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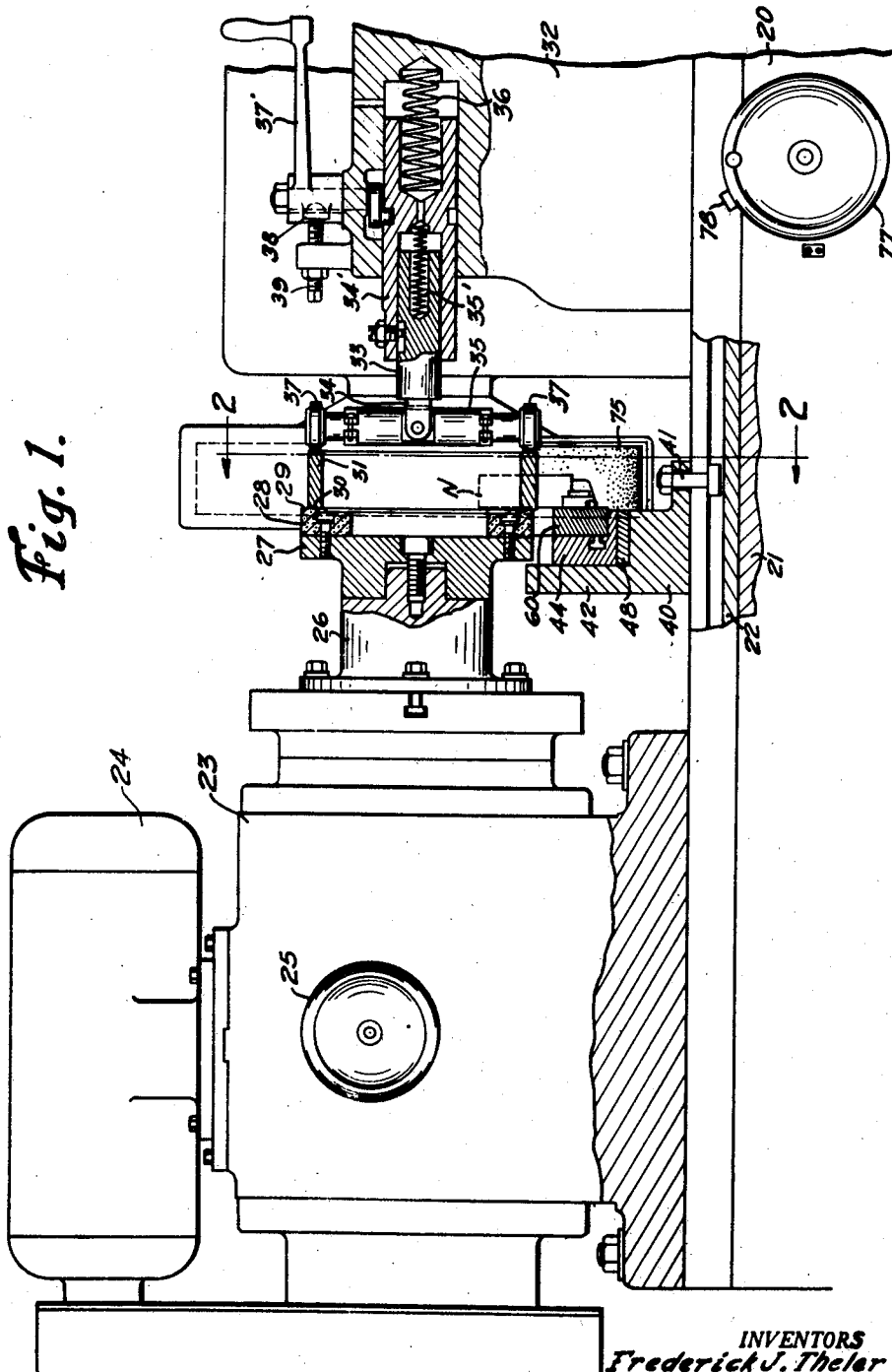
F. J. THELER ET AL

2,478,607

GRINDING MACHINE

Filed April 15, 1946

5 Sheets-Sheet 1



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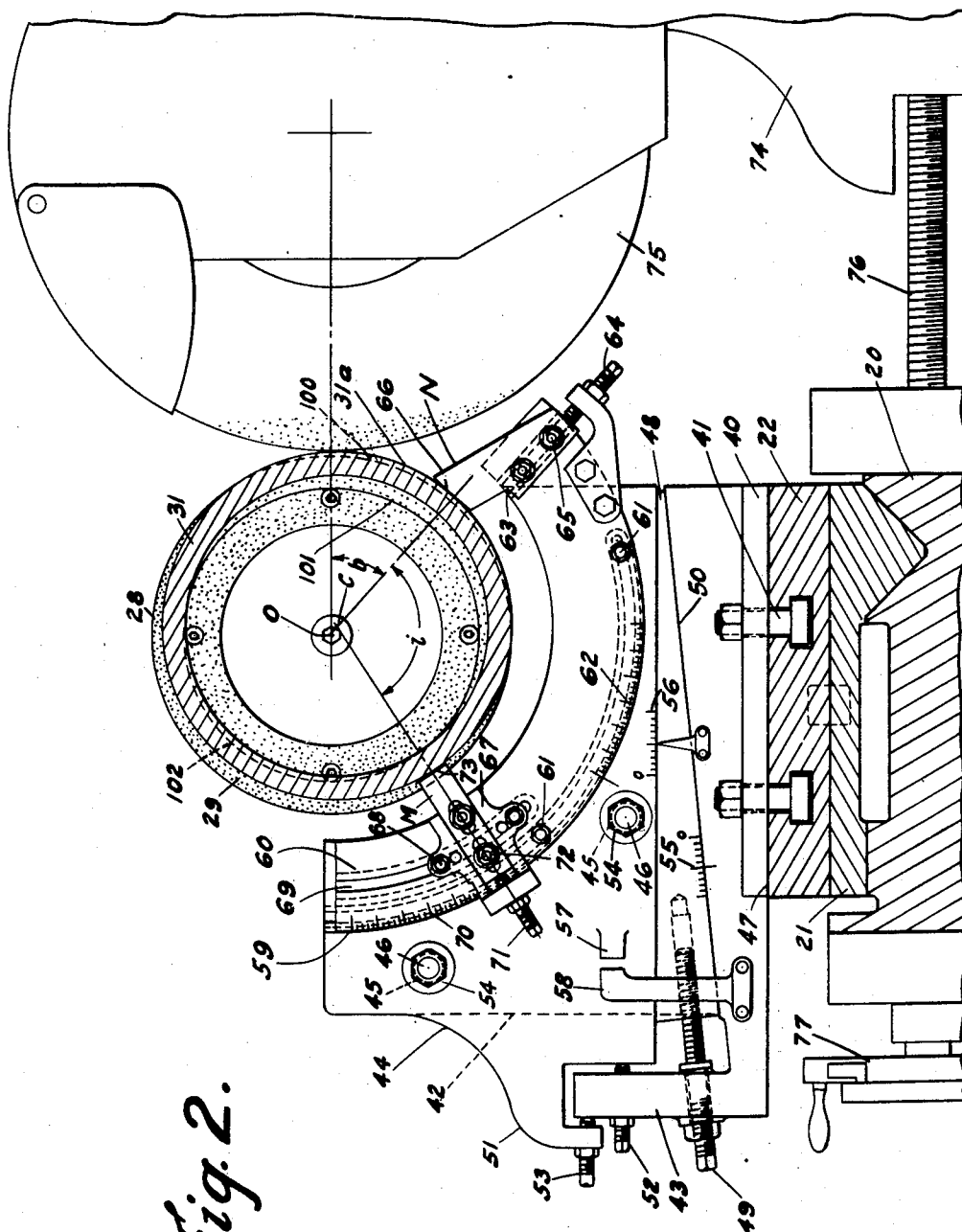


Fig. 2.

