In passing toward the workpiece the wheel passes over the diamond dressing tool **74** and is dressed. At this stage of the cycle the workpiece is firmly held against the shoes **17** and **18**; because the platen **19** is rotating and because of the eccentric position of the platen, the workpiece is forced into positive contact with the shoes **17** and **18**. The O.D. compensation feeler is, of course, unclamped and engages the outside diameter of the workpiece **11**. In a similar manner, the O.D. reference feeler engages the outside of the workpiece, but the I.D. feeler **27** remains clamped as before. In the third stage of the dressing cycle, the wheel resides within the bore of the workpiece and, as is evident in Figure 3, the wheel is slightly longer than the bore, so that during this portion of the cycle it extends from both ends of the workpiece. However, it extends only by a sufficient amount to permit the reciprocating action which is usual with machines of this type. During this third portion of the grinding cycle, when the wheel is entirely within the bore, the O.D. compensation feeler **21** becomes clamped and is moved into an inoperative position. This is because of the fact that the cam **53** no longer depresses the plunger **43** of the valve **48**. While the wheelhead and wheel were in retracted position, the cam **53** held the plunger **49** in a downward position, so that the valve was in effect closed and the line **52** was connected with atmosphere so that clamping did not take place in the clamping means **32**. As the wheel moves into the bore, however, the cam **53** is removed from the plunger so that the plunger moves upwardly to connect the air pressure line **47** to the line **52** and to permit air to enter the bore **61** in the block **55**. The air, therefore, presses the plunger **62** and **63** apart. This has the effect first of clamping the feeler **21** in its bore **58** and, secondly, to move the block and feeler upwardly about the pivot furnished by the reeds **56** and **57**. The block ultimately strikes the stop **67** and cannot move upwardly further. By that time the feeler **21** has been moved away from outer surface of the workpiece **11**. The O.D. reference feeler **25** continues to engage the outside diameter of the workpiece and the I.D. feeler **27** is still clamped. At the fourth part of the cycle the wheel at the end of one of its reciprocations ex-

tends from the end of the bore in the manner shown in Figure 3. The O.D. compensation feeler **21** remains clamped and in its inoperative position and the O.D. reference feeler **25** continues to engage the workpiece. The I.D. feeler **27**, however, is unclamped and engages the wheel. This is because of the fact that, as the wheel comes out of the bore, the cams **53** and **54** straddle the plunger **44** of the valve **43** and the plunger is no longer depressed. This means that the plunger is in its upright position in which the line **42** is not connected to the line **46** and the line **46** is open to atmosphere. The plunger **78** is thus relieved of pressure and the spring **29** presses the feeler **27** forwardly against the surface of the wheel **12**. The sizing gap, which is the space between the nozzle **26** and the surface **76** of the block **31** is, therefore, indicative of the wall thickness of the workpiece at that moment. The condition of the elements described in connection with Steps 3 and 4 are repeated as the wheel reciprocates within the bore of the workpiece. The I.D. workpiece feeler **27** being clamped when the wheel does not extend from the bore and being unclamped and engaging the wheel when it does extend from the bore. Eventually the pressure is reached at which the bellows **38** closes the switch **39** and energizes the coil **41** thus stopping the feed of the machine and retracting the wheel. In Step 6 of the cycle, wherein the wheel starts to retract, the O.D. compensation feeler **21** is still clamped and is in its inoperative position. The O.D. reference feeler **25** continues to engage the outside diameter of the workpiece and the I.D. feeler **27** is in clamped condition. The final Step 7 of the cycle comes about when the wheel is entirely retracted and the workpiece is removed from the shoe. With the wheel in retracted position the cam **53** again engages the plunger **49** of the valve **48** and puts it in lower position so that the line **52** is open to atmosphere and the block **55** swings downwardly and the feeler **21** is free to slide in its bore **58** under the impetus of the spring **23**. The O.D. reference feeler **25**, as always, continues to float in raised position under the biasing action of the spring **28**; furthermore, the I.D. feeler **27** is clamped, since the cam **54** resides on the upper end of the plunger **44** of the valve **43** and causes air pressure to act against the plunger **78**.

