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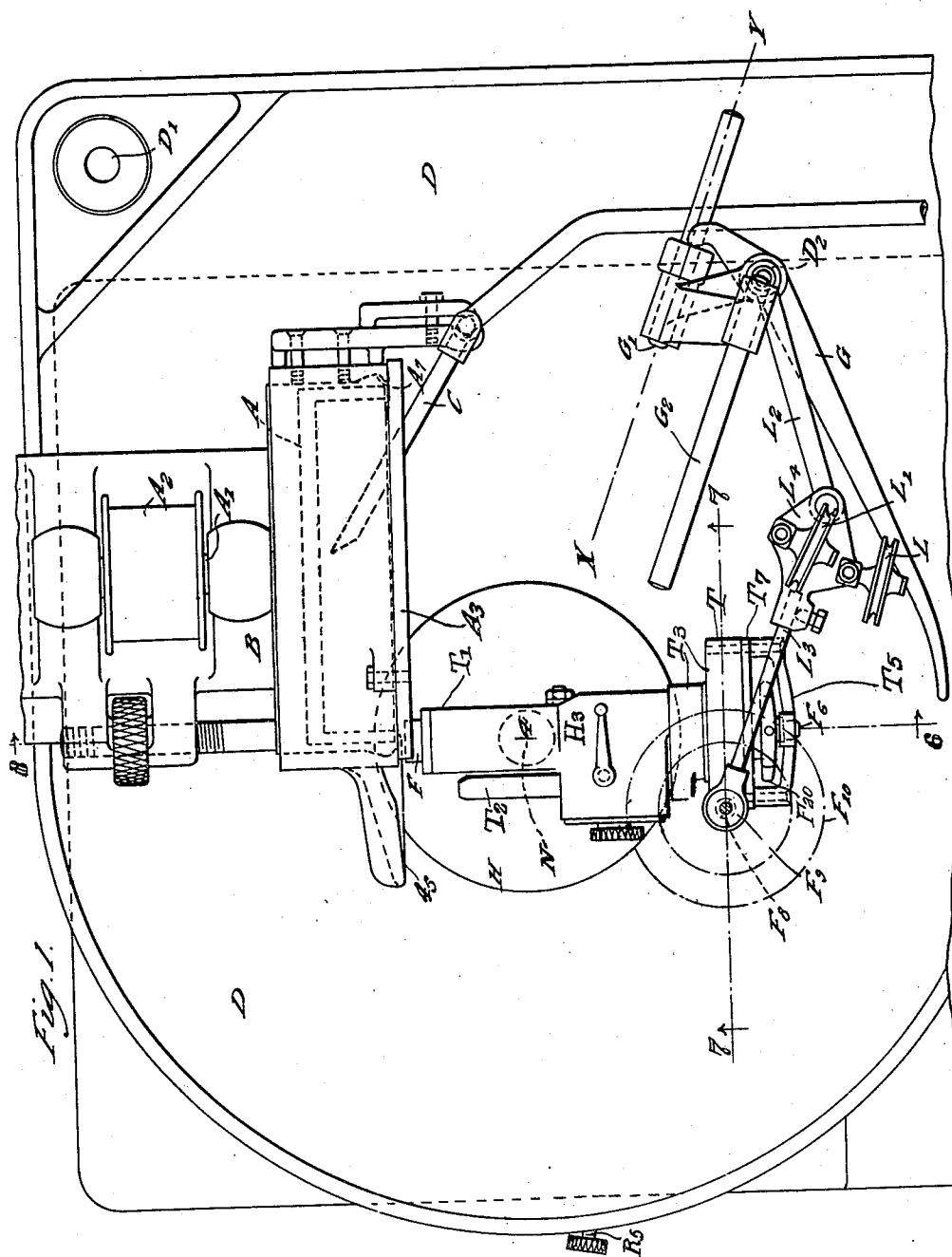
W. TAYLOR

1,479,843

GRINDING MACHINE

Filed Aug. 9, 1917

7 Sheets-Sheet 1



Attest:

Frederick Bachmann
Lillian R. Fox

Inventor

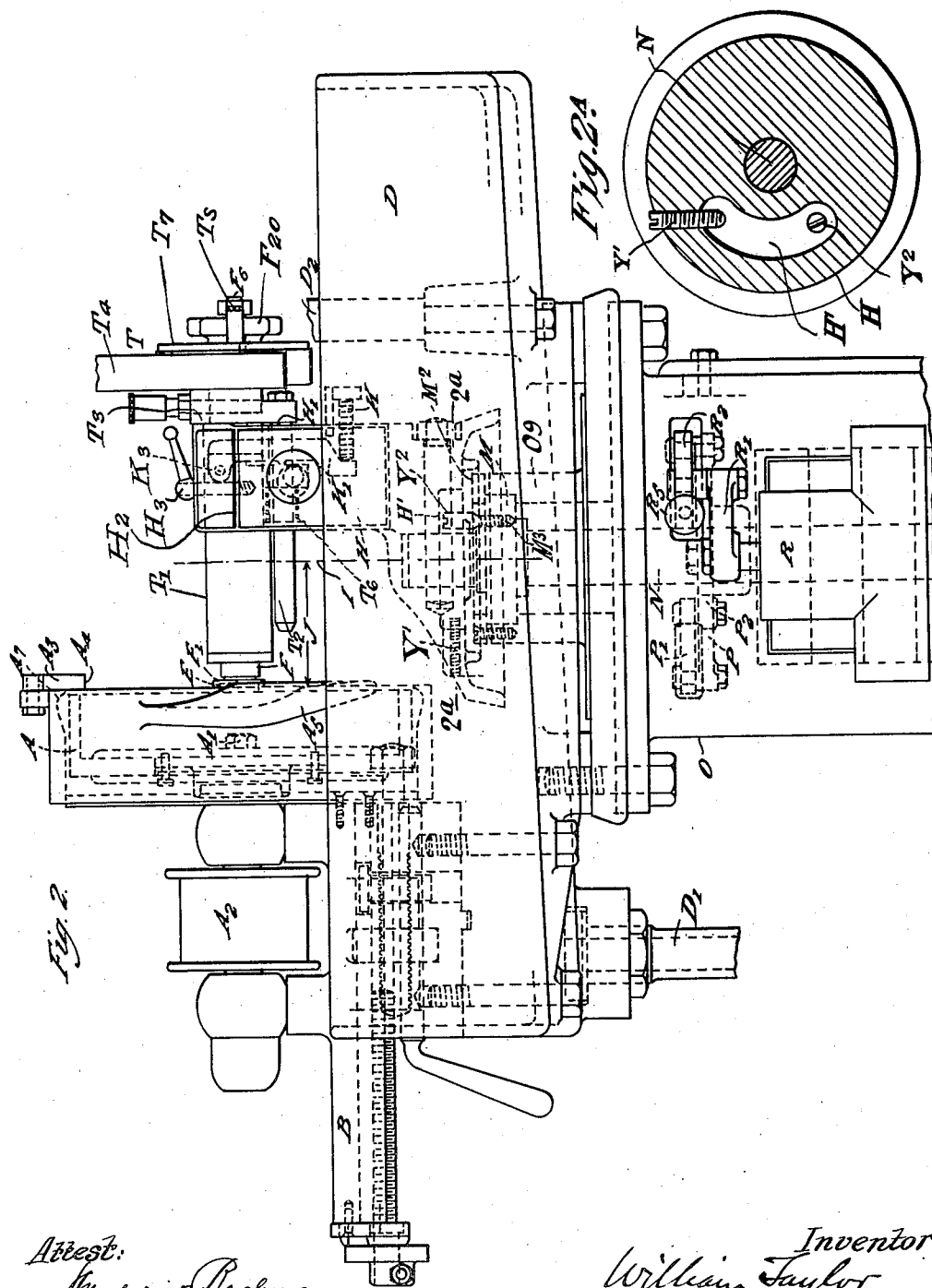
William Taylor
by Arthur H. Kent, Atty.
for