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Fig. 3

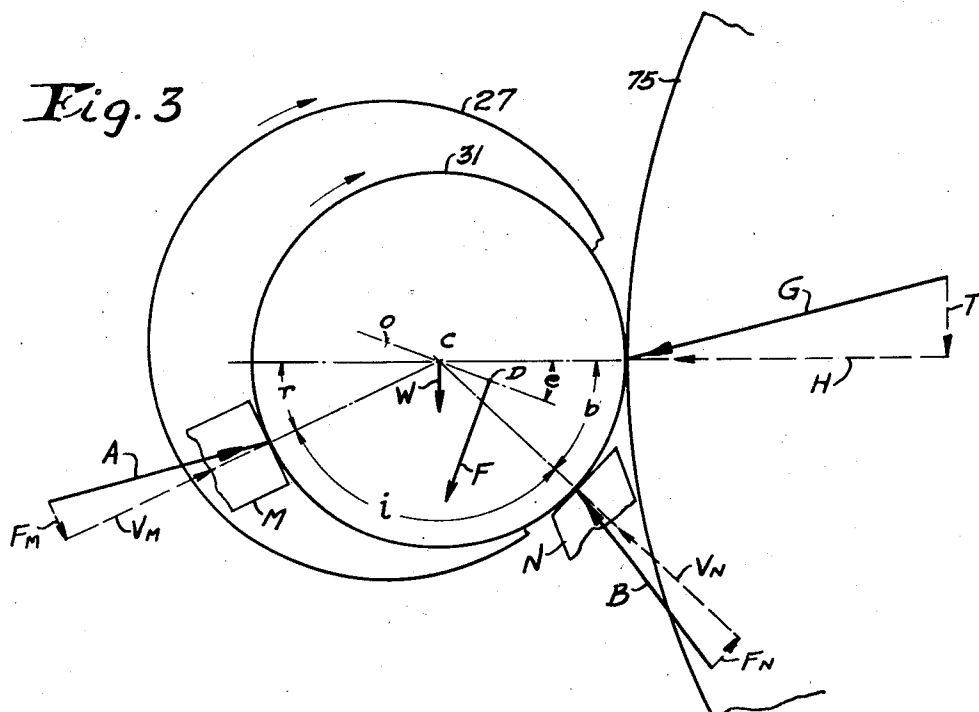


Fig. 4

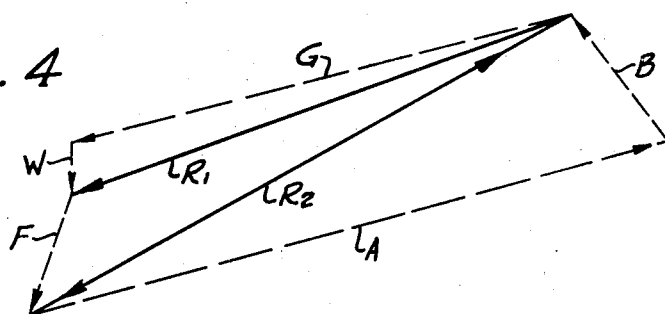
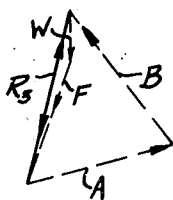


Fig. 5



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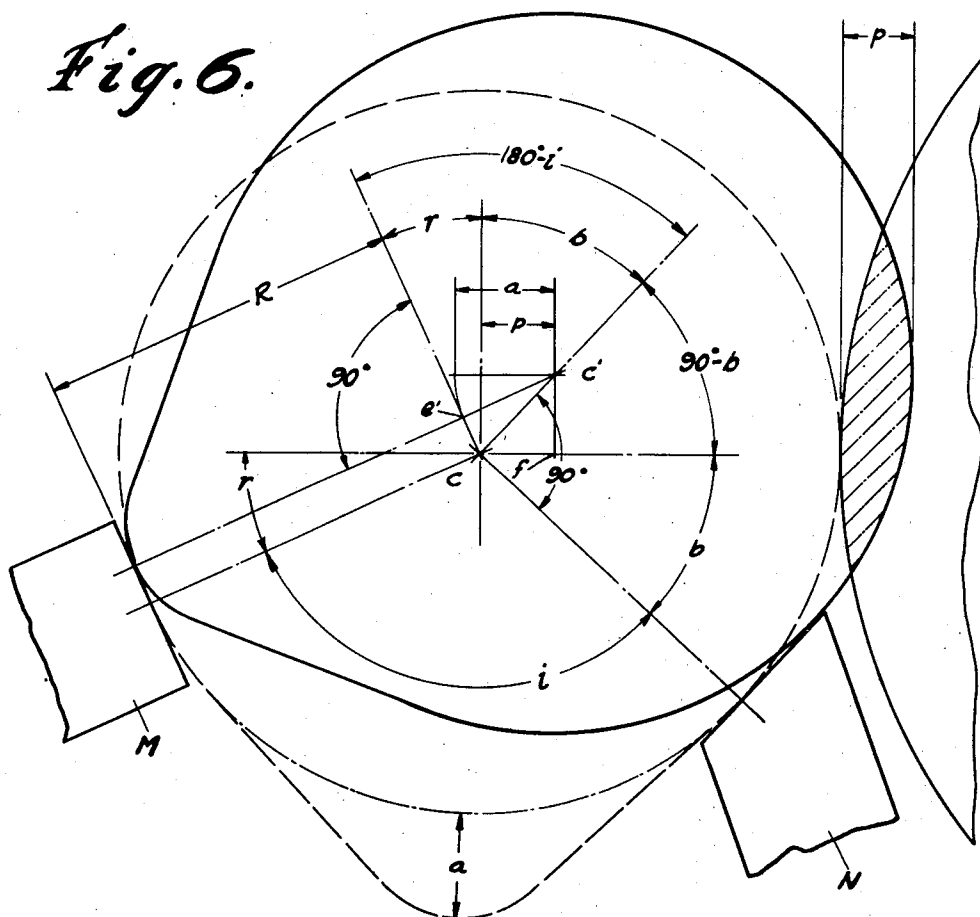
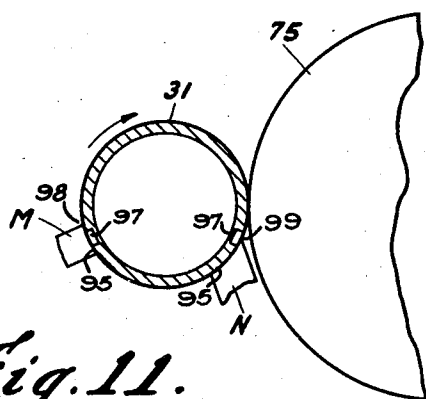
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GRINDING MACHINE .

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5 Sheets-Sheet 4



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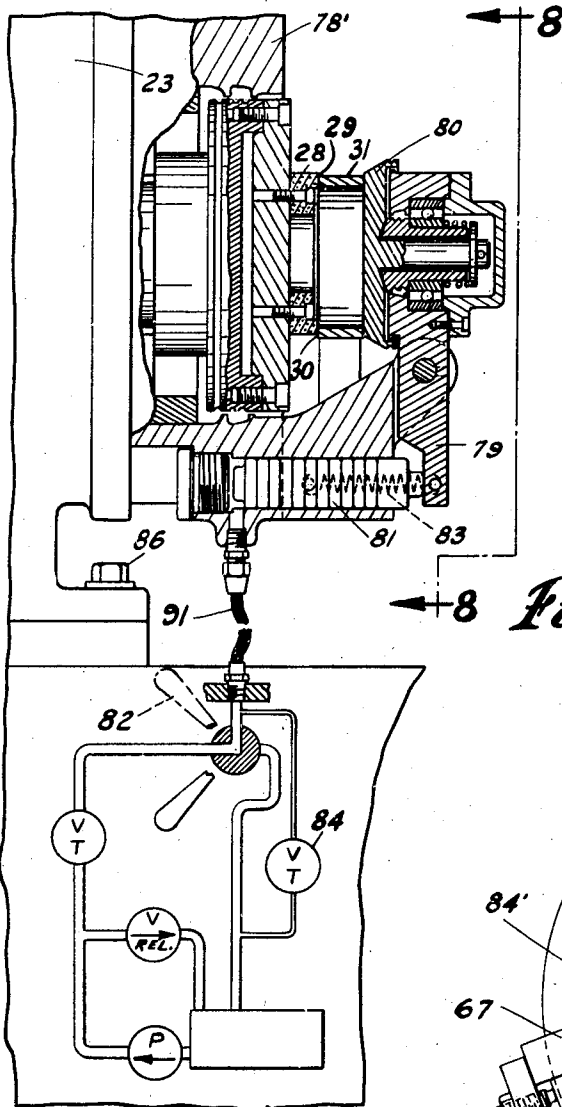
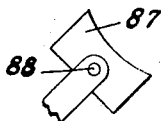
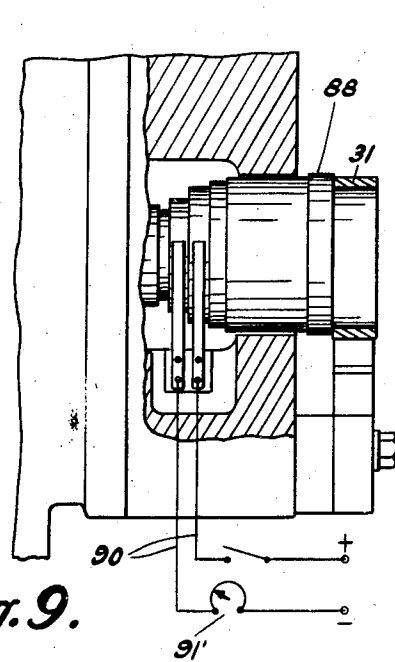
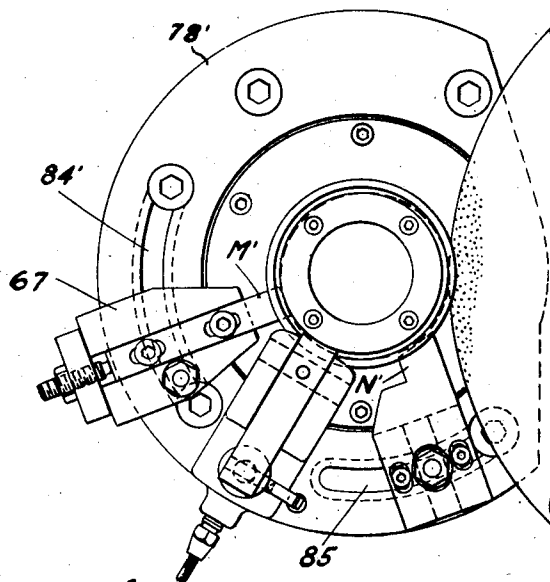


Fig. 8.

