July 7, 1936. H. L. BLOOD 2,047,055

GRINDING MACHINE AND METHOD

Filed June 1, 1934 4 Sheets-Sheet 1

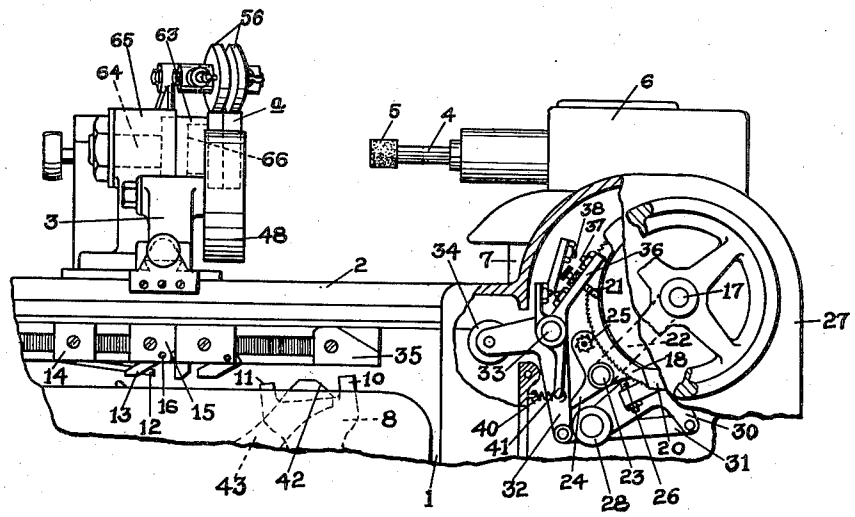


Fig. 1

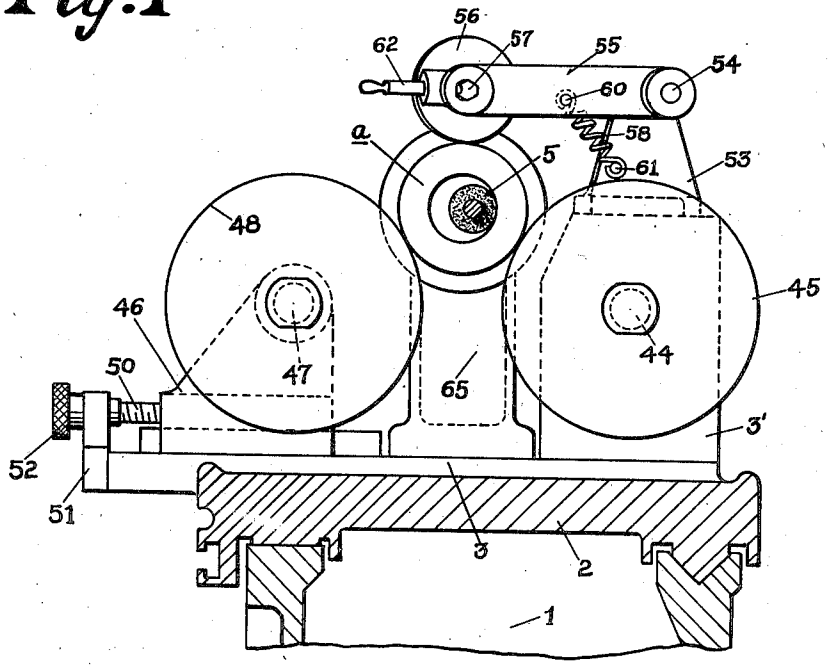


Fig. 2

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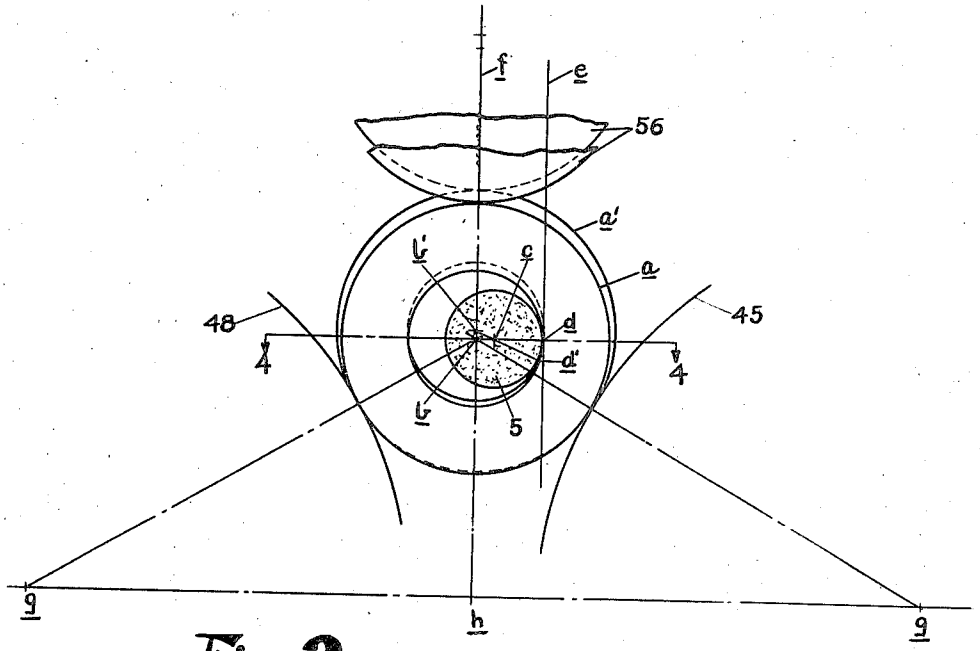


Fig. 3

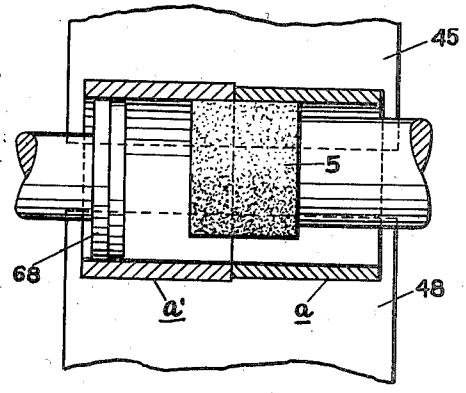


Fig. 4

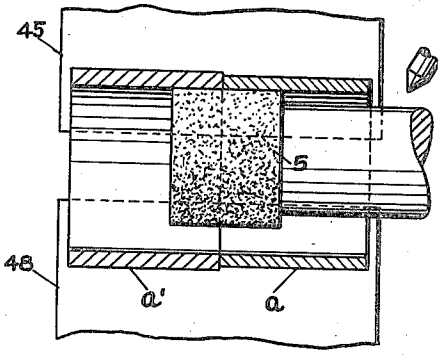


Fig. 5

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GRINDING MACHINE AND METHOD

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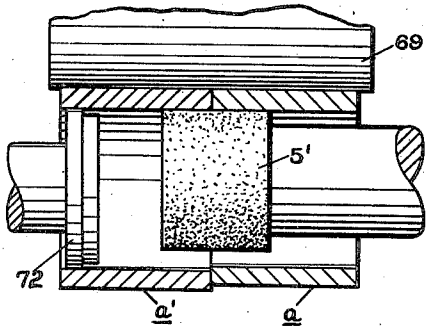