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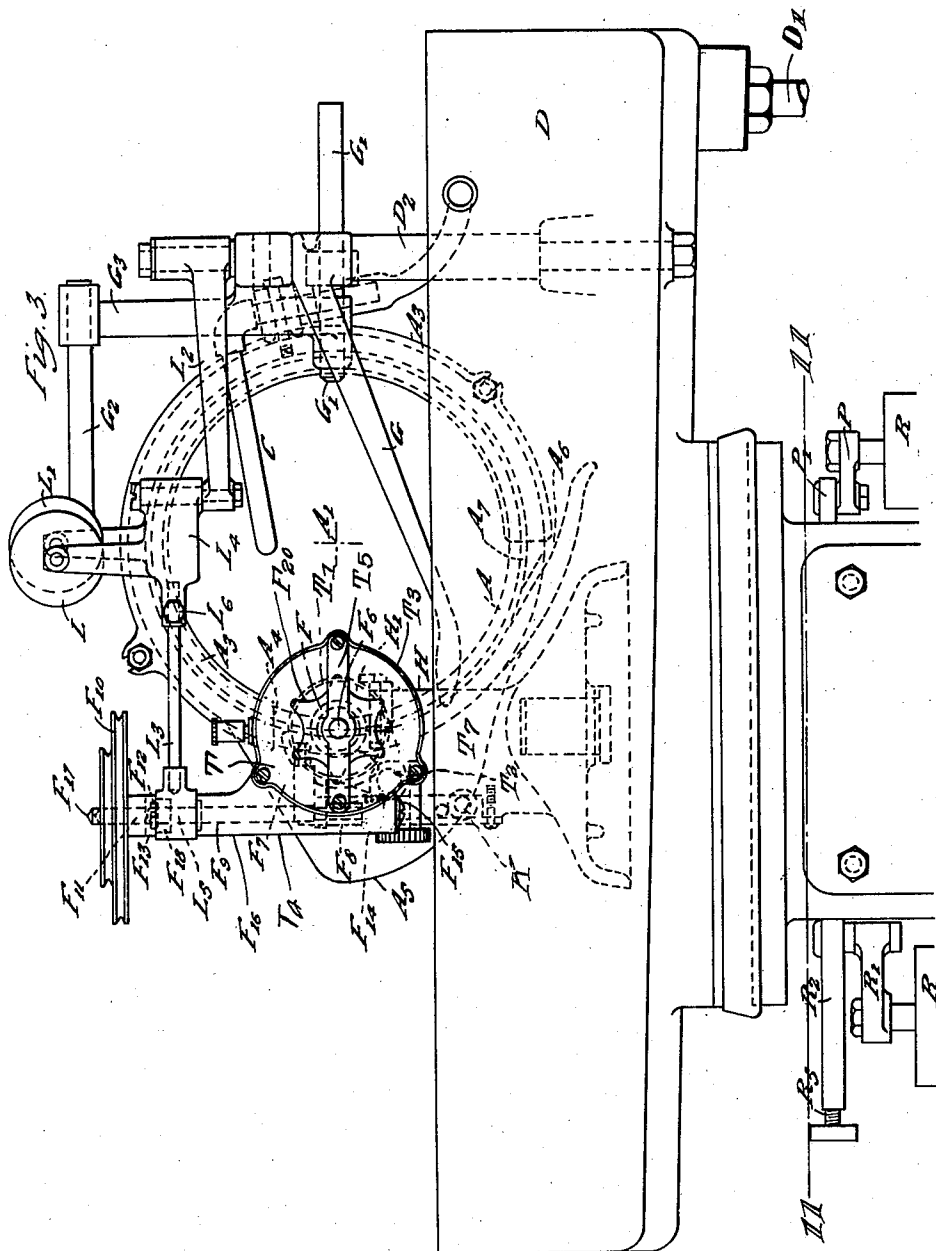
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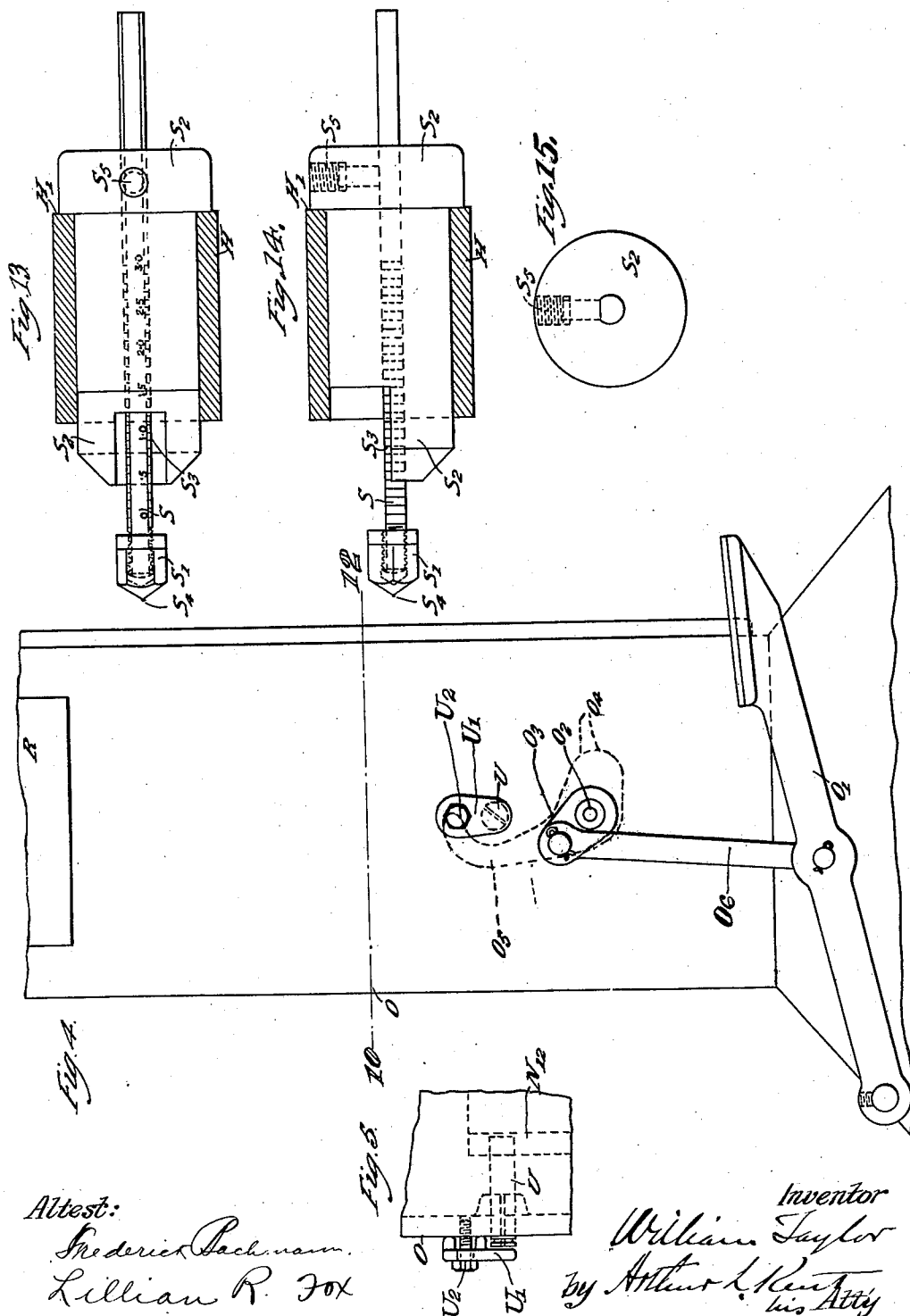
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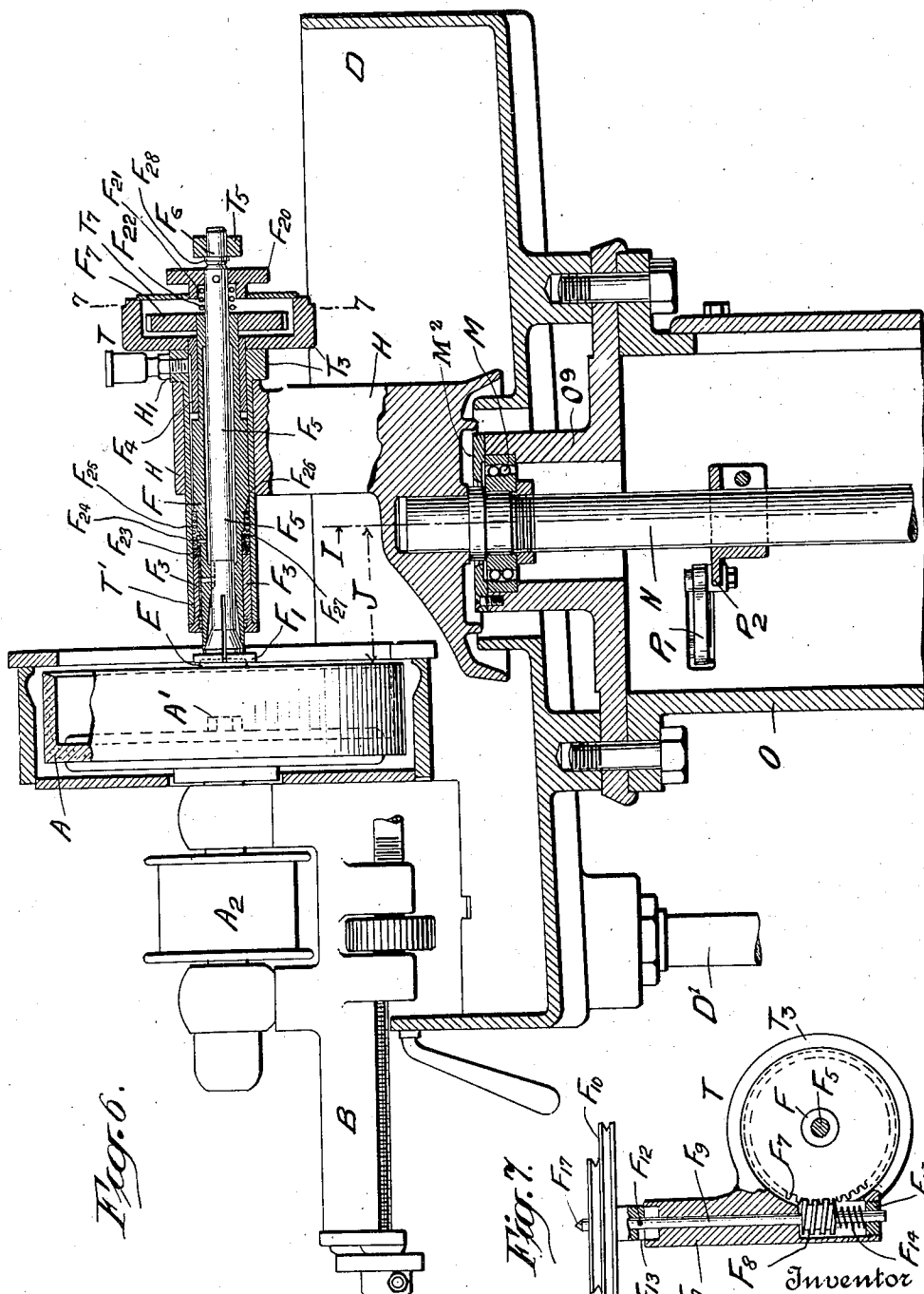