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2,478,607

GRINDING MACHINE

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Application April 15, 1946, Serial No. 662,191

45 Claims. (Cl. 51—103)

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This invention relates to improvements in grinding machinery for precision production of a surface of revolution on a work piece.

In the normal process of manufacturing, the accuracy of ground parts has been improved over a period of years, and modern grinding machines under favorable conditions produce parts within limits as close as .001" in diameter. Besides this accuracy in size, modern demands require in certain industries also that the work produced is a theoretical circle within a few millionths of an inch—that is to say that the departure from the theoretical circumference, caused by unavoidable defects in the grinding method employed or the machine used, at no point varies more than twenty millionths of an inch. To obtain such precision, the grinding operation was generally performed in the past in the laboratory with painstaking care by the operator, extra care of the grinding machine and preparation of the work piece and a time-consuming slow method of metal removal, all of which makes the cost of producing such an accurate part exceedingly high. Additionally, a subsequent lapping operation was generally required.

Some of the objects of the invention are:

First, to produce a machine and method to grind work to a high degree of roundness with a precision of the order of twenty millionths of an inch or less.

Second, to obtain this high degree of precision and on a high production basis with a machine which is only built to conventional precision accuracy and operated by one of ordinary skill.

Third, to simultaneously obtain with this precision a sufficiently high quality of surface that subsequent finishing operations, such as lapping, are rendered unnecessary.

Fourth, to obtain a surface of revolution on a work piece which is in definite and precise relationship with a previously finished surface thereon.

Fifth, to produce such a highly accurate and finished surface on a work piece in less time than is possible with present methods.

Sixth, to produce a machine which can perform grinding operations on work pieces which cannot be produced on the conventional centerless grinders such as shouldered work with flanges, work pieces in which the surface of revolution has interruptions like keyways, and so forth.

Other objects and advantages of the present invention should be readily apparent by reference to the following specification considered in con-

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nection with the accompanying drawings illustrative of certain embodiments thereof, and it will be understood that various modifications may be made in the specific structural details and method described within the scope of the appended claims without departing from or exceeding the spirit of the invention.

In the drawings there have been illustrated certain embodiments of the principles of the present invention and diagrams illustrating the preferred relationships of the essential parts.

Figure 1 is a fragmentary view partly in elevation and partly in section of one form of machine embodying the principles of the present invention.

Fig. 2 is a fragmentary sectional view on the line 2—2 of Figure 1.

Figure 3 is a diagrammatic view illustrating the force component reactions and resultants.

Figures 4 and 5 are force component diagrams.

Figure 6 is a schematic diagram of the rounding up action.

Figure 7 is a fragmentary view illustrating the employment of hydraulic clamping means.

Figure 8 is a view as on line 8—8 of Figure 7.

Figure 9 illustrates the employment of electrical holding means.

Figure 10 is a detailed view of a rocking type shoe structure.

Figure 11 is a fragmentary view illustrating the production of a work piece having an interrupted surface.

For attainment of the objects of the present invention, including the accurate production of precision surfaces of revolution, we have discovered consideration should be given to the following.

First, the support and drive for the work must be positive in character but with sufficient flexibility to permit the work to shift freely radially the amount necessary for self-determination of its axis.

Second, as the work is to be supported on the surface being generated during the tooling operation which removes stock from that surface, the supports should be of such a nature and so arranged within stability limits as to facilitate maximum rounding up correction per revolution.

Third, as the final tooling involves minute stock removal and thus extremely light contact of the wheel with the work, to prevent chatter-producing pulsations or vibrations of the work, it is necessary that same be given a continuous positive rotation independent of the grinding wheel reaction thereon and be continuously urged and

held firmly in stabilized position against its supports and oscillation toward the grinding wheel prevented.

Fourth, in the formation of thin-walled easily distortable articles, such as rings or anti-friction bearing elements, the work must be properly maintained and rotated in opposition to the grinding wheel but without peripheral or other pressure tending to distort same and interfere with proper rounding up action.

In the drawings in which similar reference characters are employed to denote the same or similar parts, the numeral 20 designates the bed of a machine embodying principles of the present invention having mounted thereon and longitudinally movable with respect thereto the table 21 on which is swiveled the work supporting and controlling structure 22.

This includes a power unit 23 provided with a driving motor 24. Contained within the unit 23 is suitable speed change mechanism controlled by speed adjuster 25.

Projecting from the member 23 is spindle 26 on which is removably mounted a face plate 27 bearing a work engaging ring or disc 28, preferably formed of suitable friction material and having a raised annulus providing a narrow face 29 for engagement with the preformed or finished face 30 of work piece 31, here indicated as a thin-walled ring or race member intended for use as a part of an anti-friction bearing.

Disposed on member 22 in opposition to unit 23 is a member 32 provided with resiliently actuated spindle 33, terminating in a yoke 34. Pivoted in the yoke is a self-adjusting or oscillatable cross arm 35 terminally provided with rollers 37 for engagement with one end face of the work piece 31 to hold same against face 29. To control the holding pressure, spindle 33 has limited axial movement in sliding sleeve 34', being outwardly urged relative thereto by spring 35'. Sleeve 34' is outwardly urged by spring 36, effecting first bodily movement of spring 35' and the spindle, and then relative movement and compression of spring 35' as the rollers engage the work. Handle 37' serves to effect retraction of the clamp when moved counterclockwise, while adjustable stop 39 engaging lug 38 on the handle limits its clockwise movement and thus the compression of spring and the actual clamping force exerted against the work piece.

The details of a universally adjustable form of work support mechanism for cooperating with the parts just described in maintaining the work in proper position during grinding are shown in Figure 2.

The work supporting fixture

Mounted on the pivoted slide 22 and disposed below and adjacent the plate 27 is the work support fixture base 40. This base is supported on the member 22 for movement in a direction toward and away from the plate 27 and may be secured in adjusted position as by tightening of the clamp bolts 41. The base 40 has a main up-standing bracket portion 42 and an adjacent spaced lug or boss 43. Mounted on the face of the portion 42 is a plate 44 having enlarged apertures 45 receiving clamp bolts 46 carried by the bracket. The difference in size of apertures and bolts permits of limited movement of the plate with respect to the bracket for effecting relative adjustment of the parts. Member 40 has an inclined or wedge surface or guideway as at 50 for

cooperation with the sliding wedge 48 whose horizontal upper face supports and forms a horizontal guide for plate 44. An adjusting screw 49 threaded into wedge 48 and mounted in boss 43 for rotary and vertical sliding movements facilitates accurate vertical adjustment of the plate 44 by inward or outward movement of the wedge.

The plate 44 is further provided with a yoke 51 spanning the upper portion of boss 43. Adjusting screw 42 carried by the boss exerts an inward pressure against the yoke and plate while a second adjusting screw 53 limits the inward movement or alternatively effects retraction. By this construction a slight loosening of screw 52 or 53 unclamps the yoke; and vertical adjustment of the plate may be effected by wedge 48, the screws riding on the boss and preventing an in and out movement of the plate. Correspondingly, when the wedge 48 is stationary, adjustment of screws 52 and 53 will effect in and out movements of plate 44 along the horizontal face of wedge 48 as a guide while the exact adjustment of the parts is maintained. In either event tightening of clamp nuts 54 on bolts 46 will then rigidly lock the parts in desired position. Wedge 48 and base 40 may be provided with suitable cooperating indicia as indicated at 55 for determining the vertical adjustment effected by movement of the wedge while the transverse adjustment of the plate may be determined either by the provision of corresponding cooperating indicia on the base and plate as indicated at 56 or by formation of a lug as at 57 on the plate and a cooperating gage element 58 carried by the base of the fixture. Interposition of suitable thickness gages between the elements 57 and 58 serve to facilitate most accurate in and out relative adjustment of the parts.

Milled in the forward upper portion of plate 44 is an arcuate guideway 59 in which is mounted for angular adjustment the sector 60 which may be secured in desired adjusted position as by tightening of T bolts 61. Suitable cooperating indicia as at 62 on the plate and sector serve to determine the relative angular adjustment of said parts.

Mounted on the inner end of the sector and guided for radial adjustment as by the tongue slot 63 is a work shoe support N adjustable as by screw 64 and adapted to be secured in adjusted position by tightening of clamp bolts 65. As here shown the member N has been indicated with a plain bearing face as at 66 for engagement with the periphery 31a of the work piece.

It will be understood that this contacting surface 66 may be either of the plain form shown, or of any of the fixed or floating shoe types, such for example as those illustrated in other figures of the drawings, the element N being replaceable either for introduction of different types of shoes or for length in the event that the variation in diameter of work pieces is in excess of the adjustment effectable by screw 64.