Fig. 6

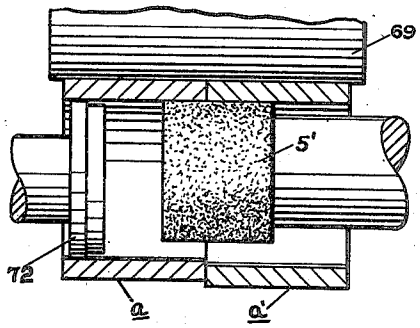


Fig. 7

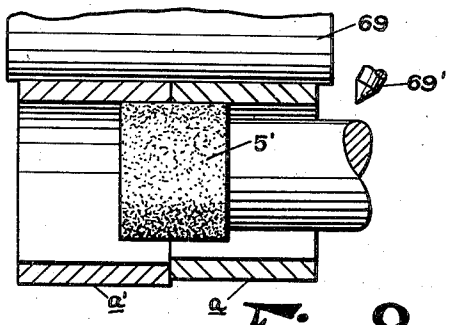


Fig. 8

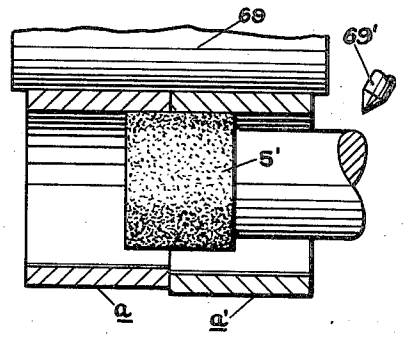


Fig. 9

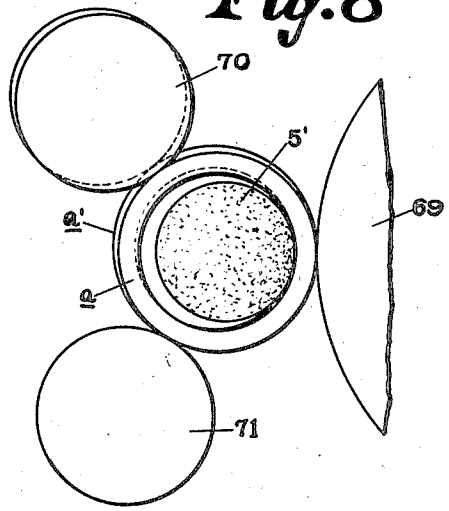


Fig. 10

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GRINDING MACHINE AND METHOD

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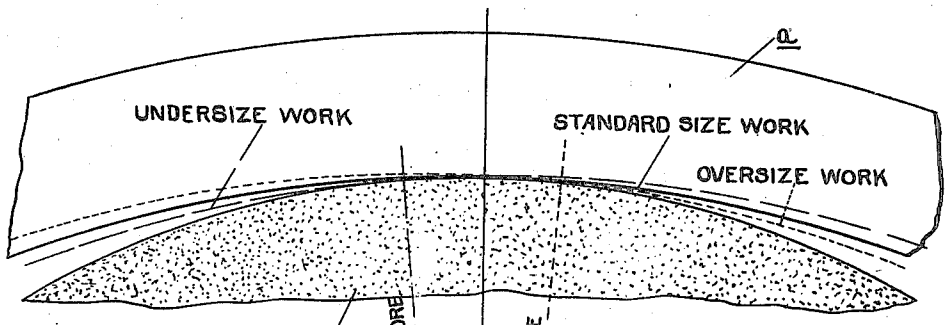


Fig. 11

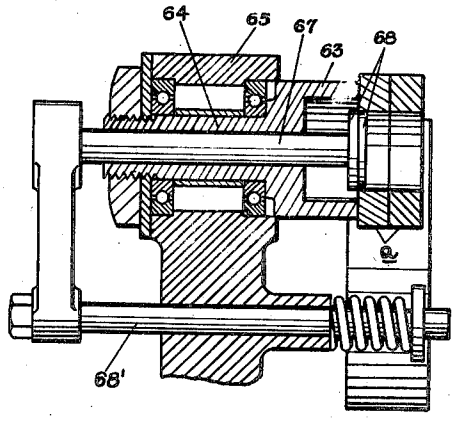


Fig. 12

Fig. 13

Fig. 14

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Patented July 7, 1936 2,047,055

UNITED STATES PATENT OFFICE

2,047,055

GRINDING MACHINE AND METHOD

Harold L. Blood, Birmingham, Mich., assignor to The Heald Machine Company, Worcester, Mass., a corporation of Massachusetts

Application June 1, 1934, Serial No. 728,566

32 Claims. (Cl. 51—95)

The present invention relates to grinding machines, and its particular utility is in connection with internal grinding machines for grinding the cylindrical or conical inner surfaces of sleeves, gears, bushings or like articles. This application is a continuation in part of applicant's prior copending application for Grinding machine, Serial No. 684,970, filed August 14, 1933.

In the Einstein Patent No. 1,772,932, dated August 12, 1930, the workpiece is supported on its cylindrical outer surface by a centerless type of work-supporting structure which normally comprises a positively rotated wheel which engages the outer surface of the workpiece and procures a corresponding rotation thereof, a work support spaced from the wheel, and a pressure member which also engages with the outer surface of the workpiece and urges the latter against the positively rotated wheel and the work support. The copending application of Highberg, Serial No. 266,287, filed March 31, 1928 now U. S. Patent No. 2,003,713 dated June 4, 1935, and the Guild Patent No. 1,887,154, dated November 8, 1932, the latter being an improvement on the application above referred to, also show a type of centerless work-supporting structure corresponding in general to that of Einstein patent. In each of these constructions, the relative cross feed between grinding wheel and workpiece, for the progressive enlargement of the latter's bore, takes place in a plane substantially radial to the axis of the positively rotated wheel.

When work-supporting structures such as above referred to are used in connection with size control mechanisms of the type disclosed in the Guild Patent No. 1,682,672, and the Taylor Patent No. 1,682,673, both dated August 28, 1928, each successive grinding operation is automatically terminated when the cutting surface of the grinding wheel reaches a predetermined vertical plane, which plane is spaced a fixed distance away from the surface of the positively rotated work-supporting wheel. This machine arrangement is fairly satisfactory when the accuracy required in the ground bore is no greater than the accuracy within which the outside diameters are formed. It is apparent, however, that variations in the outside diameters of successive workpieces or an irregularity in the outer surface of any workpiece will result, when workpieces are ground singly, in corresponding variations in the internal diameters of the workpieces or in corresponding irregularities in the inner surface, since, by the arrangement shown, each workpiece is reduced to a predetermined uniform wall thickness independently of the variations in outside diameters of the several workpieces. The ground bore of each workpiece can accordingly be no more accurate than the accuracy of the outer surface. One of the objects of the present invention is to provide for the grinding of successive workpieces all to substantially the same internal diameter, independently of variations in the outside diameters when the workpieces are ground in machines which incorporate a size control mechanism of the type above referred to.

Variations in internal diameters due to non-uniform outside diameters have been partly overcome by the mechanical arrangement disclosed in the Nenninger Patent No. 1,881,870, dated October 11, 1932, in which a gage member, actuated by the grinding wheel, is shifted relative to the work-supporting structure to compensate for the varying outside diameters of successive workpieces. Although this machine compensates for variations in outside diameter when the workpieces are ground singly, the bore of each workpiece is no more accurately cylindrical than the outer surface since each workpiece is reduced to a uniform wall thickness independently of irregularities in the outer surface. A further object of the invention is to avoid this objection by providing for grinding of the inner bores of workpieces in centerless machines to produce workpieces whose inner surfaces are more accurately cylindrical than the preformed outer surfaces.