Fig. 6.

Fig. 7.

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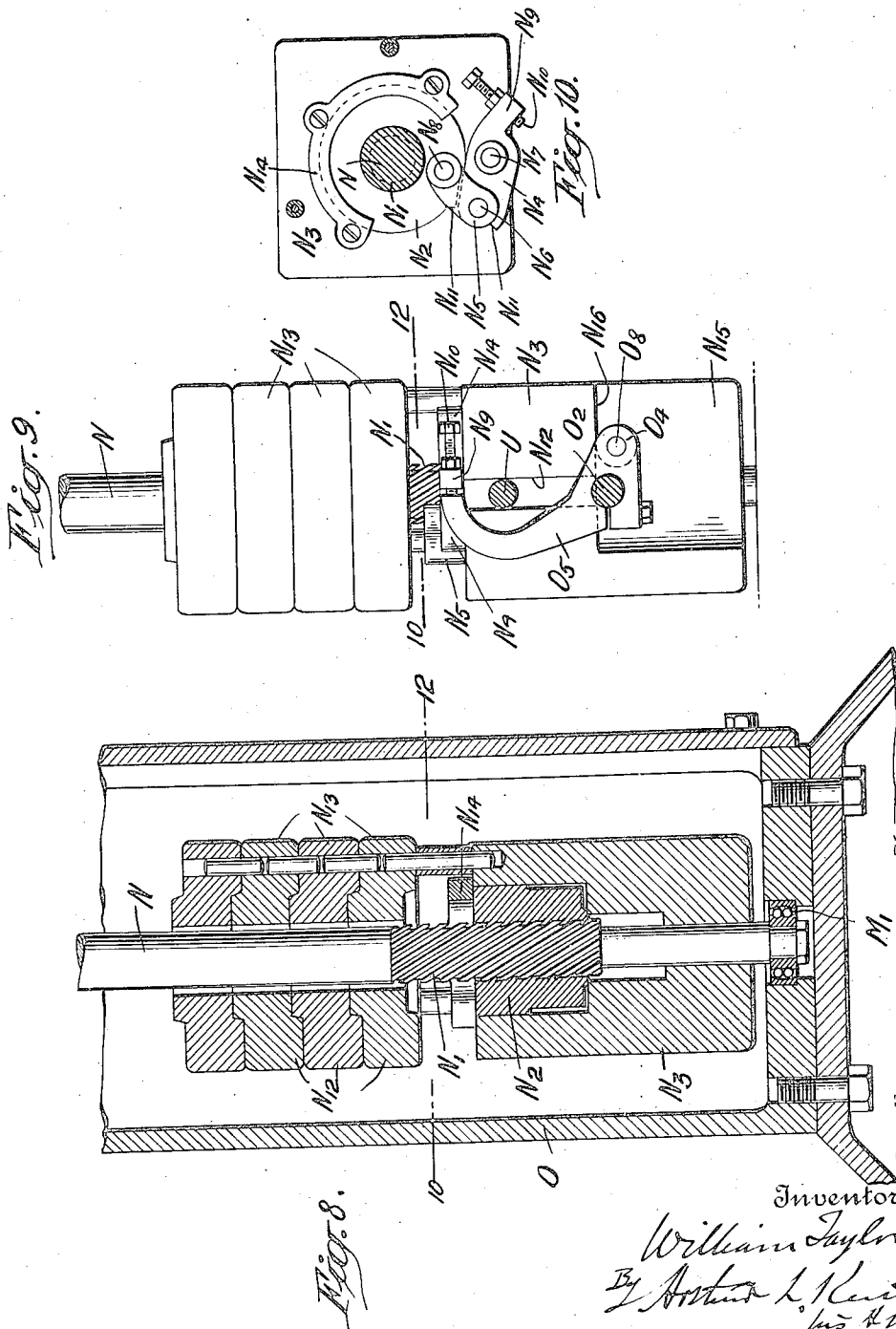
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W. TAYLOR

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Fig. 12.