Accurately spaced from the support N an amount measurable by the angle i is a second work support mechanism also carried by the sector plate. This mechanism includes a base 67 carrying T bolts 68 engaged in the supplemental T slot 69 formed in the segment 60. By loosening of these bolts the base 67 may be angularly adjusted about the center of the segment arc to vary the angle i an amount determinable as by the indicia 70. This base, in turn, supports the shoe support element M radially adjustable as by screw 71 and clampable as by members 72 in de-

sired adjusted position. Like the member N this may be provided with differing forms of work contacting surfaces as at 73 for engagement with the surface 31a of the work piece at the determined angle i with respect to the point of engagement of the contacting surface 66. The member M is likewise replaceable to care for varying work diameters.

By reference to Figure 2 it will be noted that the members M and N by peripheral engagement with the surface of the work piece determine the location of its center or axis c . When M and N are correspondingly adjusted this center will coincide with that of the guideway 59. When so positioned, the position of the work center will remain constant during arcuate adjustment of the sector 60 and shoes M and N supported thereby. The dimensions of the several parts are such that by use of the adjustments indicated the center c of the work may be made to coincide with the axis of rotation o of the drive plate 27. Alternatively, by employment of these adjustments the work may be moved in and out by the adjusting screws 52—53 to determine the amount of horizontal eccentricity of c with respect to o in a direction toward or from the grinding wheel, and may be independently adjusted by shifting of wedge 48 to vary the center height of c above or below that of o . As hereinafter pointed out, these adjustments serve to control the amount of driving torque and tangential force applied to the work piece upon rotation of the plate 27. Additionally, the angle i intervening the two work supports may be varied as desired by adjustment of the member 67 on segment 60 while the position of the elements M and N as an entirety and the nature of angle b as a measure of the relationship between the point of grinding contact and contact of N with the work surface being generated may be varied by bodily adjustment of the sector 60, all without any change in work center position.

Relative feeding movement of work and grinding wheel must be effected for necessary stock removal. This feeding is ordinarily slight but continuous, resulting in a spiral removal of the work surface, the feeding being stopped for final sparking out to produce a true precision cylinder. Conventional mechanism has been illustrated comprising the grinding wheel carriage 74, slidably mounted on the bed, and supporting the rotatable grinding wheel 75 in opposition to the work support.

A screw 76, carried by the bed, engages the carriage and is operable as by pilot wheel 77. An adjustable stop, as at 78, may be employed to limit the infeed movement.

By reference particularly to Figures 1, 2, and 7, it will be noted the width of the annular face 29 is so proportioned with respect to the wall thickness of the work piece that during the sliding of the work transversely with respect thereto, the work will wipe across the inner and outer edges of face 29. The projection of the work outwardly beyond face 29 will be evident by reference to the dotted line showing of the outer edge of the face at 100 in Figure 2, while circle 101 shows the inner edge of the face which is overlapped by the work as in area 102. This insures equalized wear of the supporting face 29 and prevents formation of deleterious grooves or ridges on the face, in or adjacent the work path which might cause variable work piece reactions in continuous production grinding.

Force components

Figure 3 is a schematic diagram to illustrate the several force components developed in grinding in accordance with this invention. In this figure the drive plate 27 is positively driven clockwise. The work indicated as 31 is held against the face of the drive plate by the previously described pressure member with resilient adjustable loading so that the pressure between drive plate and work can be varied by adjustment of stop 38 as required. The grinding wheel indicated as 75 is shown in position to grind. The work center is eccentrically displaced from the drive plate center o along a line OD at an angle e to the horizontal. The work is supported in this position by the two shoes M and N, each of which is adjustable for work diameter and for angular relation with reference to each other and to a line connecting the centers of the work and grinding wheel. The letter r has been used to indicate the position angle of shoe M, and the letter b the angle for N, as respects said line.

In this set-up there are a number of external forces which act on the work 31 which produce or resist its rotation and movement from its position as shown. The first of these forces is from the grinding wheel which acts during the grinding operation only. In order that the grinding wheel will penetrate and remove stock from the work it is necessary that the grinding wheel be held against the work with a horizontal force H, which tends to displace or push back the work and a tangential force T tending to rotate the work. These two forces may be combined into a resultant G, and its direction is relatively constant for any given set-up but its value will vary with the rate of stock removal. Shoe M, since the work is resting on it, has two forces which act on the work. One of these is a force V_M acting radially to the work and the other is a force F_M which acts tangentially to the work, resisting rotation by reason of the friction between work surface and shoe surface. These two forces may be resolved into a single resultant A which for any given coefficient of friction has a constant direction, and its value is a function of the other applied forces which increase or decrease the pressure between work and shoe. Likewise, the shoe N exerts a force V_N and a force F_N which may be resolved into a single force B. This latter combination of forces is exactly similar to those at the shoe M. The weight of the work acting through its center of gravity which is generally the same as its center of rotation always acts vertically downward as indicated, by arrow W.

The final force independent of the grinding wheel acting on the work is shown as F, and it is produced as a result of the pressure between work and driving plate and from the rotation of the drive plate. This force acts perpendicular to the line OD.

It is obvious that for the work to be stable, that the resultant of the grinding force, the weight, and the force F must be equal to the resultant of the shoe forces A and B, and furthermore, that the line of action of the two resultants must coincide. This condition of stability is indicated by the force diagram in Figure 4 and is shown for considerable values of G, that is, when a grinding cut is being taken. It is obvious from this diagram that if the force F was zero and force due to the weight of the work was a negligible, the resultants of these forces R_2 75 would be nearly parallel to G and from the con-

figuration would tend to push the work to the left about the shoe M as a fulcrum.

Therefore, the force F which tends to depress downward the resultant of the three forces F, G, and W, is a very important consideration. Furthermore, if there is no grinding cut, or if the grinding cut is reduced to a very low value as when near the finished diameter of the work, the only force which will produce rotation is F, and then it must be sufficiently high to overcome the friction losses at the two shoes and in a direction to hold the work in stabilized engagement with the shoes. This condition is shown schematically in Figure 5 where R₃ is the resultant of the forces F and W and A and B again represent the forces acting at shoes M and N respectively. The force G is entirely eliminated, indicating absence of grinding pressure.

Radial increases and decreases in relative eccentricity of the centers o and c correspondingly vary the force F, while arcuate adjustment of c about o varies the resultant direction of reaction of that force. It will be noted that the form of supporting fixture shown in Figure 2 permits ready effecting of these adjustments without any change of the relation between the support shoes and the work.

If stability of the work were the only consideration, it would be possible to reduce the value of r for shoe M in Figure 3 to equal or be less than the angle between H and G, the horizontal component and the resultant forces of the grinding wheel on the work, and then under all conditions the work would be stable. However, as one of the purposes of this invention is to generate work which is round to closer tolerance than has been possible by prior devices, and the positions of shoe M and the shoe N have a very important control over this factor, it is essential that these be so positioned as to attain maximum rounding compatible with necessary stability.

Rounding action

The means for producing cylindrical work by grinding which is geometrically round and free from chatter marks will be analyzed next. The work is located and supported in relation to the drive plate center by the two spaced shoes M and N which contact the surface to be ground. The grinding wheel is then fed toward the work.

The positions of these shoes in relation to each other and in relation to the grinding wheel determine production of work which is geometrically round and free from chatter marks. With the shoes in certain spaced relationships, there will be no correction of an out of round condition in a rough blank when it has been ground to a finished size. Other relationships will generate true cylinders from irregular blanks with greater or less efficiencies. A formula can be used to show what the relative positions of the shoes should be to secure the maximum rounding effect or which position of the shoes will produce no rounding effect. Further, this formula can be used to compare the rounding efficiency of two different shoe relationships.

The errors in roundness of rough blanks to be ground are relatively small, usually in the order of .002"-.010" measured across the diameter. In order to analyze the action which takes place, this error has been greatly exaggerated. To further simplify the analysis, the action caused by a single error on the periphery of an otherwise round blank will be analyzed.

Practice has proven two conditions are necessary to grind work round. The first is that an error in the rough blank cannot be permitted to cause an increase or decrease in stock removal rate diametrically opposite from itself, and that a change from the normal infeed rate can be tolerated only if it is spaced more or less than 180 degrees from the error which produces it. The second condition is that the amount or degree of such change must be less than the error which causes it. In order to produce round work, the configuration of the shoes relative to the work and their position to the grinding wheel must satisfy both of these considerations. If it satisfies both conditions, round work will be produced, but if it violates either or both, then it is impossible to produce work which is both round and free of chatter marks.

In Figure 6 shoe N is placed at an angle b from the grinding wheel contact, and shoe M is spaced angle i from shoe N. With this arrangement, the extra penetration p is caused at a position on the work (i plus b) from the error a which causes it. Therefore, if the quantity (i plus b) is less than 180 degrees, the first condition necessary to produce round work is satisfied.