As has been described above, the bellows **38** actuates the switch **39** to end the grinding cycle when the pressure in the bellows rises above a pre-determined value. The pressure in the bellows is determined by the sum of the leakages through the O.D. gap and through the sizing gap. At the beginning of the grinding cycle the sizing gap is very large so that the pressure in the bellows is fairly low, irrespective of how small the O.D. is. As the workpiece bore approaches the desired size the sizing gap gets smaller and smaller. Eventually, the amount of air escaping from the O.D. gap and from the sizing gap is so small that the pressure rises sufficiently to cause the bellows **38** to close the switch **39** and terminate the grinding cycle. Let us suppose, for instance, that the outside diameter of the workpiece is larger than its normal value. Then, the O.D. gap is small and the leakage of air through the O.D. gap is also small so that its pressure contribution to the bellows **38** is larger than normal; this means that the sizing gap does not have to become quite as small as usual to bring the total pressure up to the amount necessary to actuate the cycle stopping switch. Naturally, since the sizing gap is larger, when the switch is actuated in this unusual condition, the wall thickness (O.D.—I.D./2) will be greater, which is what is desired to give a fixed I.D. when the O.D. is too large. If the cross-sectional area A of the O.D. nozzle is selected to be twice that of the cross-sectional area B of the sizing nozzle **26**, the change in sizing gap will exactly compensate for the fact that the O.D. is too large. This is because of the fact that, if the O.D. is large by a certain amount d, the wall thickness must be increased by half that amount $d/2$, to obtain the selected I.D. Since the O.D. gap increases by the same amount as the O.D. decreases, thus increasing the escapement area by the nozzle circumference multiplied by the change in gap, the sizing gap (at the moment of switch actuation) must be decreased an amount sufficient to keep the total of the escapement areas constant. The amount of decrease of the sizing escapement area must be equal to the increase in escapement area at the O.D. gap. That is to say, I want to keep the sum of the escapement areas the same, irrespective of whether the O.D. is large or small. This means that

$$\sqrt{\frac{4B}{3.14}}$$

(normal sizing gap decrease in the sizing cap e) plus

$$\sqrt{\frac{4A}{3.14}}$$

(normal O.D. gap$+d$) should always be maintained equal to

$$\sqrt{\frac{4B}{3.14}}$$

(normal sizing gap)$+$

$$\sqrt{\frac{4A}{3.14}}$$

(normal O.D. gap). Since it is necessary to keep the I.D. constant, it is necessary that e equal $d/2$; then $B \times d/2$ must equal $A \times d$ or A/B equals ½. If the area, A, of the O.D. nozzle is ½ of the area B of the sizing nozzle, the correct compensation of I.D. will be made for every variation of O.D. It will be understood that, since the nozzle **24** of the O.D. gap "memorizes" the diameter of the workpiece before the grinding cycle begins, the subsequent expansion of the workpiece during the grinding cycle will not affect the size of the finished surface after the workpiece has cooled. The apparatus, therefore, is effective to compensate for thermal changes during the grinding cycle.

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 in 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 for use with a workpiece having an outer surface and a bore of circular cross-section, comprising means giving a first signal indicative of the position of the said outer surface of the workpiece relative to a reference plane, means giving a second signal indicative of the position of the surface of the bore of the workpiece relative to the reference plane, the said second signal changing during the grinding operation as the diameter of the bore becomes larger, means adding the first and second signals and serving to terminate the grinding operation when the sum reaches a predetermined value.

2. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-section, comprising an abrasive wheel for grinding the surface of the bore, the wheel being longer than the bore so that it extends from the ends of the bore, means adapted to engage the outer surface for producing a first signal indicative of its position relative to a reference plane, means for engaging the surface of the wheel when it extends a substantial amount from one end of the bore, the position of said means producing a second signal indicative of the position of the surface of the bore of the workpiece relative to the reference plane, the said second signal changing during the grinding operation as the diameter of the bore becomes larger, means adding the first and second signals in serving to terminate the grind-

ing operation when the sum reaches a pre-determined value.

3. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-section, comprising an abrasive wheel for grinding the surface of the bore, the wheel being longer than the bore so that it extends from the ends of the bore, means adapted to engage the outer surface for producing a first signal indicative of its position relative to a reference plane, means for engaging the surface of the wheel when it extends a substantial amount from one end of the bore, the position of said means producing a second signal indicative of the position of the surface of the bore of the workpiece relative to the reference plane, means for maintaining the second signal at its previous value while the wheel is in the bore and is not engaged with said means the said second signal changing during the grinding operation as the diameter of the bore becomes larger, means adding the first and second signals and serving to terminate the grinding operation when the sum reaches a pre-determined value.

4. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-section, comprising an air gauging system including a sizing nozzle and a sizing surface associated therewith for determining the air escapement area, a feeler engaging the outer surface and serving to move the sizing nozzle an amount indicative of the position of the said outer surface of the workpiece relative to a reference plane, a feeler serving to move the sizing surface an amount indicative of the position of the surface of the bore of the workpiece relative to the reference plane, the said second signal changing during the grinding operation as the diameter of the bore becomes larger, the sizing nozzle and sizing plane determining an air pressure which serves to terminate the grinding operation when the pressure reaches a predetermined value.

5. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-section, comprising an abrasive wheel for grinding the surface of the bore, the wheel being longer than the bore so that it extends from the ends of the bore, an air gauging system including a sizing nozzle and a sizing surface associated therewith for determining the air escapement area, a feeler engaging the outer surface and serving to move the sizing nozzle an amount indicative of the position of the said outer surface of the workpiece relative to a reference plane, a feeler for gauging the surface of the wheel when it extends a substantial amount from one end of the bore, the feeler serving to move the sizing surface an amount indicative of the position of the surface of the bore of the workpiece relative to the reference plane, means for fixing the position of the feeler while the wheel is in the bore and is not engaged with the feeler, the said sizing surface changing during the grinding operation as the diameter of the bore becomes larger, the sizing nozzle and sizing plane determining an air pressure which serves to terminate the grinding operation when the pressure reaches a pre-determined value.

6. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-section, comprising means giving a first signal indicative of the diameter of the outer surface, a shoe having a surface contacting the said outer surface and supporting the workpiece during a grinding operation, means giving a second signal indicative of the position of the surface of the shoe relative to a reference plane, and means operative to terminate the grinding operation when the bore has been enlarged to a normal finished size varied by an amount which is proportional to the amount of variation of the ratio of the first signal to the second signal from a pre-determined value.

7. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-section, comprising a grinding element, means adapted to engage the outer surface for producing a first signal indicative of the diameter of the outer surface, a shoe having a surface contacting the said outer surface and supporting the workpiece during a grinding operation, means adapted to engage the grinding element for producing a second signal indicative of the position of the surface of the shoe relative to a reference plane, a given change in the diameter of the outer surface producing one half as much change in the first signal as is produced in the second signal by the same amount of change in the position of the surface of the shoe relative to the reference plane, and means operative to terminate the grinding operation when the bore has been enlarged to a normal finished size varied by an amount which is proportional to the amount of variation of the ratio of the first signal to the second signal from a pre-determined value.

8. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-section, comprising means adapted to engage the outer surface for producing a first signal indicative of the diameter of the outer surface, said means being disengaged from the workpiece at the beginning of a grinding operation and maintaining the first signal at its previous value, a shoe having a surface contacting the said outer surface and supporting the workpiece during a grinding operation, means adapted to engage the grinding element for producing a second signal indicative of the position of the surface of the workpiece relative to a reference plane, and means operative to terminate the grinding operation when the bore has been enlarged to a normal finished size varied by an amount which is proportional to the amount of variation of the ratio of the first signal to the second signal from a pre-determined value.

9. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-section, comprising an air gauging system including an outside diameter compensating nozzle and a sizing nozzle, the compensation nozzle being responsive to the position of a feeler engaging the workpiece for producing a first pressure indicative of the diameter of the outer surface, a shoe having a surface contacting the said outer surface and supporting the workpiece during a grinding operation, the sizing nozzle being responsive to the position of a feeler for producing a second pressure indicative of the position of the surface of the shoe relative to a reference plane, a means operative to terminate the grinding operation when the bore has been enlarged to a normal finished size varied by an amount which is proportional to the amount of variation of the ratio of the first pressure to the second pressure from a pre-determined value.

10. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-section, comprising an air gauging system including an outside diameter compensating nozzle and a sizing nozzle, the areas of the said nozzles being in the ratio of one to two, the compensating nozzle being responsive to the position of an associated feeler for producing a first pressure indicative of the diameter of the outer surface, means for moving the compensating nozzle feeler away from the workpiece at the beginning of a grinding operation and maintaining the first pressure at its previous value, a shoe having a surface contacting the said outer surface and supporting the workpiece during a grinding operation, the sizing nozzle being responsive to the position of an associated feeler for producing a second pressure indicative of the position of the surface of the shoe relative to a reference plane, a given change in the diameter of the outer surface producing one half as much change in the first pressure as is produced in the second pressure by the same amount of change in the position of the surface of the shoe relative to the reference plane, and means operative to terminate the grinding operation when the feed depth has reached a normal finish position varied by an amount which is ½ of the O.D. variation and the resulting air pressure has reached a pre-determined value.

11. A grinding machine for use with a workpiece having an outer surface and a bore of circular cross-sectional shape, comprising means giving a first signal indicative of the diameter of the outer surface, means giving a second signal indicative of the position of the surface of the bore relative to a fixed reference plane, the said second signal changing in value during the grinding operation as the diameter of the bore becomes larger, a shoe having a surface contacting the said outer surface and supporting the workpiece during a grinding operation, means giving a third signal indicative of the position of the surface of the shoe relative to the reference plane, and means for receiving and adding the three signals and terminating the grinding operation when the summation of the signals reaches a pre-determined value.

12. An internal grinding machine for use with a workpiece having a bore and an outer surface of circular cross-section comprising an abrading wheel, a support for contacting and supporting the outer surface of the workpiece during the grinding operation, the support including shoes contacting the outer surface at angularly spaced positions, an outside diameter compensation gauge engaging the outer surface of the workpiece at a position diametrically opposite the position of contact with one of the shoes and giving a first signal indicative of the diameter of the workpiece, an outside diameter reference gauge engaging the outer surface of the workpiece near the position of contact with one of the shoes, an inside diameter gauge engaging the wheel when it extends from the bore, the reference gauge and the inside diameter gauge being inter-related to give a second signal indicative of the wall thickness of the workpiece, the second signal changing as the grinding operation progresses, and means receiving the signals and acting to terminate the grinding operation when their sum reaches a pre-determined value.

13. An internal grinding machine for use with a workpiece having a bore and an outer surface of circular cross-section, comprising an abrading wheel, a support for contacting and supporting the outer surface of the workpiece during a grinding operation, an air gauging system including an outside diameter compensating nozzle and a sizing nozzle, the areas of the said nozzles being in the ratio of one to two, the support including shoes contacting the outer surface at angularly-spaced positions, the outside diameter compensation nozzle having an associated feeler engaging the outer surface of the workpiece at a position diametrically opposite the position of contact with one of the shoes for producing a first pressure indicative of the diameter of the workpiece, an outside diameter reference gauge engaging the outer surface of the workpiece nearer the position of contact with one of the shoes, an inside diameter gauge engaging the wheel when it extends from the bore, the reference gauge and the inside diameter gauge being interrelated with the sizing nozzle to give a second pressure indicative of the wall thickness of the workpiece, the second pressure changing as the grinding operation progresses, and means receiving the pressure and acting to terminate the grinding operation when their sum reaches a pre-determined value.