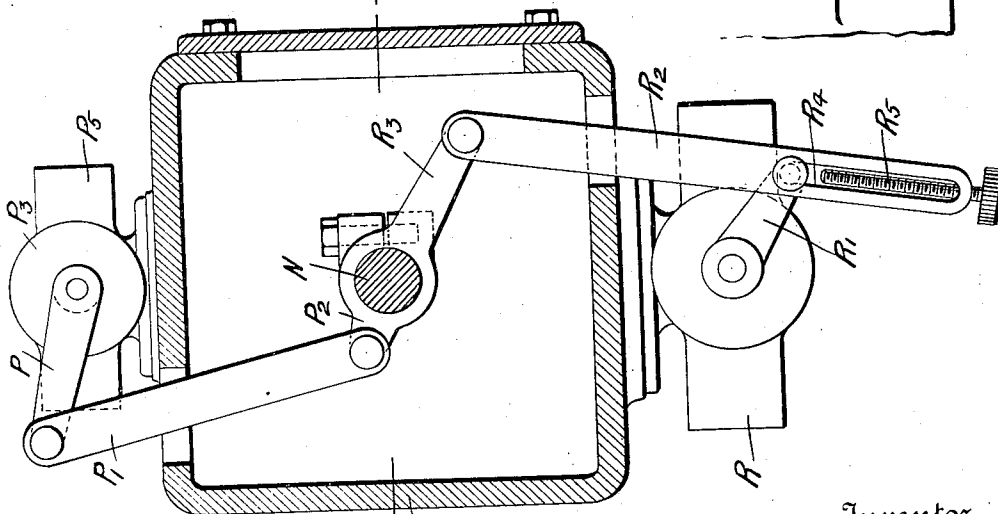
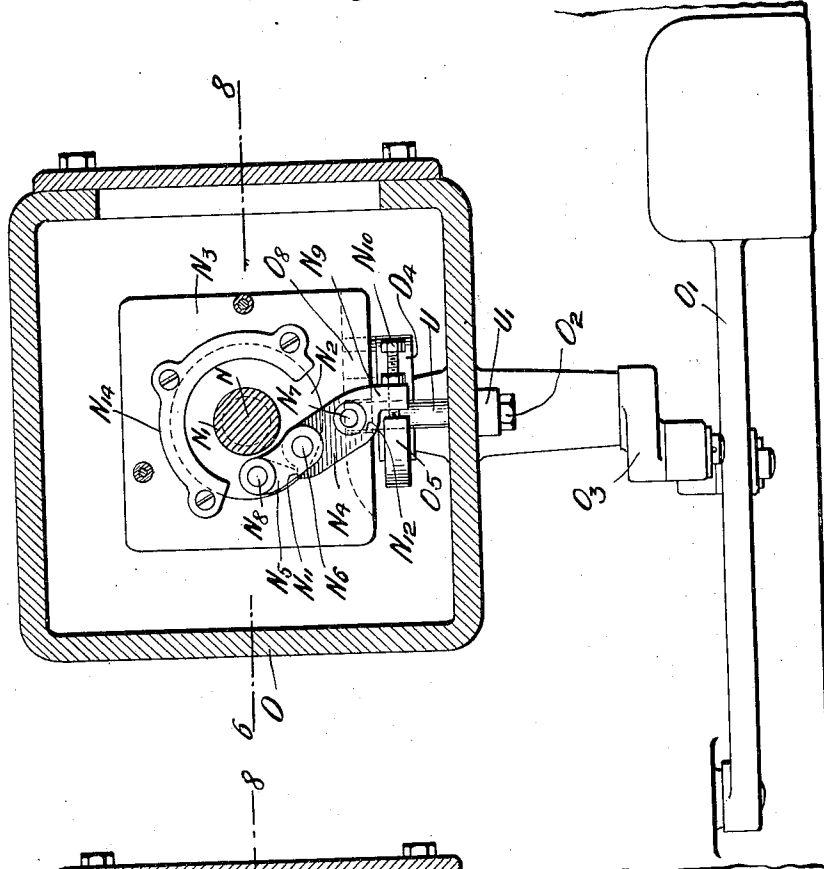


Fig. 11.

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UNITED STATES PATENT OFFICE.

WILLIAM TAYLOR, OF LEICESTER, ENGLAND.

GRINDING MACHINE.

Application filed August 9, 1917. Serial No. 185,338.

To all whom it may concern:

Be it known that I, WILLIAM TAYLOR, a subject of the King of Great Britain, residing in Leicester, England, have invented certain new and useful Improvements in Grinding Machines, of which the following is a specification.

This invention relates to machines for grinding spherical surfaces by means of abrasive wheels, and especially for grinding the convex surfaces of lenses when such lenses are made from discs of glass, the machines being of the kind in which the work is mounted and rotated on a work spindle about a primary axis, and a relative motion of the work and the abrasive wheel is effected about a secondary axis intersecting the primary axis of the work spindle, the abrasive wheel operating on the work at a point in the plane which contains the primary axis at all times, and the radius of the spherically curved surface formed being variable by varying the distance in such plane between the operative point of the wheel and the secondary axis. The invention consists in improvements which are hereinafter described and have for their principal objects to provide a machine of the kind above referred to, in which the rotation of the work about its primary axis and the relative movement of the work and abrasive wheel about the secondary axis are effected automatically, and in which the said relative movement may be produced by a predetermined limited force and can be effected at a varying rate.

I will describe my invention with the help of the accompanying drawings which illustrate a grinding machine having the improvements applied and arranged to grind convex spherical surfaces, the several parts of the machine hereinafter referred to in describing the invention being indicated on the drawings by means of reference letters. Fig. 1 of the drawings is a plan of the machine, the work carrying spindle, rotatable about its own, i. e. the primary axis, being shown in operative relation to the wheel and capable of being turned about a secondary axis; Figs. 2 and 3 show, respectively, front and side elevations of the machine and of the upper portion of its pedestal; Fig. 2^a is a fragmentary horizontal section taken on the line 2^a—2^a of Fig. 2; Fig. 4 is a front

elevation of the lower portion of the pedestal; Fig. 5 is an elevation at right angles to the view in Fig. 4, of a part of the pedestal wall shown in that figure; Fig. 6 is a vertical section of the upper part of the machine and the upper portion of the pedestal on the plane indicated by the lines 6—8 in Figs. 1, 11, 12; Fig. 7 is a fragmentary side elevation showing the driving mechanism for the work spindle and partly sectioned upon the plane indicated by the lines 7—7 in Figs. 1, 6; Fig. 8 is a vertical section of the lower portion of the pedestal on the plane indicated by the lines 6—8 in Figs. 1, 11, 12; Fig. 9 is a front elevation of the mechanism within the lower part of the pedestal; Fig. 10 is a horizontal section of the parts shown in Fig. 9, on the plane indicated by the lines 10—12 of Figs. 4, 8, 9; Fig. 11 is a horizontal section upon the plane indicated by the lines 11—11 in Fig. 3; Fig. 12 is a horizontal section upon the plane indicated by the lines 10—12 of Figs. 4, 8, 9; and Figs. 13, 14, 15 are respectively an elevation, plan and end view of a gauge for setting the working face of the abrasive wheel at any required distance relatively to the secondary axis.

In the drawings, A is an abrasive wheel which may be of any convenient form, but I prefer that of a cylindrical cup having an annular grinding edge as shown for example in Fig. 1. The wheel is mounted upon a wheel spindle A₁ and this is carried in such a manner, as by means of the screw actuated slide B, that the wheel may be moved toward or from the secondary axis I, to vary the radius of curvature J of the work and to take up wear of the wheel. I supply the wheel with a cooling lubricant through a pipe C, and a pan D to catch the surplus liquid and detritus, and discharge the same through outlet D₁.

The wheel may be driven from any convenient source of power by a pulley A₂ fixed to spindle A₁.

The disc E to be ground is chucked on a suitable hollow work spindle F which is rotatably mounted in bushings F₂, F₁ carried by the tubular portion T₁ of the slide T, the mounting and construction of which are hereinafter explained.

The work spindle F is adapted to receive a split chuck F₁ of the kind well known in

connection with watch machinery and lathes, the chuck being suitably bored and recessed according to the diameter and thickness of the glass disc to be held.

5 The chuck F_1 is drawn into the conical mouth of the spindle F so as to grip the glass disc E , by the draw-in spindle F_2 , which is attached to the rear end of the chuck and has fixed upon it a star wheel F_{20} ,
10 in a chamber F_{21} of which is a compression spring F_{22} adapted to close the chuck by pulling back the draw-in spindle (Fig. 6). The strength of this spring is such that while it holds the glass securely in the chuck
15 F_1 , it does not crush it. In order to secure uniform thickness of the finished work, I may give the work spindle F a limited end shake in its bearings and provide means such as an abutment plunger F_6 carried by
20 the slide T and adapted to take the end thrust of the chuck F_1 through the draw-in spindle F_2 , whereby the chuck may be positioned with respect to the slide T and thus with respect to the secondary axis independently of the work spindle F whose longitudinal position may vary according to the diameter of the blank E .

In order that the spindle F may be free
25 endwise for this purpose while being unable to stray unduly, a retaining collar F_{23} is fastened to the spindle F by a screw F_{24} , and a light compression spring F_{25} is provided to thrust against the collar F_{23} and a shoulder F_{26} on the spindle F so as to move
30 the spindle F towards the abutment plunger F_6 while a suitable but limited end shake in the bearings is permitted by the space between the collar F_{23} and a shoulder F_{27} on the spindle F (Fig. 6).