The second condition necessary is that the penetration produced by an error shall be less than the error itself. In Figure 6, when the error on the periphery of the work reaches the shoe M, it produces the penetration p. In moving from the dotted line position with center at C to the new position indicated by solid line with center at C', its geometric center is caused to move along a line C-C' which is parallel to the face of shoe N. The new position of the center C' is (R plus a) from the face of shoe M where R is the radius of the work and a is the height of the error. In the triangle Ce'C', C'e' is the value or height of the error or a. Therefore:

$$CC' = \frac{a}{\sin(180-i)} = \frac{a}{\sin i} \quad (1)$$

In the triangle C/C', C/ is the penetration of the wheel into the work or p caused by the error a. Therefore:

$$p = CC' \cos(90-b) = CC' \times \sin b \quad (2)$$

Substituting the value of CC' from Equation 1 above in Equation 2:

$$p = a \times \frac{\sin b}{\sin i} \quad (3)$$

An inspection of Equation 3 shows several things. First, if angle i has the same value as b, the quantity

$$\frac{\sin b}{\sin i}$$

becomes unity and p, the extra penetration, is equal to a the error which produced it. Therefore, any configuration where angle b is equal to angle i will not produce round work even though one of the conditions for rounding exists; namely, the penetration is not opposite the producing error. Therefore, it is necessary that angle i must always exceed angle b if there is to be a roundness correction.

Next, the equation shows that angle b should be as small as possible in order to secure the greatest rounding effect per revolution. Obviously, the less penetration any error produces, the less stock is required to be removed to produce the perfect cylinder. Also, since the maximum

value of the sin is at 90 degrees and equals unity, then for any value of angle b , angle i should be as near 90 degrees as possible.

Therefore, from the rounding effect viewpoint the conditions would be satisfied if the shoe N would be placed as near as possible to the wheel and the angle between the shoes M and N should be made 90 degrees. In some cases, however, the work would be unstable under such conditions and the angle i must be increased above 90 degrees to favor stability.

With the relationship of parts illustrated in Figure 6, for example, when the angle b is 42 degrees angle r is 33 and angle i is 105, a practical and satisfactory stabilized rotation of the work is attained by which work can be finished to within a few millionths of an inch as respects roundness and absence of irregularities or chatter marks. For heavier cuts angle i is preferably slightly increased and corresponding accuracy attained with a rounding-up action of 25 to 30 per cent per revolution. This is many times the rate of rounding up hitherto attainable by previously known methods of centerless grinding. Actual grinding has established that the final accuracy of the finished products is to precision limits not attainable by previous production grinding machines and methods.

An alternative form of work clamping mechanism has been indicated in connection with Figures 7 and 8 in which the headstock 23 is mounted for angular adjustment by bolts 86 and is provided with a bracket 78' having pivoted thereto a rock arm 79 bearing at its upper end a self-centering clamping disc 80 for terminal engagement with the work piece 31. A flexible conduit 91 maintains the hydraulic couple. This member is actuated into clamping engagement with the work as by piston 81 controlled by handle 82 and is shifted into releasing position on relief of pressure against the piston as by spring 83 connecting 78' and 79. An adjustable resistance as at 84 permits of accurate control or variation of the amount of end pressure exerted by member 80 against the work 31 for holding same against the friction driving disc 28.

The bracket member 78', as indicated in Figure 8, is of substantial circular form and provided with the slots 84' and 85 in which the work supporting slides 67 and N' are respectively mounted for arcuate adjustment. The radially adjustable work engaging members M' and N' are indicated as rigid blade elements, but it is to be understood fixed or rocking shoes, as shown in Figure 10 for example, may be substituted, their location and function otherwise corresponding.

It will further be understood that the bracket 78' may be secured direct to the headstock, as indicated, or through the medium of an interposed adjustable plate such as shown in Figure 2. When secured direct, the eccentric positioning of the work is determinable by suitable adjustment of members M' and N'.

In Figure 9 there is illustrated an alternative form of work holding means comprising a magnetic chuck 88 energizable as through leads 90 having the inserted rheostat or equivalent control 91' for determining the force reaction of the magnetic chuck against the work piece 31.

A rocking form of shoe 87 is illustrated in detail in connection with Figure 10 in which the shoe may be left free to rock or means such as the clamp bolt 88 employed for locking the shoe type work support in desired angularly adjusted position so that it will be rigid during the actual

grinding operation. These shoes preferably have a curvature substantially corresponding to that of the final work.

In performance of the grinding operation a stream of suitable coolant is directed to the point of contact of work and grinding wheel. This coolant is carried around with the work and also sprayed on the shoes, resulting in the formation of a liquid film between the work and the shoes. This will produce a partial or complete hydrodynamic film between the shoes and work piece, reducing friction and lightening the torque load. This reduces shoe wear and eliminates necessity for use of hard high grade blade material as any good bearing material may be employed, while the length of arc of the shoes with intervening supporting film tends to span short pitch irregularities on the work surface, minimizing their positive or negative reproduction by the grinding wheel and thus assisting in precision surface generation.

The eccentricity between the centers o and c and their vertical displacement in accordance with this invention is ordinarily but a few thousandths of an inch. As material is removed from the supported surface of the work, it will tend to slightly settle down between the supports, effecting a corresponding lowering of the center c . While the action is slight, it effects a change in the angularity of line $o-c$ and the direction of effectiveness of force component F automatically correspondingly shifts during the cut from its point of maximum resistance to the wheel component G to a point effecting greater F force stabilization of the work against the supports as G decreases in the final sparking out of the grinding.

From the foregoing it will be noted we have provided a novel process of precision generation of a surface of revolution or circular shape in cross section in which the work is supported at spaced points on said surface so located as to enhance the rate of "rounding-up" per revolution, effecting a generative grinding of said surface while the work is rotated on and firmly held by a follow-up pressure against the supporting means, and simultaneously held by controlled endwise pressure against axial tilting with respect to a preformed terminal surface, so that the final surface generated has its axis normal to said preformed terminal surface.

It will further be noted there have been provided improved machine structures for maintaining the axis of the work under controlled pressure against tilting with respect to a preformed surface, for effecting rotation and tangential urge of the work in a controlled direction, and for supporting the surface of the work being ground at points so related to the point of grinding contact as to increase the rounding up capacity per revolution as respects prior art structures. Additionally, means have been provided for radial and angular adjustments of the supporting means individually or conjointly, and for bodily adjustment in angular related directions with respect to the terminal driving member to vary the rotative reaction and direction of tangential reaction as respects the work, and in which the work will be firmly held and rotated in stabilized relation to its supports irrespective of the grinding wheel engagement therewith or reaction thereon.

In Figure 11 there has been illustrated the employment of the present invention in connection with formation of a precision surface

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of revolution on a work piece having surface interruptions such as a transverse keyway, oil groove, or the like, as indicated at 97. In this form of the invention the shoes 95 have been indicated as of such width that at all times during the rotation of the work piece 31 a stabilizing portion of the periphery of the work piece will be engaged by the shoes. In the position indicated at 98 the shoe 95 overlaps the surface interruption 97 while in the position indicated at 99. As the interruption is moving into engagement with the shoe the span of the shoe on the adjacent periphery of the work is such that the piece is completely stabilized and no movement of the work center effected by such negative recess on the work periphery. With this structure it is possible to generate a precision surface of revolution on articles having negative surface interruptions, a result impossible of attainment with previously known centerless grinding machines and methods.

What is claimed is:

1. A machine for accurate production of articles of circular cross section, comprising a grinding wheel for engagement with the surface to be ground of a work piece, a first work supporting member having a work engaging portion disposed to engage the surface to be ground of the work in proximity to the grinding wheel, a second work supporting member disposed to engage the surface to be ground of the work piece at a point remote from the grinding wheel and spaced from the first member more than 90 degrees circumferentially of the work, means to rotate the grinding wheel in the direction of said supporting members whereby during grinding the radial and tangential thrusts of the grinding wheel urge the work against said supporting members, and additional means for holding and rotating the work piece on the supporting members independently of the reactions of the grinding wheel, said means having terminal sliding engagement with the work piece for effecting its rotation.

2. A machine for accurate production of articles of circular cross section, comprising a grinding wheel for engagement with the surface to be ground of a work piece, a first work support having a work engaging portion disposed to engage the surface to be ground of the work in proximity to the grinding wheel, a second work support disposed to engage the surface to be ground of the work piece at a point remote from the grinding wheel and spaced over 90 degrees circumferentially of the work from the first support, means to rotate the grinding wheel in the direction of said supports, whereby during grinding the radial and tangential thrusts of the grinding wheel urge the work against said supports, disc means rotatable about an axis parallel to the axis of the grinding wheel and eccentric to the support determined axis of the work, and means for maintaining the work and disc frictionally interengaged, whereby the disc will exert a drive rotating the work piece and maintaining the surface being ground against the work supports during the surface forming grinding operation.

3. A centerless precision grinding machine, including a grinding wheel for operation on the periphery of a work piece, a first work support for engagement with the surface of the work to be operated upon disposed in proximity to the grinding wheel, a second work support remote from the grinding wheel and spaced from the first sup-

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port to contact the work at least 90 degrees circumferentially thereof from the first whereby said supports peripherally engage the portion of the work being ground to determine its axial position in opposition to the tangential and radial thrust components of the grinding wheel, and additional driven means for engagement with the work exerting rotational and radial thrust components in a direction to urge the work against the supports whereby the work will be held against and rotated on said supports irrespective of the engagement of the grinding wheel therewith.