The compensatory mechanism disclosed in the Nenninger patent above cited is effective for compensating for over-size or under-size workpieces only when the workpieces are ground singly. Where several workpieces are positioned in axial alinement in the work-supporting structure for grinding of said workpieces in multiple, the compensatory mechanism is effective only in connection with the workpiece having the largest diameter and the remaining workpieces, whose outer diameter is smaller, will not be reduced to the proper internal diameter.

A similar objection arises in the use for multiple grinding of the size-controlling mechanism disclosed in the Guild and Taylor patents, above referred to. The several workpieces positioned at one time in the work-supporting structure will all be reduced to a uniform wall thickness and, accordingly, if the outside diameters of the several workpieces vary, there will be a corresponding and equal variation in the internal diameter, thus preventing the grinding of the in-

ternal bores of workpieces in multiple within closer limits than the limits of the previously formed outer surfaces.

In the use of plug gages of the type disclosed in the Kempton and Gallimore Patent No. 1,731,719, dated October 15, 1929, for controlling the size of workpieces in centerless work-supporting structures of the type above referred to, each ground workpiece is accurately sized only when the individual workpieces are ground separately or when all of the workpieces are precisely the same outside diameter. In the grinding of workpieces in multiple with the sizing of said workpieces by plug gages, all of the workpieces, during a single grinding operation, are reduced to the same wall thickness. Since the gage is effective only on the workpiece adjacent thereto, and since the outside diameter of the workpiece adjacent to the gage may be oversize (but within the limits required), or may be precisely to the desired size, each successively ground group of workpieces will vary in wall thickness, depending on the outside diameter of the workpiece adjacent to the gage. Accordingly, the workpieces ground during each successive grinding operation will not have a uniform internal diameter; in fact, as will be apparent, the variation in the internal diameters will be twice as great as the variation in the outside diameters of the workpieces. One of the principal objects of the present invention is to provide for the grinding of workpieces in multiple to produce finished workpieces whose internal diameters are all the same size, within predetermined limits, independently of the variations in the outside diameters of said workpieces, the invention providing for the grinding of the inner surfaces within closer limits than the outside diameter of the workpieces.

According to the present invention, the workpieces to be ground are supported so that variations in the outside diameters of the workpieces will result in an offsetting of the axes of the workpieces relative to each other in a direction substantially perpendicular to the direction of movement of the grinding wheel relative to the workpiece during the radial feeding movement of said wheel against the workpiece, whereby to minimize the variations in internal diameters as a result of the variations in the outside diameters. Other and further objects and advantages of the invention will appear from the following detailed description taken in connection with the accompanying drawings, in which:—

Fig. 1 is a fragmentary front elevation of a machine embodying the invention.

Fig. 2 is a large scale vertical section of the workhead.

Fig. 3 is a diagrammatic view of the work-supporting parts shown in Figs. 1 and 2, indicating the relative positions of two workpieces when one is the proper outside diameter and the other is somewhat oversize, the variations in diameters being greatly exaggerated.

Fig. 4 is a horizontal sectional view substantially along the line 4—4 of Fig. 3, indicating diagrammatically the grinding of workpieces in multiple under the control of gages.

Fig. 5 is a view corresponding to Fig. 4 indicating diagrammatically the sizing of workpieces by mechanism responsive to the crossfeed movement.

Fig. 6 is a diagrammatic view showing the error introduced in the grinding of workpieces under the control of gages when the workpieces are supported in the usual centerless workheads.

Fig. 7 is a view corresponding to Fig. 6 with the gage entering the normal-sized workpiece.

Figs. 8 and 9 are diagrammatic views indicating the errors introduced in the multiple grinding of workpieces supported in the usual centerless workheads when the workpiece size is controlled by mechanism responsive to the crossfeed movement.

Fig. 10 is a diagrammatic view showing the location of workpieces in the usual centerless work-supporting structure.

Fig. 11 is a greatly exaggerated diagrammatic view indicating, in connection with the present invention, the small change in internal diameter of a workpiece resulting from a relatively large change in the outside diameter.

Fig. 12 is a vertical sectional view through the workhead when the machine is controlled by gages.

Fig. 13 is a diagrammatic view corresponding to Fig. 3, showing a workpiece having an irregular outer surface positioned in the crosshead.

Fig. 14 is a view corresponding to Fig. 13, with the workpiece in another relative position.

Like reference characters refer to like parts in the different figures.

Referring first to Fig. 1, the machine has a base 1 on which the usual reciprocatory table or carriage 2 is slidably mounted. In such a machine, either the grinding wheel or the work to be ground may be carried on the table, the reciprocations of the latter being utilized in either case to produce a relative traversing movement between the grinding wheel and the workpiece. As here shown, the table supports and carries a workhead 3 supporting the workpiece to be ground, and the spindle 4 for the grinding wheel 5 is journaled in a wheelhead 6 mounted on a bridge 7 which spans the slideways provided by the base of the machine for the movement of the table. The grinding wheel 5 is rotated at a high speed by any suitable well-known mechanism and the workpiece is rotated at a slower speed by a structure which will be disclosed hereinafter.

The back and forth movement of the table 2 to cause the grinding wheel to make the required traversing movement relative to the workpieces *a* in the workhead is imparted by any suitable structure such as that disclosed in the Heald and Guild Patent No. 1,582,468, issued April 27, 1926. It is sufficient to note for the purposes of the present application that fluid under pressure is alternately directed to opposite ends of a cylinder, not shown, positioned within the base of the machine to procure movement of a piston therein, the latter being suitably connected to the table. The flow of fluid to the cylinder is controlled by a reversing member 8 having upwardly projecting lugs 10 and 11 which, during the grinding operation, when the grinding wheel is positioned within the bore of the workpiece, are engaged by the reversing dogs 12 and 13 respectively. Engagement between the reversing dogs and the lugs on the reversing member procure shifting movement of said member and accordingly reverse the direction of flow of fluid to the cylinder, thereby procuring a reciprocation of the table for traversing the grinding wheel over the surface of the workpiece. The dogs 12 and 13 are carried by blocks 14 and 15 adjustably mounted on the front of the table, the dog 13 being pivotally mounted on the block 15 by a pin 16 to provide for elevation of said dog out of alinement with the cooperating lug 10 of the reversing member

to permit an extended movement of the table to the left during, or at the end of, the grinding operation, for purposes which will hereinafter appear.

The grinding wheel 5 is given a lateral or crossfeed movement on the bridge to position and maintain the surface of said wheel in engagement with the surface of the workpiece. The crossfeed movement is procured in response to the reciprocations of the table by a mechanism fully disclosed in the copending application of Guild, Serial No. 658,745, filed Feb. 27, 1933, now U. S. Patent No. 1,971,138 dated August 21, 1934. It is sufficient to note for the purposes of the present application that the wheelhead is mounted on a cross-slide, not shown, and movement thereof is obtained by rotation of a crossfeed screw 17 which engages an internally threaded portion, not shown, of the cross-slide. During the crossfeed movement, the crossfeed screw 17 is rotated in unison with a ratchet wheel 18 actuated in response to the reciprocations of the table. A compensatory mechanism, not shown, connects the ratchet wheel 18 to the crossfeed screw 17 so that, during the retraction of the crossfeed movement between successive grinding operations, the reduction in size of the grinding wheel will be compensated for. Thus, when the cam 20, which is rotatable with the ratchet wheel 18, strikes an adjusting screw 21, the cutting surface of the grinding wheel will always be in a predetermined vertical plane relative to the workhead regardless of the reduction in size of said wheel.