35 The slide T which carries the bearings for the work spindle F is slidably mounted upon a carriage H fixed to the top of a vertical shaft N so that it may be turned about the secondary axis I , the slide T being used
40 to set the work so that it is ground to the required thickness. The slide T comprises a tubular portion T_1 within which the work spindle F is mounted as above described, a plunger T_2 parallel to the sleeve T_1 , and a
45 frame T_3 to which the rear ends of the sleeve T_1 and the plunger T_2 are attached (Figs. 1, 2, 3). The upwardly extending portion of the carriage H contains two transverse holes in which the sleeve T_1 and the plunger T_2 are mounted. At one side of
50 the frame T_3 is a post T_4 (Figs. 3, 7) which supports the hereinafter described mechanism for rotating the work spindle F . Across the rear end of the frame T_3 is a
55 cover plate T_7 and a saddle piece T_5 in which the abutment plunger F_6 is mounted (Figs. 1, 2, 3). The plunger F_6 has a shoulder F_{28} which by engagement with the saddle piece T_5 prevents the plunger from moving outwardly (Fig. 6). The plunger may, how-

ever, be pressed inwardly by the chuck opening means hereinafter described. The entire slide T is pressed outwardly with respect to the carriage H by a compression spring T_6 (Fig. 2). A micrometer screw K
60 in a tapped hole in the carriage H and a lever K_1 pivoted to the carriage H at K_2 and engaging the plunger T_2 serve to restrain the backward movement of the slide T under the effect of the spring T_6 and may be used
65 for fine adjustment of the position of the slide T in the carriage H . The upper portion of the carriage H is split at H_2 and a screw bolt H_3 is provided for drawing the carriage together so that it fits tightly upon the tubular portion T_1 of the slide T and
70 locks the slide in the position to which it may be adjusted by the micrometer screw K .

Instead of turning the work about the secondary axis I , I may alternately fix the
75 position of the work and move the abrasive wheel about the secondary axis. The secondary axis I is preferably vertical, and the work spindle and wheel spindle axis preferably lie in one horizontal plane.

80 The work spindle may be rotated by a belt from any convenient source or power, and in order to rotate the spindle while leaving it free to be moved about the secondary axis, I prefer to drive it by means of worm
85 or helical gearing F_8 meshing with a gear F_7 fixed upon the work spindle F (Figs. 6, 7). The worm shaft F_8 is mounted in the pillar T_4 of the slide T with its axis vertical and parallel with the secondary axis I ,
90 and I may drive the worm shaft F_8 by means of a pulley F_{10} , which may be fixed thereon but is preferably adapted to be unclutched therefrom automatically at the end of a
95 grinding operation by means hereinafter described, and a driving band passing from a suitable countershaft over a pair of guide pulleys L , L_1 , supported from a pillar D_2 ,
100 carried by the frame of the machine or pan D , by means of an arm L_2 and a member E_4 pivotally mounted on the arm L_2 and which is connected with the worm shaft F_8 in such manner that the tension of the band is not varied by the turning of the work about the secondary axis I . The connection between
105 the member L_2 and the shaft F_8 can be conveniently effected by means of a coupling member L_5 and a strut L_3 attached at one end to the coupling L_5 and at the other end adjustably clamped to member L_4 by aid of
110 the set screw L_6 .

Means adapted to open the chuck, when a finished piece of work is to be replaced
115 by a fresh blank, may be provided and such means or opening device is preferably so placed as to act on the chuck when the work-carrying spindle F has been turned about the axis I sufficiently to attain a position wherein the work has become removed from the abrasive wheel, and the spindle be-
120

comes unclutched from pulley F_{10} as described below. Such a position is hereinafter termed the normal position of rest, and may conveniently be that indicated by the line X—Y in Fig. 1.

The chuck opening device may comprise a thrust rod G_1 suitably supported by the vertical pillar D_2 and adapted, when actuated by the hand lever G , pivotally mounted on pillar D_2 , to contact with the outer end of the abutment plunger F_6 and slide the plunger inwardly in the saddle piece T_5 . This movement of the plunger pushes in the draw-in spindle F_5 against the action of a spring F_{22} and moves the chuck F_1 out of the tapered mouth of the work spindle F so as to release its grip upon the glass disc E .

I may provide means whereby when the work spindle F is in its position of rest its rotation will cease. To this end I fix to the pillar D_2 by means of a bracket G_3 an appropriately shaped bar or abutment piece G_2 , and I engage the pulley F_{10} to the worm shaft F_9 by means of a clutch pin F_{12} fixed crosswise through the shaft and arranged to engage a notch F_{13} cut in the hub F_{11} of pulley F_{10} . I maintain shaft F_9 normally in the working or a raised position by means of a spring F_{14} supported by a plug F_{15} in the bottom of the pillar T_4 for the shaft F_9 . While the shaft F_9 is in the raised position the pin F_{12} engages the notch F_{13} , but when the work spindle is turned to its normal position of rest, the fixed abutment piece G_2 thrusts upon the coned upper end F_{17} of the worm shaft F_9 and depresses it against the action of spring F_{14} so that the pin F_{12} is withdrawn from the notch F_{13} into a recess F_{18} formed in the member L_5 , so that the pulley F_{10} and shaft F_9 become disconnected and the latter ceases to rotate (Figs. 1, 3, 7).

Means, such as the set of speed pulleys F_{10} or worm shaft F_9 , may be provided for varying the speed of the work spindle F .

In order to turn the work spindle about the secondary axis I at a suitable speed or speeds and with the utmost rigidity of control, I may mount the work spindle carriage H on a vertical shaft N whose axis is the secondary axis, the shaft N being mounted at its upper and lower ends in ball bearings M and M_1 and conveniently housed in a pedestal or column O which may constitute the machine frame and support the pan D and the wheel spindle A_1 aforesaid.

I prefer to effect the turning of the work spindle about the secondary axis by means of a suitably and definitely limited force and to provide means for limiting the rate of turning so that while it may be less than, it cannot exceed a predetermined rate, and may vary inversely with the resistance to grinding. To these ends, upon the shaft N

within the column I may form a screw N_1 upon which is a nut N_2 and a weight N_3 adapted to move vertically without rotation.

The weight N_3 surrounds the nut N_2 which is located in a central cylindrical recess in the upper portion of the weight N_3 . The weight N_3 is retained upon the nut N_2 by a collar N_4 which is screwed to the top of the weight N_3 (Figs. 8, 10, 12). The weight N_3 is retained against rotation by a pin U which is fixed in the wall of the column O . The pin U extends through the wall of the column O and is prevented from coming out by a cap U_1 which is held to the wall of the column O by a screw bolt U_2 (see Figs. 4, 5, 12). The inner end of the pin U engages a vertical slot N_{12} in the weight N_3 (Figs. 5, 9, 12). As the weight N_3 is thus held against rotation it is apparent that when the nut N_2 is locked to the weight N_3 by mechanism hereinafter described, the descent of the weight N_3 under the force of gravity will turn the shaft N and the work carried on the upper end of the shaft about the secondary axis. Mechanism is provided for raising the weight N_3 to its starting position after it has descended under the force of gravity. In the form shown in the drawings this mechanism comprises a foot treadle O_1 connected by a rod O_6 to a crank O_3 upon a shaft O_2 which is journaled in the wall of the column O . The shaft O_2 extends both inside and outside of the wall of the column O and the before mentioned crank O_3 is attached at the outer end of the shaft. At the inner end of the shaft O_2 within the wall of the column O is a crank O_4 provided with a crank pin O_5 which extends into a recess N_{15} formed in the lower portion of the weight N_3 and serves by engagement with the upper edge N_{16} of this recess to raise the weight N_3 when the shaft O_2 is rotated by depressing the treadle O_1 (Figs. 4, 9, 12).