14. An internal grinding machine for use with a workpiece having a bore and an outer surface of circular cross-section, comprising an abrading wheel, a support for contacting and supporting the outer surface of the workpiece during a grinding operation, the support including shoes contacting the outer surface at angularly-spaced positions, an outside diameter compensation gauge engaging the outer surface of the workpiece at a position diametrically opposite the position of contact with one of the shoes and giving a first signal indicative of the diameter of the workpiece, means for moving the compensation gauge away from the workpiece at the beginning of a grinding operation and maintaining the said first signal at is previous valve during the time that the compensation gauge is so moved, an outside diameter reference gauge engaging the outer surface of the workpiece near the position of contact with one of the shoes, an inside diameter gauge engaging the wheel when it extends from the bore, the reference gauge and the inside diameter gauge being inter-related to give a second signal indicative of the wall thickness of the workpiece, the second signal changing as the grinding operation progresses, and means receiving the signals and acting to terminate the grinding operation when their sum reaches a pre-determined value.

15. An internal grinding machine for use with a workpiece having a bore and an outer surface of circular cross-section, comprising an abrading wheel, a support for contacting and supporting the outer surface of the workpiece during a grinding operation, the support including shoes contacting the outer surface at angularly-spaced positions, an outside diameter compensation gauge engaging the outer surface of the workpiece at a position diametrically opposite the position of contact with one of the shoes and getting a first signal indicative of the diameter of the workpiece, an outside diameter reference gauge engaging the outer surface of the workpiece near the position of contact with one of the shoes, an inside diameter gauge engaging the wheel when it extends from the bore, a reference gauge and the inside diameter gauge being inter-related to give a second signal indicative of the wall thickness of the workpiece, the second signal changing as the grinding operation progresses, a given change in the diameter of the outer surface producing in the second signal by the same amount of change in the position of the surface of the shoe relative to the reference plane, and means receiving the signals and acting to terminate the grinding operation when their sum reaches a predetermined value.

16. An internal grinding machine for use with a workpiece having a bore and an outer surface of circular cross-section, comprising an abrading wheel for grinding the surface of the bore, the wheel being longer than the bore so that it extends from the ends of the bore, a support for contacting and supporting the outer surface of the workpiece during a grinding operation, an air gauging system including an outside diameter compensating nozzle and a sizing nozzle, the areas of the said nozzles being in the ratio of one to two, the support including shoes contacting the outer surface at angularly-spaced positions, the outside diameter compensation gauge nozzle being responsive to the position of an associated feeler engaging the outer surface of the workpiece diametrically opposite the position of contact with one of the shoes for producing a first pressure indicative of the diameter of the workpiece, means for moving the compensation gauge away from the workpiece at the beginning of the grinding operation and maintaining the first pressure at its previous value, an outside diameter reference gauge engaging the outer surface of the workpiece near the position of contact with one of the shoes, an inside diameter gauge engaging the wheel when it extends a substantial amount from one end of the bore, means for maintaining the inside diameter gauge at its previous setting while the wheel is in the bore and is not associated therewith, the reference gauge and the inside diameter gauge being inter-related with the sizing nozzle to give a second pressure indicative of the wall thickness of the workpiece, the second pressure changing as the grinding operation progresses, a given change in the diameter of the outer surface producing one half as much change in the first pressure as is produced in the second pressure by the same amount of change in the position of the surface of the shoe relative to the reference plane, and means receiving the pressures and acting to terminate the grinding operation when their sum reaches a pre-determined value.

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