As indicated in Fig. 1, an arm 22 is pivotally mounted on the shaft 17 and has secured in its outer end a pin 23 on which a lever 24 is mounted. One arm of said lever carries a pawl 25 engageable with the ratchet wheel 18, and a second arm of the lever is engageable with an adjustable stop 26 positioned in the casing 27 mounted on the front of the bridge 7. An abutment, not shown, is provided on the arm 22 and engages with the second arm, above referred to, of the lever 24 to prevent counterclockwise turning movement of said lever beyond the position shown. A third arm of the lever 24 is in a position for engagement with a roller 28 on a bell crank lever 30 journaled on a pin, not shown, in the casing 27. The other arm of the lever 30 is connected by a link 31 to one arm of a bell crank lever 32 journaled on a pin 33 in the casing 27. The opposite arm of the lever 32 carries a roller 34 which, during the grinding operation, when the grinding wheel is positioned within the bore of the workpiece, engages and is elevated by a cam 35 adjustably positioned on the front of the table. Each reciprocation of the table procures an elevation of the roller 34 and a corresponding elevation of the roller 28, moving the latter into engagement with the lever 24, and rocking said lever about the pin 23 until the pawl 25 engages the ratchet wheel. Thereafter, in response to further elevation of the roller 28, the lever 22 is rocked about the shaft 17, and procures a slight clockwise turning movement of the ratchet wheel.

During the grinding operation, the cam 20, above referred to, is advanced clockwise and engages and elevates the adjusting screw 21, the latter being positioned as shown in Fig. 1 in an arm 36 journaled on the pin 33. Movement of the arm 36, when the screw 21 is struck by the cam 20, shifts a contact member 37 on said arm into engagement with a stationary contact 38 to complete a circuit that (as illustrated by Patent No. 1,682,672) procures cessation of the grinding operation. The arm 36 is normally retained in the position shown by a spring 40 which resiliently connects an arm 41 integral with the arm 36 to the casing 27.

The cessation of the grinding operation, which involves a runout of the table to the rest position shown, is procured by mechanism fully described in the Guild Patent No. 1,682,672, above identified, or by mechanism disclosed in the Guild application above referred to. It is sufficient to note, for the purposes of the present application, that when the contacts 37 and 38 are brought together, an electrical circuit is established for elevating the dog 13 out of alinement with the lug 11, as by raising the cam surface 42 on an arm 43 into alinement with the lower end of said dog. Elevation of the dog 13 prevents said dog from engaging the lug 11 so that the reversing member is not shifted and fluid under pressure urges the table to the left beyond its operative position into the position of Fig. 1 where it is brought to rest by any suitable mechanism such as that shown in the Heald and Guild Patent No. 1,582,468, above referred to.

The above described mechanism is not, in itself, a feature of the present invention; the latter involves the attainment in connection with grinding instrumentalities of the above, or similar types, of the novel results above set forth. Referring now to Fig. 2, the workhead 3 has an upstanding bracket 3' supporting a horizontal shaft 44 to which a roll 45 is secured, the latter engaging the periphery of the workpieces *a* as indicated. The roll 45 is positively driven by any suitable mechanism at a relatively slow speed to procure, by its engagement with the periphery of the workpieces, a slow rotation of said workpieces. Opposite to the bracket 3', the workhead supports a movable bracket 46 in which is journaled a spindle 47 on which a roll 48 is mounted. The spindle 47 is preferably in horizontal alinement with the shaft 44 and said spindle and shaft are preferably parallel to each other. The rolls 45 and 48 are also substantially equal in diameter and as the roll 48 also engages the periphery of the workpieces *a*, the latter are supported above and between the rolls with the axis of said workpieces in a vertical plane midway between the axes of said rolls. The bracket 46 is adjustable transversely of the machine by a screw 50 held against axial movement in a lug 51 on the table and engaging a threaded bore in the bracket 46. Turning of the screw 50 by a knurled knob 52 in the end thereof procures a transverse movement of the roll 48 toward or away from the roll 45, for adjusting the machine to accommodate various sizes of workpieces. In the normal operation of the machine, the roll 48 is adjusted so that the axes of the workpieces *a* coincide with the horizontal plane of movement of the grinding wheel during the crossfeed movement.

The bracket 3' supports a bracket 53 thereon and the latter has a pin 54 which provides a pivotal support for a plurality of arms 55. Said arms project forwardly from the bracket and each is provided with a roll 56 journaled on a spindle 57 provided by the corresponding arm, said rolls engaging the peripheries of the workpieces *a* and holding the latter in engagement with the rolls 45 and 48. A spring 58 for each arm engages a pin 60 on each of the arms 55 and a pin 61 on the bracket 53, thereby normally urging the arms 55

downwardly to hold the rolls 56 resiliently against the workpieces. The arms 55 project forwardly from the spindle 57 and have handles 62 on the forward ends thereof by which said arms may be manually elevated for the release of finished workpieces from within the workholder and the insertion of unground workpieces therein.

The spindles 57 are preferably positioned at a slight angle to the axis of the spindle 47 and shaft 44, thereby urging the workpieces, as the latter are rotated, into engagement with a rotary backing plate 63 corresponding in structure to the backing plate disclosed in the Guild Patent No. 1,887,154 above referred to. As shown, the rotating backing plate has a projecting stud 64 journaled in a bracket 65 extending upwardly from the table. The backing plate supports the workpieces against axial movement in the work-supporting structure and has a recess 66, as indicated, to prevent contact between said plate and the grinding wheel while the latter is operating on the workpieces.

Referring now to Figs. 3 and 11, the normal-sized workpiece *a* has its center of rotation at the point *b*, and the grinding wheel 5, whose center of rotation is in the same horizontal plane as said point *b*, engages the workpiece in said plane and is fed relative to the workpiece in said plane. The grinding operation, which is under the control of the mechanism above described, is automatically terminated when the cutting surface of the wheel reaches the point *d* in a vertical plane *e*, which is in predetermined relation to a vertical plane *f* passing through the axis of rotation of the workpiece. When the grinding wheel is in this position, the center of rotation being then at the point *c*, the wheel is withdrawn from the workpiece as above pointed out. The distance *b*, *d* between the planes *e* and *f* represents the radius of the finished bore of the workpiece.