In order that when the grinding operation is complete the work may be at once turned backwards about the secondary axis I to its normal position of rest X—Y, where the work may be changed, I mount the said nut N_2 rotatably within the weight N_3 and connect it with the weight by locking means adapted to prevent rotation of the nut within the weight during the grinding operation, and automatic means operating to release the locking means upon the completion of the grinding operation and thus set the shaft N free to be turned backwards by means such as a spring actuated arm P , connecting rod P_1 and crank P_2 provided for the purpose. The locking means shown in the drawings comprise two toggle links N_4 , N_5 pivoted together at N_6 . The link N_4 is pivoted to the top of the weight N_3 at N_7 , while the link N_5 is pivoted to the top of the nut N_2 at N_8 . The links N_4 and N_5 are provided with cooperating abutment surfaces N_{11} which are

brought together when the links are extended (Figs. 9, 10, 12). The mechanism for releasing the locking means or breaking the toggle N_4, N_5 comprises a crank O_5 mounted upon the shaft O_2 . The crank O_5 may be made integral with the crank O_4 as shown in the drawings (Figs. 4, 9, 12). The upper end of the crank O_5 is so located that at the end of a grinding operation it strikes an adjustable screw N_{10} in the end N_9 of the toggle link N_4 . The spring actuated arm P , the connecting rod P_1 , and the crank P_2 which turn the shaft N backward when the locking toggle is released are best shown in Fig. 11.

A dashpot P_3 or equivalent device may be used to prevent too rapid returning of the shaft N . The members P and P_3 may, as shown on the drawing, be parts of an ordinary hydraulic door check.

Cooperating stops Y_1, Y_2 are provided to arrest the backward turning of the shaft N when the axis of the work spindle F reaches the position of rest indicated by the line $X-Y$ in Fig. 1. The stop Y_1 is screwed horizontally into the carriage H so that its inner end projects into an arcuate recess H_1 provided in the bottom of the carriage H . The stop Y_2 is fixed. It is formed by the elongation of the head of one of the screws M_3 which secure the cover M_2 of the ball bearing M to the upper portion O_6 of the column O (Figs. 2, 2^a, 6).

The operation of the mechanism described comprises three steps.

The normal position of the parts of the apparatus, that is, the position which they occupy at the beginning of the first step in the operation and again at the end of the third step in the operation will first be described. The work spindle F is in the position of rest indicated by the line $X-Y$ in Fig. 1, the shaft N , which is continually urged to turn in an anti-clockwise direction (looking from the top) by the spring-actuated arm P , being retained against rotation by the engagement of the stop Y_1 on the carriage H with the fixed stop Y_2 . The toggle levers N_4, N_5 occupy the position illustrated in Fig. 10. The weight N_3 is in its lowest position, while the treadle O_1 is in its highest position as indicated in Fig. 4.

In the first step of the operation the treadle O_1 is pressed down, pulling down the rod O_6 and the crank O_3 . This rotates the shaft O_2 in an anti-clockwise direction (looking from the front of the machine) and raises the crank O_4 from the position shown in Figs. 4 and 9. The pin O_5 of the crank O_4 contacting with the surface N_{10} of the weight N_3 raises the weight N_3 , while at the same time the crank O_5 is moved to the left from the position shown in Figs. 4 and 9. As the weight N_3 is raised, the nut N_2 rotates within the weight N_3 so that the shaft N is not turned. This rotation of the

nut N_2 is in a clockwise direction looking from above, so that the pivot point N_6 is moved away from the pivot point N_7 , causing the toggle links to straighten out until they occupy the position indicated in Fig. 12 with their abutment surfaces N_{11} in engagement. These surfaces engage just after the toggle links have passed dead center, and when the weight N_3 has been raised to its highest point by depressing the treadle O_1 to its lowest point.

In the second step of the operation the treadle O_1 is released and the weight N_3 descends under the force of gravity. As during the descent of the weight N_3 , the nut N_2 is locked against rotation by toggle links N_4, N_5 whose abutment surfaces N_{11} are in engagement with each other, the descent of the weight N_3 and nut N_2 cause the shaft N to rotate. The turning of the shaft N and the carriage H mounted upon its upper end swings the axis of the work spindle F about the secondary axis I from its starting position $X-Y$ towards the position of the work spindle F indicated in full lines in Fig. 1. This turning of the work axis brings the face of the work progressively into contact with the edge of the grinding wheel A . The descent of the weight N_3 serves also to force down the crank O_4 because of the engagement of the crank pin O_5 with the surface N_{10} of the weight. This rotates the shaft O_2 in a clockwise direction raising the treadle O_1 and moving the upper end of the crank O_5 to the right. When the grinding operation is completed, which in the arrangement shown in the drawing occurs when the center of the disc E has been brought in contact with the edge of the grinding wheel A by movement of the axis of the work spindle F to the position shown in full lines in Fig. 1, the end of the crank O_5 comes into contact with the end of the screw N_{10} in the portion N_9 of the link N_4 (Figs. 9, 12). The crank O_5 moves the end N_9 of the link N_4 slightly to the right (Figs. 9, 12), swinging the pivot point N_6 across dead center and breaking the toggle so that the nut N_2 is free to turn within the weight N_3 .

The third step in the operation begins automatically when the toggle is broken by the end of the crank O_5 . As soon as the toggle is broken the spring actuated arm P , which has opposed the turning movement of the shaft N under the effect of the weight N_3 during the grinding operation, turns the shaft N backward until the inner end of the stop Y_1 upon the carriage H engages the fixed stop Y_2 , thus swinging the axis of the work spindle F from the position shown in full lines in Fig. 1 to its normal position of rest $X-Y$. In this backward turning of the shaft N the nut N_2 is turned with the shaft in a counter-clockwise direction look-

ing from the top so that the pivot point N_2 of the nut N_2 is moved from the position shown in Fig. 12 to the position shown in Fig. 10. All the parts thus occupy the same position as they did before the treadle O_1 was depressed to place the mechanism described in operation. After the disc E has been removed and a new disc substituted, the treadle O_1 is again depressed and the operation repeated.

In grinding spherical surfaces, the abrasive wheel is generally arranged to commence at the periphery of the work and finish at its centre, and as in grinding convex surfaces there is most work to be done at the periphery, it is desirable that the rate of turning about the secondary axis should be an accelerating rate. The converse is required for concave surfaces.

For this purpose I may employ any convenient means, but I prefer, while using a weight to effect the turning, to use means for retarding its rate of descent, and such means may comprise a dashpot R which may have the form of an ordinary liquid door check attached to the column O , the crank R_1 of such check being connected by a connecting rod R_2 with a crank arm R_3 on the secondary axis shaft N (see Fig. 11), and either or both of the crank arms may be so set that the resistance of the dashpot to the turning of the shaft diminishes or increases throughout the grinding operation.

As a further means of securing such acceleration or deceleration, I may so set one or both of the cranks O_3 , O_4 connecting the treadle to the weight that the effect of the weight of the treadle upon the turning of the shaft changes suitably throughout the grinding operation. Furthermore, with the same object, I may so adjust or vary the weight N_3 and resistance of the dashpot R , that, when by reason of there being much material to be removed the resistance to turning the work about the secondary axis is a maximum, the weight N_3 , which may be varied by adding weights N_{13} (Figs. 8, 9) is about sufficient only to turn the work at the desired rate, and as the operation proceeds and the resistance to turning diminishes, the rate of turning will automatically increase, but cannot exceed a rate predetermined by the setting or adjustment of the dashpot R . Such adjustment may be the adjustment of a by-pass such as is usual in a liquid door check.

When a fresh blank E has been inserted in the chuck F_1 and the work is turned about the secondary axis I , it is desirable that, without being hindered by the retarding device R , it should be free to be turned promptly into the position where the work is about to encounter the abrasive wheel, and at this point only the retarding device should commence its operation.

For this purpose I prefer to form the connecting rod R_2 , which connects the crank arms R_1 , R_3 , on the check R and the shaft N respectively, with a longitudinal slot R_4 engaging one of the cranks so as to permit backlash, and I provide a screw R_5 or the like means for varying the length of such slot (Fig. 11).

The machine which has been described and is illustrated in the drawings is adapted for grinding convex spherical surfaces, but it will be understood that, by withdrawing the work and work spindle longitudinally to the other side of the secondary axis and grinding with the periphery of a disc wheel, the machine could be employed for grinding concave surfaces.