4. A centerless precision grinding machine, including a grinding wheel for operation on the periphery of a work piece, a first work support for engagement with the surface to be ground of the work disposed in proximity to the grinding wheel, a second work support remote from the grinding wheel and spaced from the first support to contact the work at least 90 degrees circumferentially thereof from the first whereby said supports peripherally engage the portion of the work being ground to determine its axial position in opposition to the tangential and radial thrust components of the grinding wheel, driving means for terminally frictionally engaging the work piece, and means supporting the driving means for rotation about an axis displaced in a direction away from the grinding wheel as respects the support determined position of the work axis, whereby rotation of the said means will hold down the work against the supports and effect rotation thereof.

5. In a grinding machine, a grinding wheel, a driving member for controlling the rotation of a work piece from a preformed end surface, work supporting members positioned to support the work by engagement with the surface which is to be ground to a high degree of precision and in definite angular relation to said end surface, said work supporting members being located in such a geometric relation that the distance between the grinding wheel contact with the periphery to be ground of the work and the contact of the adjacent support member periphery to be ground of the work is smaller than the distance between the center contact points of the two support members for the work whereby the reaction of the grinding wheel on said supported surface of the work will produce a surface of revolution of high degree of accuracy in a minimum of time.

6. A machine for generation of a precision surface of revolution on a work piece, including a rotatable grinding wheel and a work support mechanism including spaced members for peripheral engagement with said surface during the grinding thereof, means for effecting relative feeding movements between said parts, whereby during grinding the grinding wheel will exert both a radial penetrating thrust force and a tangential thrust force against the work, said support members being disposed to subtend the work peripherally within the arcuate segment defined by the line of resultant of the grinding wheel thrusts against the work, and independent means exerting a combined rotary and radial thrust against the work in the direction of the supports, whereby a work piece on the supports is positively rotated in a stabilized position during both idling and grinding.

7. A machine for generation of a precision surface of revolution on a work piece, including a rotatable grinding wheel and a work support mechanism including spaced members for periph-

eral engagement with said surface during the grinding thereof, means for effecting relative feeding movements between said parts, whereby during grinding the grinding wheel will exert both a radial penetrating thrust force and a tangential thrust force against the work, said support members being disposed to subtend the work in the segment defined by the intersection of the line of resultant of the grinding wheel thrusts against the work chordally as respects the surface being ground, and independent means in the form of a driven rotary end stop positioned to terminally engage a supported work piece and exert a combined rotary and radial thrust against the work in the direction of the supports, whereby a work piece on the supports is positively rotated in a stabilized position during both idling and grinding, said supports and grinding wheel being geometrically related to effect a high corrective generation per revolution of the work piece, substantially as described.

8. A machine for generation of a precision surface of revolution on a work piece, including a rotatable grinding wheel and a work support mechanism including spaced members for peripheral engagement with said surface during the grinding thereof, means for effecting relative feeding movements between said parts, whereby during grinding the grinding wheel will exert both a radial penetrating thrust force and a tangential thrust force against the work, said support members being spaced and disposed one adjacent to and one remote from the grinding wheel to subtend the work in the segment defined by the intersection of the line of resultant of the grinding wheel thrusts against the work with peripherally spaced points on the work surface, rotatable driving means adapted to terminally engage the work piece, said driving means being rotatable about an axis displaced from the support adjacent the grinding wheel an amount less than the amount of spacing of the support members in a direction away from the grinding wheel whereby the axis will be located in eccentric relation to the support determined axis of the work, and means to maintain a controlled endwise pressure engagement between the work and driving means, whereby due to their eccentric relationship the latter will exert continuous rotational and bodily thrust component against the work to insure positive rotation of the work and modify the radial thrust component reaction of the grinding wheel to maintain the surface of the work as generated in positionally stabilized engagement with the supports during both grinding and idling.

9. A machine for generation of a precision surface of revolution on a work piece, including a rotatable grinding wheel and a work support mechanism including spaced members for peripheral engagement with said surface during the grinding thereof, means for effecting relative feeding movements between said parts, whereby during grinding the grinding wheel will exert both a radial penetrating thrust force and a tangential thrust force against the work, said support members being disposed to subtend the work in the segment defined by the intersections of the line of resultant of the grinding wheel thrusts against the work with the periphery of the work, rotatable driving means positioned to terminally engage the work piece, said driving means being rotatable about an axis displaced from the support determined axis of the work in a direction away from the grinding wheel, means to maintain a controlled endwise pressure engagement

between the work and driving means, whereby due to their eccentric relationship the latter will exert continuous rotational and bodily thrust components against the work to insure positive rotation of the work and modify the radial thrust component reaction of the grinding wheel to maintain the surface of the work as generated in positionally stabilized engagement with the supports during both grinding and idling, and adjustable means for variably determining the resultant direction of reaction of the thrust components of the driving means and grinding wheel as respects the supports.

10. A machine for generation of a precision surface of revolution on a work piece, including a rotatable grinding wheel and a work support mechanism including inner and outer spaced support members for peripheral engagement with said surface during the grinding thereof, means for effecting relative feeding movements between said wheel and support members, whereby during grinding the grinding wheel will exert both a radial penetrating thrust force and a tangential thrust force against the work, said support members being disposed to subtend the work in the segment defined by the line of resultant of the grinding wheel thrusts against the work to oppose said thrusts, means for exerting a continuous non-peripheral follow-up pressure on the work piece in such direction that the resultant component of this and the grinding wheel force components will act in a direction intermediate the supports whereby the work will be maintained in stabilized position on the supports during grinding, the outer support being disposed to engage the surface of the work at a point inwardly of the work as respects the intersection of the projected resultant of the grinding forces with the work periphery which is remote as respects the grinding wheel, whereby the rounding up action per revolution is increased, substantially as described.

11. A machine for precision production of a surface of revolution about an axis normal to a preformed terminal portion of work pieces such as thin walled distortable rings or bearing race elements, comprising a grinding wheel, opposed work supporting and rotating means, and means for effecting relative feeding movement of the parts to control the stock removal during the grinding operation, said work supporting and rotating means including a rotatable end member for engagement with a preformed terminal portion of the work piece to determine the direction of extent of the axis of the work piece, means for holding the preformed portion of the work in frictional engagement with the end member for rotation therewith, means for effecting rotation of the end member, and means for supporting the work with its axis eccentric to that of the end member in a direction toward the grinding wheel and against the radial and tangential thrust exerted by the grinding wheel during a tooling operation, said means including a first work supporting element disposed adjacent the grinding wheel in position for peripheral engagement with the work surface being generated and a second work support disposed for peripheral engagement with the surface of the work to be formed in the adjacent quadrant of the work to that engaged by the first element and more remote from the grinding wheel, said second support having its work engaging portion in an area subtending the line of resultant forces exertable by the grinding wheel against the work and opposing the resultant of the downward force exertable by the end member

against the work on account of the eccentric relation between the axes of the work and the end member, whereby the work will at all times be held and rotated in stabilized position on the work supports during generation of the surface engaged by said supports and rapid rounding up will be effected due to absence of distortion of the work piece by extraneous peripheral pressures and to the geometric relationship of the work support and grinding wheel contacts, substantially as described.

12. In a precision grinding machine, a rotatable driving disk and a grinding wheel having substantially coplanar axes of rotation, said axes being relatively offset in said plane, a pair of spaced work supports one adjacent to and the other remote from the grinding wheel mounted adjacent said disk for engagement with the surface to be ground of a work piece, said supports being so related that the axis of a work piece resting thereon will be displaced as respects the axis of the disk in a direction towards the grinding wheel, the support adjacent the grinding wheel engaging the work at a lesser angle to the work radius normal to a line connecting the supports determined center of rotation of the work and the center of rotation of the grinding wheel than the angle between said radius and the remote support whereby the supports mutually oppose the radial and tangential thrusts of the grinding wheel during a machining operation, and means for urging the work piece into terminal driving engagement with the disk, whereby due to the eccentric positioning of the work with respect to the disk the latter will effect rotation of the work piece and exert a tangential force bodily urging the work into engagement with the supports as material is removed from the support engaged surface thereof.

13. A machine for production of a surface of revolution in definite relation to a preformed terminal surface comprising a rotatably driven disk having a surface complementary to the preformed terminal surface of the work, means for holding said surfaces in engagement, one with the other, a pair of work supporting members adjacent the disk positioned and arranged to engage the periphery of the surface to be ground and support the same with its axis in eccentric relation to that of the driven disc during all reductions in diameter of the surface being produced, whereby the disc will exert a continuous urge of the work into the included angle between the rests and effect rotation thereof and a grinding wheel for operation on said support engaged portion of the work piece disposed to peripherally engage the work and exert a pressure thereagainst in a direction in opposition to the direction of eccentric displacement of the work piece axis.

14. The process of producing on a work piece having a peripheral precision surface of revolution with its axis normal to a terminal portion thereof consisting in initially shaping the parts to substantially the desired shape, forming the terminal surface, employing said preformed terminal surface as a position determinate for the work, laterally supporting the work at spaced points on the periphery thereof with its axis normal to said preformed surface, rotating the work while progressively grinding away material from the laterally supported surface thereof to generate a precision surface of revolution thereon, and exerting a non-peripheral yielding follow up pressure against the work to maintain same

firmly laterally supported during reduction in diameter thereof.