When the workpiece *a'*, however, which is slightly oversize is positioned in the work-supporting structure, either simultaneously with the workpiece *a*, as indicated in Figs. 1 and 2 or subsequently thereto, the larger outer diameter of the workpiece causes a vertical displacement of the axis of rotation of said workpiece to a point *b'* in the same vertical plane *f* as the axis of rotation *b* of the normal-sized work-piece *a*. This vertical displacement of the axis of rotation of the oversize workpiece will cause the grinding wheel 5 to engage the bore of said oversize workpiece at a point *d'* which is in the same plane as the axis of rotation *c* of the grinding wheel and the axis *b'* of the oversize workpiece, the grinding wheel and the inner surface of the workpiece being tangent at this point. The grinding operation is brought to a close when the grinding wheel becomes tangent to the plane *e*, but, since the actual distance between the points *b* and *b'* is a relatively small amount, the distance between the points *d* and *d'* is also relatively small and the point *d'* on the grinding wheel is substantially in the plane *e* so that the oversize workpiece is reduced to the same diameter as the workpiece *a*, within very close limits.

As an example of the above, if the pressure rolls 45 and 48 are each twelve inches in diameter and the workpiece *a* is exactly four inches in outside diameter, the rolls 45 and 48 are preferably spaced apart such a distance that a line connecting the center of rotation *b* of the workpiece *a*, and either of the centers of rotation *g* of the supporting rolls makes an angle of 30° with the horizontal plane passing through the centers of rotation *g*. If the normal-sized workpiece is to be reduced to an inside diameter of two inches, the plane *e* to which the wheel becomes tangent, must be spaced from the plane *f* a distance of exactly one inch which corresponds to the inner radius of the work piece. When the diameter of the grinding wheel 5 is .75 inch, the center *c* of the wheel is spaced from the center of rotation *b* of the workpiece exactly .25 inch.

In computing the variation in internal diameter of the oversize workpiece *a'* to determine the error introduced, the following calculations are made. The distance *bg* which represents the radius of the normal workpiece and the radius of one of the supporting rolls is eight inches and accordingly the distance *gh*, since the angle *bgh* is 30°, will be exactly 6.928 inches. Assuming that the outside diameter of the oversize workpiece *a'* is 4.004 inches, this being a much greater variation in size than would normally occur in the grinding of workpieces, the distance *b'g* will be 8.002 inches. With the distance *hg* and the distance *gb'* both known, the distance *hb'* is readily determined to be 4.004. The distance *bh* being exactly four inches, it is apparent that the center of the oversize workpiece is spaced a distance above the axis of rotation of the normal-sized workpiece a distance of .004 inch, this distance also being the height of the center of the oversize workpiece *a'* above the plane of the crossfeed movement of the grinding wheel.

In order to determine the distance *b'd'*, which will be the radius of the inner surface of the oversize workpiece, it is necessary to determine the distance *cb'*, which distance added to the distance *cd'* (which is known to be .75 inch) will give the actual radius. Since the distance *bc* is known to be .25 inch and the distance *bb'* to be .004 inch the distance *b'c* is readily computed to be .25003 inch and the distance *b'd'* is accordingly 1.00003 inches. From this it will be apparent that the oversize workpiece is so nearly equal in internal diameter to the normal-sized workpiece that the variation in size is not measurable by any of the usual instruments. It will be apparent that when the outside diameters of the workpieces are held within closer limits, which normally are as low as .0004 inch oversize, the variation in internal diameter will be .0000006 inch, much less than that computed above for a larger variation in outside diameter. Thus, the error in internal diameter is substantially one percent of the variation in size of the outside diameter.

The centerless workhead above described is applicable not only to the sizing of workpieces by the mechanism disclosed in the Guild Patent No. 1,682,672 above, but also to the sizing of workpieces by the well-known gage mechanism of the Kempton and Gallimore Patent No. 1,731,719. Referring now to Fig. 12, the workhead corresponds in all respects to the workhand above described with reference to Fig. 2. In addition, the stud 64 which supports the rotating backing plate has an axial bore therethrough for the reception of a gage rod 67 on the end of which are positioned one or more gages 68 corresponding in general to the gages disclosed in said Kempton and Gallimore patent. The gages operate through a control mechanism of the type fully disclosed in said patent or through a control mechanism of the type disclosed in the Blood and Burns copending application Serial

No. 681,334, filed July 20, 1933 now U. S. Patent No. 2,011,705 dated Aug. 20, 1935; in either mechanism, entry of one of the gages within the bore of the workpiece, which occurs when said bore is reduced to the proper internal diameter, is arranged to procure cessation of the grinding operation and runout of the table 2 to rest position. In this workhead, the gage, as is customary, is allowed to have a slight radial movement and the vertical shifting of the axes of successive workpieces as a result of variations in the outside diameters thereof is not sufficient to prevent the gage from entering the bore thereof. When workpieces are ground singly in the above described workhead, the internal bore is ground more accurately cylindrical than the outer surface of the workpiece since, as will be apparent, variations in the external surface do not result in corresponding variations in the inner surface, and the gage sizing is thus more accurate.

The structure and operation of the gage mechanism is well known and need not be further described. It may be noted, however, that the gage rod is connected to and movable with a parallel rod 68', one end of which engages the bridge during the reciprocations of the table for withdrawing the gage from the workpiece to prevent contact between the grinding wheel and said gage.

Referring now to Figs. 6 and 7, which show the grinding of workpieces in multiple in the usual centerless machine in which the workpiece size is controlled by gages, and in which the axis of the regulating wheel 69 is in the plane of the crossfeed movement, the normal sized workpiece a is positioned in substantial alinement with the oversized workpiece a' with both of said workpieces being held against the regulating wheel 69 (see also Fig. 10) by a pressure roll 70, the workpieces being further supported by a supporting roll 71. In this type of structure, the regulating wheel, which is a fixed member, has its axis in the plane of the crossfeed movement of the grinding wheel and also substantially in the plane of the axis of rotation of the workpiece or workpieces being ground. The regulating wheel forms a positive backing for the workpieces, so that as best indicated in Fig. 10, if one of the workpieces be oversize, the axis of this workpiece will be offset from the cutting surface of the grinding wheel and in a plane substantially parallel to the plane of the crossfeed movement of said grinding wheel. With the arrangement shown in Fig. 6, the grinding operation is brought to a close when the oversize workpiece a' is reduced to the proper diameter as indicated by the gage member 72. Assuming the outside diameter of the workpiece a' to be .0004 inch oversize, the normal-sized workpiece a will have its inner surface .0004 inch undersize, the arrangement of the machine being such that each of the workpieces a and a' is necessarily reduced to the same wall thickness since a single grinding wheel operates on both of the workpieces simultaneously and is spaced a predetermined distance away from the regulating wheel when the grinding operation is brought to a close. Thus in the grinding of workpieces in multiple, there is no certainty that the inner bores of the several workpieces ground will be the same size.

In the use of a gage mechanism in connection with the usual centerless work-supporting structure, the error produced in the internal diameters of the multiple-ground workpieces is even greater than the variations in outside diameter. Referring now to Fig. 7, in which the normal-sized workpiece a is located adjacent to the gages and the oversize workpiece a' is spaced therefrom in precisely the opposite arrangement to that of Fig. 6, the grinding operation is brought to a close when the workpiece a reaches the proper size as determined by the gage and the workpiece a' being .0004 inch oversize will have its internal diameter oversize by the same amount since both the workpieces a and a' are reduced to the same wall thickness.

Since it is impossible to tell whether the normal-sized workpiece or the oversize workpiece is located adjacent to the gage so that the condition of either Fig. 6 or Fig. 7 may prevail, the resulting errors in the internal diameters will be the sum of the errors indicated in both of these figures. In Fig. 6, the workpiece a was undersize by the amount that the oversize workpiece was oversize; in Fig. 7, the inner diameter of the oversized workpiece was oversize an amount corresponding to the oversize in the outside diameter. Accordingly, the resultant variation in internal diameters of workpieces when ground in this manner will be precisely double the variation in size in the outside diameter.