In order to set the machine for accurately grinding spherical surfaces of any required radius of curvature, I may provide an adjustable gauge which may have the form of a bar S that can be adjustably mounted in the work spindle carriage H in a position parallel to the axis of the work spindle F . The end of the bar S may be set to make contact with the face of the abrasive wheel A , while for the purpose of measurement the bar S may be provided with a slider S_2 and co-operating graduations S_3 . The bar S is adapted to be clamped by means of the screw S_5 in position in the slider S_2 which may be set to abut against a fixed surface H_1 on the work spindle carriage H or otherwise suitably correlated with the secondary axis I . To reduce the effect of wear, the end of the bar S may carry an adjustable member S_1 having a diamond S_4 inserted in it.

The improved machine may be provided with a suitable guard A_3 surrounding the abrasive wheel A and arranged to be adjustable longitudinally thereto. The guard is made with an opening A_4 in its side to permit access of the work to the wheel, the opening being formed with a part spherical, conical or inclined surface A_5 adapted to catch without splash liquid projected from the wheel.

The guard may also have an opening A_6 below for the escape of surplus liquid and be provided in its interior with a bore A_7 , so bevelled or curved in section that the water projected tangentially from the rotating wheel will not be atomized by splashing thereon.

Having thus described the nature of the said invention and the best means I know of carrying the same into practical effect, I claim:—

1. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, and means for automatically traversing the grinding wheel across the work during a grinding operation by relative movement between said wheel

and member about an axis intersecting the axis of rotation of the work holding member, said means including means whereby such movement is effected by a definitely limited force and at a rate which may be less than but cannot exceed a predetermined rate.

2. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for traversing the grinding wheel across the work during a grinding operation by relative movement between said wheel and member about an axis intersecting the axis of rotation of the work holding member, and means for retarding such relative movement.

3. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for traversing the grinding wheel across the work during a grinding operation by relative movement between said wheel and member about an axis intersecting the axis of rotation of the work holding member, and means for retarding such relative movement comprising a fluid check device.

4. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for traversing the grinding wheel across the work during a grinding operation by relative movement between said wheel and member about an axis intersecting the axis of rotation of the work holding member, said means including means for applying a limited force tending to effect such movement and means for limiting the rate of such movement, whereby the rate of such movement may vary inversely with the resistance to grinding but cannot exceed a predetermined rate.

5. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member, said means including means for applying a definitely limited force to effect such movement, and a device for limiting the rate of such movement, adjustable to vary such rate.

6. A grinding machine, comprising in combination a rotary work holding member, a rotary grinding wheel having an annular grinding edge operable across the face of the work carried by the work holding member, and means for producing between the work holding member and wheel a relative movement about an axis intersecting the axis of rotation of the work holding member under definitely limited force and at a rate which may be less than but cannot exceed a predetermined rate.

7. A grinding machine, comprising, in

combination, a rotary grinding wheel having an annular grinding edge, a rotary work holding member, and means for causing a rotative movement of said work holding member about an axis intersecting the axis of rotation of said work holding member at a fixed angle thereto and at a point which, during the grinding operation, is at a fixed distance both from the operative edge of the wheel and from the work holding member, the grinding wheel being mounted with its axis of rotation in the same plane as the axis of rotation of the work holding member and with its grinding edge operable across the face of the work carried by the work holding member.

8. A grinding machine, comprising in combination a rotary work holding member, a rotary grinding wheel having an annular grinding edge operable across the face of the work carried by said member, means for producing between the work holding member and wheel a relative movement about an axis intersecting the axis of rotation of said member, said means including means for applying a definitely limited force to effect such movement, and means for limiting such movement so as not to exceed a predetermined rate.

9. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holder, one of said members being mounted to turn about an axis intersecting the axis of rotation of the work holder for causing a relative traversing movement between the work and the edge of the grinding wheel, and means for effecting such movement at a rate which increases throughout the grinding operation.

10. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work-holding member, means for producing between said wheel and member a relative approaching movement at a rapid rate until the work is about to reach the grinding wheel, and then a relative movement about an axis intersecting the axis of rotation of the work-holding member at a slower rate during the grinding operation.

11. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a relative movement about an axis at an angle to the axis of rotation of said member and at a rate varying automatically and inversely with the resistance between the work carried by said member and said grinding wheel, and means for preventing such relative movement exceeding a predetermined maximum rate.

12. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means including a gravity member for producing between

said wheel and member a relative movement about an axis at an angle to the axis of rotation of said member and at a rate varying automatically and inversely with the resistance between the work carried by said member and said grinding wheel, and means for preventing such relative movement exceeding a predetermined maximum rate.

13. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, and automatic means for producing between said wheel and member a relative movement about a given axis at a rate below a predetermined maximum to effect the grinding of the work and then a higher rate to effect the separation of the work and grinding wheel.

14. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, and means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member first at a rapid rate until the work is about to reach the grinding wheel and then automatically at a slower rate during the grinding operation.

15. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, and means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member, first forward at a rapid rate until the work is about to reach the grinding wheel, then automatically at a slower rate during the grinding operation, and then backward at a rapid rate.

16. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member, and retarding means arranged to come into operation when the work is about to reach the grinding wheel to limit the rate of such movement during the grinding operation.

17. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, and means for producing between said wheel and member a relative movement about a secondary axis intersecting the axis of rotation of the work holding member, said means comprising a screw having its axis in line with said secondary axis, a nut engaging said screw and means for moving one of said screw threaded members longitudinally relatively to the other to effect such movement.

18. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a

relative movement about an axis intersecting the axis of rotation of the work holding member, said means comprising coacting screw threaded members one of which is movable longitudinally relatively to the other to effect such movement, means for holding one of said screw threaded members against rotation during said relative longitudinal movement, and means operating to render said holding means inoperative after a grinding operation.

19. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a relative forward movement about an axis intersecting the axis of rotation of the work holding member, said means comprising coacting screw threaded members one of which is movable longitudinally relatively to the other to effect such forward movement, means for holding one of said screw threaded members against rotation during said relative longitudinal movement, means operating to render said holding means inoperative after a grinding operation, and means operating to effect a relative backward movement between the grinding wheel and the work holding member when said holding means has been rendered inoperative.

20. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member, said means comprising coacting screw threaded members one of which is movable longitudinally relatively to the other to effect such movement, means for holding one of said screw threaded members against rotation during said relative longitudinal movement, means operating to render said holding means inoperative after a grinding operation, and means for returning said movable screw threaded member to starting position and rendering said holding means operative.

21. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member, said means comprising coacting screw threaded members one of which is movable longitudinally relatively to the other to effect such movement, means comprising a toggle for holding one of said screw threaded members against rotation during said relative longitudinal movement, means for automatically breaking said toggle to release said member after a grinding operation, and means for returning said

movable screw threaded member to starting position and said toggle to holding position.

22. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member, said means comprising coacting screw threaded members one of which is movable longitudinally relatively to the other to effect such movement, means for holding one of said screw threaded members against rotation during said relative longitudinal movement, and adjustable means operating to render said holding means inoperative after a grinding operation.

23. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member, said means comprising coacting screw threaded members one of which is movable longitudinally relatively to the other to effect such movement, and a weight for moving said longitudinally movable member.

24. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, and means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member, said means comprising a screw threaded shaft, a nut engaging the screw thread of said shaft and adapted by longitudinal movement to turn the shaft, a weight adapted to give the nut its shaft turning movement, means for holding the nut against rotation while making its shaft turning movement, means operating to render said holding means inoperative after a grinding operation to permit the shaft to be turned backward, and means for lifting the weight and turning the nut to starting position and rendering said holding means operative.

25. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for turning the work holding member about an axis intersecting the axis of rotation of the work holding member to move the work past the operative face of the grinding wheel, said means comprising coacting screw threaded members one of which is movable longitudinally relatively to the other to effect such movement, means for holding one of said screw threaded members against rotation during such relative longitudinal movement, means operating to render said holding means inoperative after a grinding operation, and means operating to return

the work holding member to its normal position of rest when said holding means has been rendered inoperative.