15. The process of forming a work piece with a precision surface of revolution having its axis in definite relation to a terminal portion thereof, consisting in initially producing a terminal position determining surface on the work piece, holding said surface by end pressure against a positioning member, supporting the surface to be generated at spaced points on the periphery thereof, rotating the supported work with its said surface disposed in opposition to a grinding wheel for grinding thereof by the wheel, effecting relative feeding movement between the wheel and work, and effecting relative radial slipping movement between the work and terminal positioning member to maintain the periphery of the work against the supporting means as its diameter is reduced.

16. The process of producing an article having a finished precision surface of generation with its axis in predetermined angular relation to an accurately formed base surface, consisting in maintaining said preformed surface in engagement with a guide under a pressure adequate to effect frictional engagement while permitting relative sliding movement, peripherally floating the portion to be generated on spaced supports, whereby the axis of rotation is self-determinative within the original body of the article but in definite angular relation to the base surface, rotating the article, effecting a constant follow-up urge of the article in the direction of the supports, and effecting an initial spiral removal of material from the supported surface of the article for generation of a surface free from irregularities and a subsequent slight peripheral stock removal for precision generation of an accurately dimensioned surface of revolution.

17. In a grinding machine, the combination with a grinding wheel, of means for supporting a work piece in engagement with the periphery of the grinding wheel including a pair of work supporting shoes, one of said shoes being located in the quadrant adjacent the grinding wheel whereby movement of the work piece tangentially with respect to the point of engagement with the shoe will cause the contact point of the work with the wheel to move into the grinding wheel along an angular line to the contact radius of the grinding wheel, means to support the other shoe in the second quadrant in peripheral engagement with the work surface to be ground whereby out of round eminences or errors on the work surface engaging said other shoe will cause the work to move toward the grinding wheel along said angular line, said shoes being so related that the penetration of the grinding wheel along the contact radius is less than the radial height of said eminences whereby the erratic eminences are rendered nonregenerative to an equal extent, thus generating a round surface on the work, and means frictionally engaging the end of the work for imparting rotation thereto and imparting a radial thrust component on the work having a resultant direction lying between said shoes.

18. A grinding machine of the character described, including a bed, a grinding wheel mounted thereon, a positioning and driving disk carried thereby and disposed in a plane parallel to that of the grinding wheel, a pair of spaced work supporting members disposed adjacent the disk and in opposition to the operative face of the grinding wheel, and means intervening the bed and the shoes for adjusting the shoes arcuately

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individually and collectively with respect to the disk and as a unit in angularly related directions transversely with respect to the face of the disk, substantially as and for the purpose described.

19. A grinding machine of the character described, including a bed, a grinding wheel mounted thereon, a positioning and driving disk carried thereby and disposed in a plane parallel to that of the grinding wheel, a pair of spaced work supporting members disposed adjacent the disk and in opposition to the operative face of the grinding wheel, means intervening the bed and the shoes for adjusting the shoes arcuately individually and collectively with respect to the disk and as a unit in angularly related directions transversely with respect to the face of the disk, and means opposing the disk for yieldingly urging a work piece on the supports into terminal engagement with the face of the disk.

20. A grinding machine of the character described, including a bed, a grinding wheel mounted thereon, a positioning and driving disk carried thereby and disposed in a plane parallel to that of the grinding wheel, a pair of spaced work supporting members disposed adjacent the disk and in opposition to the operative face of the grinding wheel, means opposing the disk for yieldingly urging a work piece on the supports into terminal engagement with the face of the disk, and means for variably determining the amount of endwise pressure exerted on the work piece by said opposing means.

21. A grinding machine of the character described, including a grinding wheel, a rotatable driving disk disposed in parallel offset relation thereto for terminal engagement with a work piece, a pair of spaced work supports disposed adjacent the disk for peripheral engagement with the portion of the work to be ground, means mounting said supports for joint and individual angular adjustment relative to the disk, and additional means for effecting joint transverse adjustment of the supports relative to the face of the disk.

22. The process of generation of a precision surface of revolution on a work piece consisting in rotating the work piece on the surface to be formed, supporting the surface at angularly spaced points, grinding the surface at a point angularly displaced from the adjacent support less than the other support is remote therefrom and exerting a stabilizing pressure urge of the work towards the supports in a varying direction receding from the grinding point as the work piece is reduced to size.

23. In a grinding machine, in combination, a grinding wheel adapted to grind a peripheral surface of a work piece, a pair of supporting elements positioned to engage the underside of said surface during grinding thereof on opposite sides of its central vertical plane, one element being angularly closer to the grinding point than to the other supporting element, and a driving member for frictional engagement therewith coacting with a different surface of the work to exert a rotary and downward force thereon the resultant of which downward force with that of the grinding wheel intersects the work surface between said elements.

24. In a grinding machine, in combination, a grinding wheel adapted to grind a surface of the work, a pair of supporting elements positioned to engage the under side of said surface on opposite sides of its central vertical plane, one element being angularly closer to the grinding point

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than to the other supporting element, and means coacting with a different surface of the work and exerting a rotary and downward force thereon, the area of said first work surface at points angularly more remote from the grinding point than said supporting elements being free from radially outward restraint.

25. In a grinding machine, in combination, a grinding wheel adapted to grind a surface of the work, a pair of supporting elements positioned to engage the under side of the surface being ground, one of which elements is angularly substantially closer to the grinding point than to the other supporting element, and means exerting a downward and rotary force on the work by engagement with its end surface with a force permitting the work to slide downwardly thereon as it is ground away.

26. The herein described art of grinding a surface of revolution which consists in supporting the work on the surface to be ground at two points straddling its vertical diametrical plane, grinding said surface at the side with said surface unrestrained against radially outward movement at points more remote angularly from the grinding point than said points of support, and applying to the work through another surface rotary and downward frictional driving forces.

27. The herein described art of grinding a surface of revolution which consists in supporting the work at two points on the surface to be ground, one of which is angularly closer to the grinding point than it is to the other point, grinding the work and applying to the work rotary and downward forces through surfaces other than that to be ground.

28. The herein described art of grinding a surface of revolution which consists in supporting the work at two points on the surface to be ground, the inner of which is adjacent the grinding point and the outer of which is angularly spaced from the inner point a greater distance than the distance of the inner point from the grinding point, grinding said surface while maintaining said surface free from restraint against radially outward movement at points angularly more remote from the grinding point than is the outer supporting point, and applying to the work a supplemental frictional rotary and downward driving force.

29. The herein described art of grinding a surface of revolution which consists in supporting the work at two points both spaced from a plane passing through the grinding point and the axis of the work, and one of said supporting points being angularly closer to the grinding point than to the other point of support, applying a grinding wheel to the work at said grinding point, and applying a rotary and downward frictional force to the end of the work with a pressure which will permit it to slide into continuous contact with said supporting points as its surface is ground away.

30. A machine of the character described including a headstock unit, a spindle member journaled therein for rotative mounting of a work engaging face plate, a work supporting unit mounted on the headstock unit and including spaced supports for peripheral engagement with a work piece, and means for maintaining a work piece in position on the supports with a terminal face seated against the face plate of the headstock, said means including an end pressure

member carried by the headstock, means for effecting a hydraulic urge of the pressure member against the work in the direction of the face plate, and means for variably determining the amount of said hydraulic urge.

31. In a machine of the character described, the combination with a headstock, of a magnetic chuck rotatably supported thereby, a work supporting unit carried by the headstock including a pair of spaced supports for peripheral engagement with the work piece, said supports projecting adjacent the chuck and the chuck having a narrow annular work engaging face for terminal engagement with the work, and mean for varying the magnetic force of the chuck whereby a work piece will be held against the chuck with a controlled pressure while rotated on its peripheral supports, said supports being disposed to maintain the work piece with its axis in eccentric relation to the axis of rotation of the chuck whereby on rotation the chuck will exert a thrust component against the work to maintain the same in peripheral engagement with the supports.

32. A grinding machine for generation of a precision surface of revolution on a work piece in angular relation to a performed end surface, said machine including a grinding wheel for engagement with the periphery of the surface to be ground, a pair of spaced support members located and arranged to support the work from its surface to be ground against the grinding pressure, one of said support members being closer to the contact of the grinding wheel and work than it is to the other support member, a driven rotating disc disposed adjacent the work supports and adapted to frictionally engage a preformed end on a supported work piece, the axis of rotation of said disc being eccentrically disposed as respects the support determined axis of the work whereby rotation of the disc will cause a supported work piece to rotate and will force the same in the direction of the work supporting members irrespective of the operative engagement of the grinding wheel with the work, and means to hold the work in engagement with the disc for frictional actuation thereby.