Referring now to Fig. 4 which shows diagrammatically the sizing of workpieces by gages in connection with the workhead of Fig. 3, the oversize workpiece a' is located adjacent to the gage 68 and the inner bore of said workpiece will be reduced to the proper size at the end of the grinding operation. Since the workhead is arranged, however, to procure an offset of the axes of the several workpieces relative to each other in a plane perpendicular to the plane of the crossfeed movement of the grinding wheel, the axes of the workpieces a' and a will be in vertical alinement and the variation in internal diameter of the two workpieces will be immeasurable. The computed error, above given for the resultant error in oversize workpieces is applicable to this figure; it will be clear that even though the workpiece a' be oversize by as much as .004 inch, the variation in size of the workpiece a will be .00003 inch approximately. The several workpieces simultaneously ground are accordingly reduced to the same size independently of variations in the outside diameters thereof.

Referring now to Figs. 8 and 9, which show a machine arrangement for the grinding of workpieces in multiple in the usual centerless work-supporting structures, with the size controlled by mechanism of the type shown in the Guild Patent No. 1,682,672, the normal-sized workpiece a is reduced to a predetermined wall thickness, the thickness being determined by the spacing of the cutting surface of the grinding wheel from the regulating wheel 69, at the close of the grinding operation. During each successive grinding operation, the wall thickness remains uniform, since the wall thickness is determined by the position of the dressing tool 69'. This dressing tool which dresses the wheel during each grinding operation, is adjusted for the proper sizing of normal-sized workpieces and produces a uniform wall thickness regardless of the variation in the outside diameter of the workpieces since the grinding wheel is operating on the several workpieces at one time in predetermined relation to the regulating wheel. In the arrangement of Fig. 8, the workpiece a' which is oversize will have an internal diameter which is oversize to the same amount as the outside diameter of said workpiece; in the arrangement of Fig. 9, in which the normal-sized and

oversize workpieces are reversed, the same result obtains since each grinding operation ends when the workpieces are reduced to a predetermined wall thickness. The variations in size in the internal diameters of workpieces ground by mechanism of this type will accordingly be equal to the variations in the outside diameters of the workpieces and, accordingly, by this arrangement, the inner diameters can be no more accurate than the outer diameters.

This difficulty has been overcome by the workhead disclosed in Figs. 2, 3 and 5. Referring to Fig. 5, which shows diagrammatically the grinding of workpieces in this type of workhead, the several workpieces being simultaneously ground are all reduced to the same internal diameter regardless of the variations in outside diameter. Although, in this arrangement, the axes of the normal-sized workpiece *a* and the oversized workpiece *a'* do not coincide, said axes are displaced in a plane at right angles to the advance of the grinding wheel and the error introduced by this displacement of the axes is so small as to be negligible. As pointed out above, even an error as great as .004 inch will not produce a measurable variation in the inner diameter.

Where the outer surface of the workpiece is somewhat out-of-round, the workhead above described minimizes the out-of-roundness in the inside surface. Referring particularly to Figs. 13 and 14, the workpiece *a''* is supported by a regulating wheel 73 and a supporting wheel 74, the axes of both of these wheels being below the plane of the crossfeed movement of the grinding wheel 5', and the workpiece is held against the wheels 73 and 74 by a pressure roll 75 suitably mounted as disclosed in Figs. 1 and 2. The normal irregularities in the outer surface of the workpiece would be relatively small, being normally less than .0004 inch; accordingly the hump 76, diagrammatically represented in Figs. 13 and 14, is greatly exaggerated in order to show the effect of out-of-roundness in the workhead. It will be noted that the wheels 73 and 74 are not equal in diameter; the position of said wheels, however, provides for a shifting of the axis of the workpiece as a result of a variation in outside diameter, along a line making a relatively large angle with the plane of the crossfeed movement.

In the showing of Fig. 13, the hump 76 in the full line position of the workpiece, is in engagement with the supporting roll 74, and the workpiece is accordingly urged upwardly from its normal center of rotation *b''* to a center of rotation *b'''*. At this time, since the axis of rotation of the wheel 5' is at the point *c'*, the surface of said wheel engages the workpiece at a point *d''* in the same plane as the centers of rotation of the workpiece and the grinding wheel. The wheel at the finish of the grinding operation is tangent to the plane *e'* as above pointed out, and accordingly the grinding wheel, when the workpiece is in the full line position of this figure, does not grind quite to the desired inner cylindrical surface of the workpiece, but rather produces a small hump 76' on the inner surface, said hump being spaced from the hump 76 on the outer surface, as indicated. This hump 76' is much smaller than the hump 76 on the outer surface, thus materially reducing the out-of-roundness.

When the hump 76 reaches the position of Fig. 14, said hump then engaging with the regulating wheel 73, the workpiece is urged upwardly until its center of rotation is at a point *b''''*, this point being spaced above the normal center of rotation of the workpiece and away from the regulating wheel. The grinding wheel, however, being in the position shown, tangent to the plane *e'*, produces a small indentation 76'' in the inner surface of the work. This indentation, as will be apparent from either Fig. 13 or Fig. 14, is substantially in alinement with the hump 76 on the outer surface, but is materially less in height than the height of the hump 76.

It will be readily apparent that if the hump 76 is at the most only .0004 inch farther away from the center of the workpiece than the normal surface thereof making the diameter oversize by the same amount, the corresponding error in the internal surface of the workpiece will be much smaller, generally so small as to be immeasurable. Obviously, the relative positions of the regulating wheel and the supporting wheel control the amount of variation in internal diameter resulting from irregularities in the outer surface. In the usual centerless machine outlined diagrammatically in Fig. 10, a hump 76 would procure a corresponding hump of equal size in the internal surface, since, when the workpiece was backed up directly by a regulating wheel in the plane of the cross-feed movement, the finished workpiece is reduced to a uniform wall thickness. The present invention minimizes the variations in the internal surface of a workpiece resulting from variations in outer-of-roundness in the outer surface, such as chatter-marks and the like, thus providing an inner surface as nearly truly cylindrical as possible.

From the foregoing, it will be apparent that the present invention provides for the grinding of workpieces in multiple in a centerless grinding machine to produce finished workpieces whose internal diameters vary within much closer limits than the variations in the outside diameters of said workpieces. At the same time, the workpieces may be ground singly in the grinding machine in the same manner to produce accurately-sized internal bores. In addition, the present invention provides for the grinding of the internal surfaces of workpieces to a more accurately cylindrical form than that of the outer surfaces of the workpieces.

I claim,

1. In the grinding of workpieces in multiple to reduce all the workpieces to substantially the same internal diameter, the steps which involve supporting and rotating the workpieces on their outer surfaces in substantial alinement with each other in such a manner that as a result of variations in the outside diameters of the workpieces, the axes of the several workpieces will be offset relative to each other in a plane substantially at right angles to the plane of the crossfeed movement of the grinding wheel relative to said workpieces, whereby the resultant variations in inside diameter are minimized, and advancing the grinding wheel in the plane of the crossfeed movement for a cutting action on the workpieces.