26. A grinding machine, comprising, in combination, a rotary work holding member, a rotary grinding wheel having an annular grinding edge operable across the face of the work carried by said work holding member, and means for producing between the work holding member and wheel a relative movement about an axis intersecting the axis of rotation of the work holding member at a fixed angle and at a point which, during the grinding operation, is at a fixed distance both from the operative edge of the wheel and from the work holding member.

27. A grinding machine, comprising, in combination, a rotary work holding member, a rotary grinding wheel having an annular grinding edge operable across the face of the work carried by said work holding member, means for producing between the work holding member and the wheel a relative movement about an axis intersecting the axis of rotation of the work holding member at a fixed angle and at a point which, during the grinding operation, is at a fixed distance from the work holding member, and means for adjusting the grinding wheel axially to take up for wear on its grinding edge so as to retain its operative edge at a fixed distance from said point of intersection.

28. A grinding machine, comprising, in combination a rotary grinding wheel having an annular grinding edge, a rotary work holding member, and supporting means for said grinding wheel and the work holding member permitting relative rotative movement between the same about a secondary axis intersecting the axis of the work holder, said supporting means including means whereby said grinding wheel may be moved longitudinally of its axis and means whereby said work holding member may be moved longitudinally of its axis to vary the distance between the operative point of said wheel and the secondary axis.

29. A grinding machine, comprising, in combination, a work holder for rotating the work about an axis passing through the surface to be ground, a grinding wheel positioned to contact with the work during a grinding operation, automatic means for causing a relative separating movement between the work and the grinding wheel on the completion of a grinding operation, and means automatically brought into operation by said separating movement for causing the rotation of the work to cease.

30. A grinding machine, comprising, in combination, a work holder for rotating the work about an axis passing through the surface to be ground, a grinding wheel,

means for causing between the grinding wheel and the work a relative bodily movement adapted to traverse the grinding wheel over the face of the work, and means automatically actuated by said relative bodily movement for causing a separation of the work and wheel and for stopping the rotation of the work on the completion of a grinding operation.

31. A grinding machine, comprising in combination a grinding wheel, a rotary work holding member, means for turning the work holding member about an axis intersecting the axis of rotation of the work holding member to move the work past the edge of the grinding wheel and for transferring said member to a position of rest after a grinding operation is completed, and means for causing the rotation of the work holding member to cease when it is returned to its position of rest and to be resumed when said member is moved to begin a new grinding operation.

32. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding device, and means for producing between said wheel and device a relative movement about a secondary axis intersecting the axis of rotation of said device, said device comprising a work spindle, a chuck thereon operated by movement longitudinally of the spindle, and means determining the position of the chuck with respect to the secondary axis independently of the position of the work spindle, whereby the work is ground to a uniform thickness regardless of its diameter.

33. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding device, and means for producing between said wheel and device a relative movement about a secondary axis intersecting the axis of rotation of said device, said device comprising a work spindle, a chuck thereon operated by movement longitudinally of the spindle, means determining the position of the chuck with respect to the secondary axis independently of the position of the spindle whereby the work is ground to a uniform thickness regardless of its diameter, and means for moving said chuck longitudinally to open the same.

34. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work-holding device, and means for producing between said wheel and device a relative movement about a secondary axis intersecting the axis of rotation of said device, said device comprising a work spindle support, a work spindle having a limited axial movement in said support, a chuck upon said spindle adjustable axially thereof, and an abutment cooperating with said chuck to determine its posi-

tion with respect to the secondary axis independently of the position of the spindle.

35. A machine for grinding spherically curved surfaces, comprising in combination a rotary grinding wheel, a rotary work holding member, means for traversing the surface of the work across the operative surface of the grinding wheel by producing between said wheel and said member during a grinding operation a relative movement about a secondary axis intersecting the axis of the work holding member, and automatic means for causing a separating movement between the grinding wheel and the work in a direction different from said first-mentioned movement upon completion of a grinding operation.

36. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for moving the work holder about an axis intersecting the axis of rotation of the work holder from a position of rest across the grinding wheel during a grinding operation, and automatic means for withdrawing the work holder from the grinding wheel and returning it to such position of rest after the completion of a grinding operation.

37. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holder, means for releasing the work from said work holder, means for causing a rotative movement of the work holder about an axis intersecting the axis of rotation of the work holder during a grinding operation, and automatic means for withdrawing the work holder from the wheel and bringing it into operative relation with said releasing means.

38. A machine for grinding spherically curved surfaces, comprising means for rotating the work about an axis passing through the surface to be ground, a rotary grinding wheel, means for causing between the work and wheel a relative turning movement about an axis intersecting the axis of rotation of the work, the grinding wheel being so formed and arranged that the middle point of the line of contact between the wheel and the work is moved across the face of the work along a radial line joining the periphery and axis of the work by said turning movement, and means for automatically separating the wheel and work when the middle point of the line of contact reaches one end of said radial line.

39. A machine for grinding spherically curved surfaces, comprising means for rotating the work about an axis passing through the surface to be ground, a rotary grinding wheel, means for causing between the wheel and the work a relative turning movement about an axis intersecting the axis of the work, the grinding wheel being so formed

and arranged that the middle point of the line of contact between the wheel and the work is moved by said turning movement across the face of the work from the periphery of the work to the axis of the work, and automatic means for stopping said turning movement when the middle point of the line of contact reaches the axis of the work.

40. A machine for grinding spherically curved surfaces, comprising a work holder rotary about an axis passing through the surface to be ground, a rotary grinding wheel, means for causing between the work holder and the wheel a relative turning movement about a secondary axis intersecting the axis of rotation of the work, the grinding wheel being so formed and arranged that the line of contact between the wheel and the work is moved by said turning movement across the face of the work, means for retaining the wheel and the work holder at fixed distances from the secondary axis during the grinding operation, and automatic means for stopping said turning movement on completion of a grinding operation.

41. A machine for grinding spherically curved surfaces comprising a work holder rotary about an axis passing through the surface to be ground, a rotary grinding wheel, means for causing between said wheel and said work holder a relative turning movement about a secondary axis intersecting the axis of the work holder, the grinding wheel being so formed and arranged that the line of contact between the wheel and the work is moved by said turning movement across the face of the work, means for retaining said wheel and said work holder at fixed distances from the secondary axis during a grinding operation, and automatic means for separating the wheel and work on completion of a grinding operation.

42. A machine for grinding spherically curved surfaces, comprising a work holder having a surface adapted to engage and position the rear face of the work, means for rotating said work holder about an axis passing through the front face of the work, a rotary grinding wheel, means for causing between said wheel and said work holder a relative turning movement about an axis intersecting the axis of the work holder, the grinding wheel being so formed and arranged that the middle point of its line of contact with the work is moved from the edge to the axis of the work by said turning movement, means for retaining the positioning surface of the work holder at a

fixed distance from the secondary axis during such turning, and automatic means for stopping said turning movement when the middle point of the line of contact between the work and the wheel reaches the axis of the work.

43. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holder, means for causing between said wheel and said work holder a relative turning movement about an axis intersecting the axis of the work holder, through an arc of predetermined length, and means for varying the rate of said movement by variable increments without varying the length of said arc.

44. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holding member, means for producing between said wheel and member a relative movement about an axis intersecting the axis of rotation of the work holding member, first, at a rapid rate, then, automatically at a slower rate, and means for varying the arc through which the movement is effected at the slower rate.

45. A grinding machine, comprising in combination a rotary grinding wheel, a rotary work holder, turning means for causing a movement of said work holder about an axis intersecting the axis of rotation of the work holder, means arranged to set said turning means in operation, driving means for rotating the work holder, and means operated by said turning movement for setting said driving means in operation.

46. In grinding apparatus, the combination of a grinding wheel, a work holder comprising a work spindle and a chuck upon said work spindle opened and closed by movement of the chuck longitudinal of the spindle, means for causing a relative movement between said grinding wheel and said work holder about a secondary axis intersecting the axis of the work spindle, and means cooperating with said chuck to determine the position of the work relatively to the secondary axis independently of the relative longitudinal position of said spindle and chuck and comprising an abutment having a predetermined positional relation to the secondary axis.

In testimony whereof I have signed my name to this specification in the presence of two subscribing witnesses.

WM. TAYLOR.

Witnesses:

Y. E. HUDSON;
ELSIE M. BENT.