33. In a grinding machine of the character described including a bed or support, a grinding wheel support unit, a grinding wheel carried thereby, and a work carrying unit mounted on the bed, means for effecting a feeding movement of one of said units toward the other, said work carrying unit including a rotatably mounted disc adapted for terminal engagement with a work piece, said disc being rotatable about an axis substantially parallel with that of the grinding wheel, a work positioning means including a pair of spaced bearing shoes, a common support for the disc and the shoes, and means intervening the support and the shoes for determining the relative positioning of the shoes with respect to the disc, said means including a bracket member adjustable axially with respect to the disc and a transverse slide carried by said bracket and supporting the shoes and moveable in a direction toward and from the grinding wheel whereby a supported work piece will be moved in substantially radial direction as respect the axis of the disc.

34. In a grinding machine of the character described including a bed or support, a grinding wheel support unit, a grinding wheel carried thereby, and a work carrying unit mounted on

the bed, means for effecting a feeding movement of one of said units toward the other, said work carrying unit including a rotatably mounted disc adapted for terminal engagement with a work piece, said disc being rotatable about an axis substantially parallel with that of the grinding wheel, a work positioning means including a pair of spaced bearing shoes, a common support for the disc and the shoes, means intervening the support and the shoes for determining the relative positioning of the shoes with respect to the disc, said means including a bracket member adjustable axially with respect to the disc and a transverse slide carried by said bracket and supporting the shoes and moveable in a direction toward and from the grinding wheel whereby a supported work piece will be moved in substantially radial direction as respects the axis of the disc, and additional means for effecting joint bodily adjustment of the shoes in a second direction at an angle to the first direction of adjustment.

35. In a grinding machine of the character described including a bed or support, a grinding wheel support unit, a grinding wheel carried thereby, and a work carrying unit mounted on the bed, means for effecting a feeding movement of one of said units toward the other, said work carrying unit including a rotatably mounted disc adapted for terminal engagement with a work piece, said disc being rotatable about an axis substantially parallel with that of the grinding wheel, a work positioning means including a pair of spaced bearing shoes, a common support for the disc and the shoes, means intervening the support and the shoes for determining the relative positioning of the shoes with respect to the disc, said means including a bracket member adjustable axially with respect to the disc and a transverse slide supporting the shoes and movable in a direction toward and from the grinding wheel whereby a supported work piece will be moved in substantially radial direction as respects the axis of the disc, additional means for effecting joint bodily adjustment of the shoes in a second direction at an angle to the first direction of adjustment, said means including a shoe supporting plate, means guiding the plate for rectilinear movement, and an adjustable wedge member intervening the plate and the support for effecting relative adjustment of the parts and rigidly supporting the same in all positions of relative adjustment thereof.

36. A machine as specified in claim 34 in which the plate is provided with an arcuate guide portion and a retaining member for the work supporting shoes is mounted on said guide portion for arcuate angular adjustment with respect to the supporting plate.

37. Work supporting means of the character described including a pair of spaced shoe members adapted for peripheral engagement with a work piece of circular form in cross section to determine the axial positioning of the work piece, means supporting the shoes for joint arcuate adjustment and for relative arcuate adjustment one with respect to the other, means for effecting individual in and out movement of the supporting shoes, and additional means for effecting transverse bodily adjustment of the parts as an entirety.

38. Work supporting means of the character described including a pair of spaced shoe members adapted for peripheral engagement with a work piece of circular form in cross section to

determine the axial positioning of the work piece, means supporting the shoes for joint arcuate adjustment and for relative arcuate adjustment one with respect to the other, means for effecting individual in and out movement of the supporting shoes, additional means for effecting transverse bodily adjustment of the parts as an entirety, and additional means for effecting bodily adjustment of the shoes and associate parts in a second angularly different direction of movement.

39. A work supporting device for a grinding machine or the like including a base portion, a member transversely adjustable as respects the base portion, means for adjusting said member toward and from the base portion, a shoe support mounted on the member for adjustment therewith and for arcuate angular adjustment relative thereto, a pair of work engaging shoes carried by said arcuately adjustable member having their inner faces formed for peripheral engagement with a work piece, and means for effecting individual adjustments of the shoe members in a substantially radial direction as respects the arcuately adjustable member.

40. A work supporting device for a grinding machine or the like including a base portion, a member transversely adjustable as respects the base portion, means for adjusting said member toward and from the base portion, a shoe support mounted on the member for adjustment therewith and for arcuate angular adjustment relative thereto, a pair of work engaging shoes carried by said arcuately adjustable member having their inner faces formed for peripheral engagement with a work piece, means for effecting individual adjustments of the shoe members in a substantially radial direction as respects the arcuately adjustable member, and additional means for effecting relative angular adjustment of the shoe members to vary their angular relationship.

41. A work supporting device for a grinding machine or the like including a base portion, a member transversely adjustable as respects the base portion, means for adjusting said member toward and from the base portion, a shoe support mounted on the member for adjustment therewith and for arcuate angular adjustment relative thereto, a pair of work engaging shoes carried by said arcuately adjustable member having their inner faces formed for peripheral engagement with a work piece, means for effecting individual adjustments of the shoe members in a substantially radial direction as respects the arcuately adjustable member, additional means for effecting relative angular adjustment of the shoe members to vary their angular relationship, and means for rigidly locking the several parts in their respective adjusted positions.

42. A work supporting device for a grinding machine or the like including a base portion, a member transversely adjustable as respects the base portion, means for adjusting said member toward and from the base portion, a shoe support mounted on the member for adjustment therewith and for arcuate angular adjustment relative thereto, a pair of work engaging shoes carried by said arcuately adjustable member having their inner faces formed for peripheral engagement with a work piece, means for effecting individual adjustments of the shoe members in a substantially radial direction as respects the arcuately adjustable member, additional means for effecting relative angular adjustment of the shoe members to vary their angular relationship, co-

operating indicia carried by the several relatively

adjustable parts for indicating the respective relative shiftings thereof, and means for locking said parts in their correct indicia determined positions of adjustment.

43. A precision grinding machine including a supporting bed, a grinding wheel unit and a work unit carried by the bed, means for effecting relative feeding movement of the units, a grinding wheel carried by the grinding wheel unit and rotatable about a definite axis, a work driving disc carried by the work unit and rotatable about a definite axis, means for angularly adjusting the relationship of the axes of the grinding wheel and driving disc, and a work supporting means carried by the work unit including a supporting bracket disposed adjacent the disc, and adjustable axially with respect to the operative face of the disc, a slide element carried by the bracket, means for effecting transverse movement of the slide with respect to the bracket, additional means for effecting adjustment of the slide with respect to the bracket in a second angularly related direction, said slide extending into proximity to the operative face of the driving disc, a pair of work engaging shoes, a support therefor, and means mounting the support on the slide for arcuate adjustment relative thereto, said shoes extending into position to peripherally engage a support and work piece when the same is terminally seated against the driving disc.

44. A precision grinding machine including a supporting bed, a grinding wheel unit and a work unit carried by the bed, means for effecting relative feeding movement of the units, a grinding wheel carried by the grinding wheel unit and rotatable about a definite axis, a work driving disc carried by the work unit and rotatable about a definite axis, means for angularly adjusting the relationship of the axes of the grinding wheel and driving disc, and a work supporting means carried by the work unit including a supporting bracket disposed adjacent the disc, and adjustable axially with respect to the operative face of the disc, a slide element carried by the bracket, means for effecting transverse movement of the slide with respect to the bracket, additional means for effecting adjustment of the slide with respect to the bracket in a second angularly related direction, said slide extending into proximity to the operative face of the driving disc, a pair of work engaging shoes, a support therefor, means mounting the support on the slide for arcuate adjustment relative thereto, said shoes extending into position to peripherally engage a support and work piece when the same is terminally seated against the driving disc, and means for adjusting the work engaging shoes in a substantially radial direction as respects the axis of rotation of the disc.

45. A precision grinding machine including a supporting bed, a grinding wheel unit and a work unit carried by the bed, means for effecting relative feeding movement of the units, a grinding wheel carried by the grinding wheel unit and rotatable about a definite axis, a work driving disc carried by the work unit and rotatable about a definite axis, means for angularly adjusting the relationship of the axes of the grinding wheel and driving disc, and a work supporting means carried by the work unit including a supporting bracket disposed adjacent the disc, and adjustable axially with respect to the operative face of the disc, a slide element carried by the bracket, means for effecting transverse movement of the slide with respect to the bracket, additional

means for effecting adjustment of the slide with respect to the bracket in a second angularly related direction, said slide extending into proximity to the operative face of the driving disc, a pair of work engaging shoes, a support therefor, means mounting the support on the slide for arcuate adjustment relative thereto, said shoes extending into position to peripherally engage a support and work piece when the same is terminally seated against the driving disc, means for adjusting the work engaging shoes in a substantially radial direction as respects the axis of rotation of the disc, and means for effecting adjustment of one of the shoes with respect to the other to vary the included angle therebetween.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,440,639	Smith -----	Jan. 2, 1923
1,722,386	Norton -----	July 30, 1929
1,789,408	Hultgren -----	Jan. 20, 1931
2,024,283	Gertiser -----	Dec. 17, 1935
2,027,627	Blood et al. -----	Jan. 14, 1936
2,047,055	Blood -----	July 7, 1936
2,078,416	Sauer -----	Apr. 27, 1937
2,264,179	Johnson -----	Nov. 25, 1941
2,380,761	Hutchinson -----	July 31, 1945