2. In the grinding of workpieces in multiple, the method of reducing all the workpieces to substantially the same internal diameter which involves supporting the workpieces in substantially axial alinement on their outer surfaces in such a manner that the axes of the workpieces, as a result of variations in the outside diameters thereof, are offset relative to each other substantially in a predetermined plane, and advancing the grinding wheel relative to the work-

pieces for the crossfeed movement in a plane substantially perpendicular to said predetermined plane, whereby the resultant variations in inside diameter are minimized.

3. In the grinding of workpieces in multiple, the method of reducing all the workpieces to substantially the same internal diameter which involves supporting the workpieces in substantially axial alinement on their outer surfaces on fixed supports to procure an offset of the axes of the workpieces relative to each other substantially in a predetermined plane when there is a variation in the outside diameters of the workpieces, and advancing the grinding wheel relative to the workpieces for the crossfeed movement in a plane substantially perpendicular to said predetermined plane, whereby the resultant variations in inside diameter are minimized.

4. In a method of reducing the bores of successive cylindrical workpieces all to a predetermined size, in which the cutting surface of the grinding wheel is advanced to a predetermined point relative to the work-supporting structure for a crossfeed movement in a predetermined plane during the grinding of each workpiece, the step which comprises supporting and rotating each workpiece successively on its preformed outter surface during the cutting operation on the bore thereof in such a manner that, as a result of a variation in outside diameter of a workpiece, its axis will be offset from the position of the axis of a normal-sized workpiece and in a plane substantially perpendicularly to the plane of crossfeed movement of the grinding wheel.

5. In a method of reducing the bores of successive cylindrical workpieces all to a predetermined size, in which the cutting surface of the grinding wheel is in a predetermined relation to the work-supporting structure at the end of each grinding operation, the step which comprises so supporting and rotating each workpiece on its preformed outer surface in the work-supporting structure that variations in said outter surface will result in shifting the axis of the workpiece substantially in a plane parallel to the normal plane of tangency of the cutting surface of the grinding wheel and the inner surface of a workpiece whose outer surface is the proper size.

6. In the grinding of workpieces in multiple, the method of reducing all the workpieces to substantially the same internal diameter which involves supporting the workpieces in substantially axial alinement on their outer surfaces in such a manner that the axes of the workpieces, as a result of variations in the outside diameters thereof, are offset relative to each other subtantially in a predetermined plane, advancing the grinding wheel relative to the workpieces for the crossfeed movement in a plane substantially perpendicular to said predetermined plane, and controlling the size of the workpieces by a gage member which contacts with only one of said workpieces.

7. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation, of a work-supporting member for supporting and rotating a workpiece on its preformed outer surface so that a variation in size of the outer surface will shift the axis of the workpiece substantially in a plane perpendicular to the plane of the crossfeed movement of the grinding wheel.

8. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, of a work-supporting member for supporting and rotating a workpiece on its preformed outer surface, said member having means positioned to procure a shifting movement of the axis of the workpiece substantially in a plane perpendicular to the plane of the crossfeed movement in response to variations in the outside diameter in said workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation.

9. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation, of a work-supporting member for supporting and rotating consecutive workpieces successively on their preformed outer surfaces, said member having means positioned to procure an offset of the axes of successive workpieces from the position of the axis of a normal-sized workpiece substantially in a plane perpendicular to the plane of crossfeed movement in response to variations in outside diameter of said workpieces.

10. In a grinding machine for the reduction of the internal bores of successive workpieces all to the same predetermined size, the combination with a grinding wheel, and means for procuring a crossfeed movement relative to a workpiece, of a work-supporting member for supporting and rotating each workpiece successively in proper position relative to the grinding wheel, said work-supporting member comprising supporting members engageable with the periphery of the workpiece at spaced points and positioned to procure, in response to variations in the outside diameter of successive workpieces, an offset of the axes of said workpieces from the position of the axis of a normal-sized workpiece substantially in a plane perpendicular to the plane of the crossfeed movement, and a pressure member engageable resiliently with the workpiece for retaining the latter in engagement with the supporting members.

11. In a grinding machine for the reduction of the internal bores of successive workpieces all to the same predetermined size, the combination with a grinding wheel, means for procuring a crossfeed movement relative to a workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation, of a work-supporting member for supporting and rotating each workpiece successively in proper position relative to the grinding wheel, said work-supporting member comprising supporting members engageable with the periphery of the workpiece at spaced points and positioned to procure, in response to variations in the outside diameter of successive workpieces, an offset of the axes of said workpieces from the position of the axis of a normal-sized workpiece substantially in a plane perpendicular to the plane of the crossfeed movement.

12. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation, of a work-supporting member for supporting and rotating the workpiece in proper position relative to the grind-

ing wheel, said work-supporting member comprising supporting rolls engageable with the periphery of the workpiece and rotatable about fixed axes in a plane substantially parallel to the direction of the crossfeed movement, and a pressure member holding the workpiece in engagement with said rolls.

13. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation, of a work-supporting member for supporting and rotating the workpiece in proper position relative to the grinding wheel, said work-supporting member comprising supporting members engageable with the periphery of the workpiece at spaced points in a plane substantially parallel to the direction of the crossfeed movements and a pressure member for holding the workpiece in engagement with said supporting members.

14. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation, of a work-supporting member for supporting and rotating the workpiece in proper position relative to the grinding wheel, said work-supporting member comprising supporting rolls engageable with the periphery of the workpiece at points in a plane substantially parallel to the direction of the crossfeed movement, and a pressure member for holding the workpiece in engagement with said rolls.

15. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation, of a work-supporting member for supporting and rotating the workpiece in proper position relative to the grinding wheel, said work-supporting member comprising supporting rolls engageable with the periphery of the workpiece and rotatable about fixed axes in a plane substantially parallel to the direction of the crossfeed movement, and a resiliently supported pressure member for holding said workpieces in engagement with said rolls.

16. A work-supporting device for grinding machines and the like, said machine having a cutting tool movable relative to the work-supporting device for a crossfeed movement, said device comprising spaced supporting members engageable with the periphery of the workpiece at spaced points in a plane substantially parallel to the plane of the crossfeed movement, and a pressure member holding the workpiece in engagement with said supporting members, one of said members procuring rotation of the workpiece in the device.

17. In a grinding machine, the combination with a grinding wheel, of a work-supporting structure for supporting and rotating a workpiece on its preformed outer surface, said structure comprising supporting means positioned to procure, in response to variations in the outside diameter of the said workpiece, a shifting movement of the axis of the workpiece substantially in a plane parallel to the normal plane of tangency of the cutting surface of the wheel to the workpiece, and a pressure member engageable resiliently with the workpiece for retaining the latter in engagement with the supporting members.

18. In a grinding machine for the reduction of internal bores of successive workpieces all to the same predetermined size, the combination with a grinding wheel, and means operative when the cutting surface of the grinding wheel reaches a predetermined position for procuring a change in the grinding operation, of a work-supporting member for supporting and rotating each workpiece successively in proper position relative to the grinding wheel, said work-supporting member comprising supporting members engageable with the periphery of the workpiece at spaced points and positioned to procure, in response to variations in the outside diameter of the workpieces, an offset of the axes of said workpieces from the position of the axis of a normal sized workpiece substantially in a plane parallel to the normal plane of tangency of the cutting surface of the wheel to the workpiece, and a pressure member engageable resiliently with the workpiece for retaining the latter in engagement with the supporting members.

19. In a centerless grinding machine for the reduction of a plurality of workpieces all to substantially the same size, a work-supporting structure, a grinding wheel, means for procuring a crossfeed movement between said wheel and said structure, size controlling means, and means responsive to said size controlling means for terminating the grinding operation, said work-supporting structure comprising a plurality of fixed supports, all of which are out of the plane defined by the axis of rotation of the grinding wheel and parallel to the plane of the crossfeed movement, whereby to minimize the variations in size of the internal diameters.

20. In a centerless grinding machine for the reduction of a plurality of workpieces all to substantially the same size, a work-supporting structure, a grinding wheel, means for procuring a crossfeed movement between said wheel and said structure, size controlling means, and means responsive to said size controlling means for terminating the grinding operation, said work-supporting structure comprising a plurality of fixed supports arranged to procure an offset of the axes of the workpieces from the position of the axis of a normal-sized workpiece, as a result of variations in outer diameters thereof, substantially in a plane making a sufficiently large angle with the plane of the crossfeed movement so that workpieces having varying outside diameters will all be reduced to the same internal diameter.

21. In a centerless grinding machine for the reduction of a plurality of workpieces all to substantially the same size, a work-supporting structure, a grinding wheel, means for procuring a crossfeed movement between said wheel and said structure, size controlling means, and means responsive to said size controlling means for terminating the grinding operation, said work-supporting structure comprising a backing roll and a supporting member both engageable with the periphery of the workpieces out of the plane defined by the axis of rotation of the grinding wheel and parallel to the plane of the crossfeed movement, whereby variations in inside diameters as a result of variations in the outside diameters are minimized.

22. In the grinding of workpieces in multiple, the method of reducing all of the workpieces to substantially the same internal diameter, which

involves supporting the workpieces in substantially axial alinement on their outer surfaces in such a manner that the offset of the axes of the workpieces from the position of the axis of a normal-sized workpiece, as a result of variations in the outside diameters thereof, is substantially in a predetermined plane, and advancing the grinding wheel relative to the workpieces for a crossfeed movement substantially in a plane making a sufficiently large angle with said predetermined plane so that the resulting variations in inside diameter are minimized.

23. In a method of reducing the bores of successive cylindrical workpieces all to a predetermined size, in which the cutting surface of the grinding wheel is advanced to the same predetermined point relative to the work supporting structure for a crossfeed movement in a predetermined plane during the grinding of each successive workpiece, the step which comprises supporting and rotating each workpiece on its preformed outer surface during the cutting operation on the bore thereof in such a manner that a variation in its outside diameter from the diameter of a normal-sized workpiece will result in offsetting its axis from the position of the axis of a normal-sized workpiece in a direction making a sufficiently large angle with the plane of the cross-feed movement to minimize the resultant variations in the internal diameters of successively ground workpieces.

24. In the grinding of workpieces in multiple, the method of reducing all the workpieces to the same internal diameter, which involves supporting the workpieces in substantially axial alinement on their outer surfaces in such a manner that the offset of the axes of the workpieces from the position of the axis of a normal-sized workpiece, as a result of variations in the outside diameters thereof, is substantially in a predetermined plane, advancing the grinding wheel relative to the workpieces for a crossfeed movement in a direction making a sufficiently large angle with said predetermined plane so that resultant variations in internal diameters are minimized, and bringing the grinding operation to a close when the grinding wheel reaches a predetermined point relative to the work supporting structure.

25. In the grinding of workpieces in multiple, the method of reducing all of the workpieces to substantially the same internal diameter, which involves supporting the workpieces in substantially axial alinement on their outer surfaces in such a manner that the offset of the axes of the workpieces from the position of the axis of a normal-sized workpiece, as a result of variations in the outside diameters thereof, is substantially in a predetermined plane, said plane being substantially parallel to the plane of tangency of the grinding wheel and a normal-sized workpiece.

26. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation, of a work-supporting member for supporting and rotating a workpiece on its preformed outer surface so that a variation in size of the outer surface will shift the axis of the workpiece substantially in a plane approximately parallel to the plane of tangency of the grinding wheel and a normal-sized workpiece.

27. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, of a work-supporting member for supporting and rotating a workpiece on its preformed outer surface, said member having means positioned to procure a shifting movement of the axis of the workpiece substantially in a plane approximately parallel to the plane of tangency of the grinding wheel and a normal-sized workpiece, in response to variations in the outside diameter of said workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation.

28. In a grinding machine, the combination with a grinding wheel, means for procuring a crossfeed movement of said wheel relative to a workpiece, and means governed by the extent of the crossfeed movement for controlling the progress of the grinding operation of a work-supporting member for supporting and rotating consecutive workpieces successively on their preformed outer surfaces, said member having means positioned to procure an offset of the axes of successively ground workpieces which vary slightly in outside diameter from the position of the axis of a normal-sized workpiece substantially in a plane approximately parallel to the normal plane of tangency of the grinding wheel with a normal-sized workpiece, this offsetting of the axes of successively ground workpieces being responsive to variations in outside diameters of said workpieces.

29. In a grinding machine for the reduction of the internal bores of successive workpieces all to the same predetermined size, the combination with a grinding wheel, and means for procuring a crossfeed movement relative to a workpiece, of a work-supporting member for supporting and rotating each workpiece successively in proper position relative to the grinding wheel, said work-supporting member comprising supporting members engageable with the periphery of the workpiece at spaced points and positioned to procure, in response to variations in the outside diameter of successive workpieces, an offset of the axes of said workpieces from the position of the axis of a normal-sized workpiece substantially in a plane approximately parallel to the plane of tangency of the grinding wheel and a normal-sized workpiece.

30. In a grinding machine, the combination with a grinding wheel, of a work-supporting structure for supporting and rotating a workpiece on its preformed outer surface, said structure comprising supporting means positioned to procure, in response to variations in the outside diameters of successive workpieces positioned therein, an offset of the axes of successive workpieces from the position of the axis of a normal-sized workpiece, substantially in a plane approximately parallel to the normal plane of tangency of the cutting surface of the grinding wheel and the workpiece, and a pressure member engageable resiliently with the workpiece for retaining the latter in engagement with the supporting members.

31. In a grinding machine, a grinding wheel, a work-supporting structure, and means for procuring a crossfeed movement therebetween, said work-supporting structure having a plurality of spaced fixed work-supporting members engageable with the periphery of the workpiece and so positioned as to procure a relative offsetting of the axes of workpieces of slightly varying diameters, said offsetting being substantially in a plane mak-

ing a sufficiently large angle with the plane of the crossfeed movement to minimize resultant variations in the inside diameters of the workpieces.

32. In a centerless grinding machine for the reduction of a plurality of workpieces all to substantially the same internal diameter, a work-supporting structure, a grinding wheel, means for procuring a crossfeed movement between said wheel and said structure, size-controlling means and means responsive to said size-controlling means for terminating the grinding operation, said work-supporting structure comprising a plurality of fixed supports, all of which are out of the plane defined by the axis of rotation of the grinding wheel and parallel to the plane of the crossfeed movement and all being on the same side of said first plane, whereby variations in size of the internal diameters of the workpieces are minimized.

HAROLD L. BLOOD.