

March 18, 1952

W. D. FOWLER

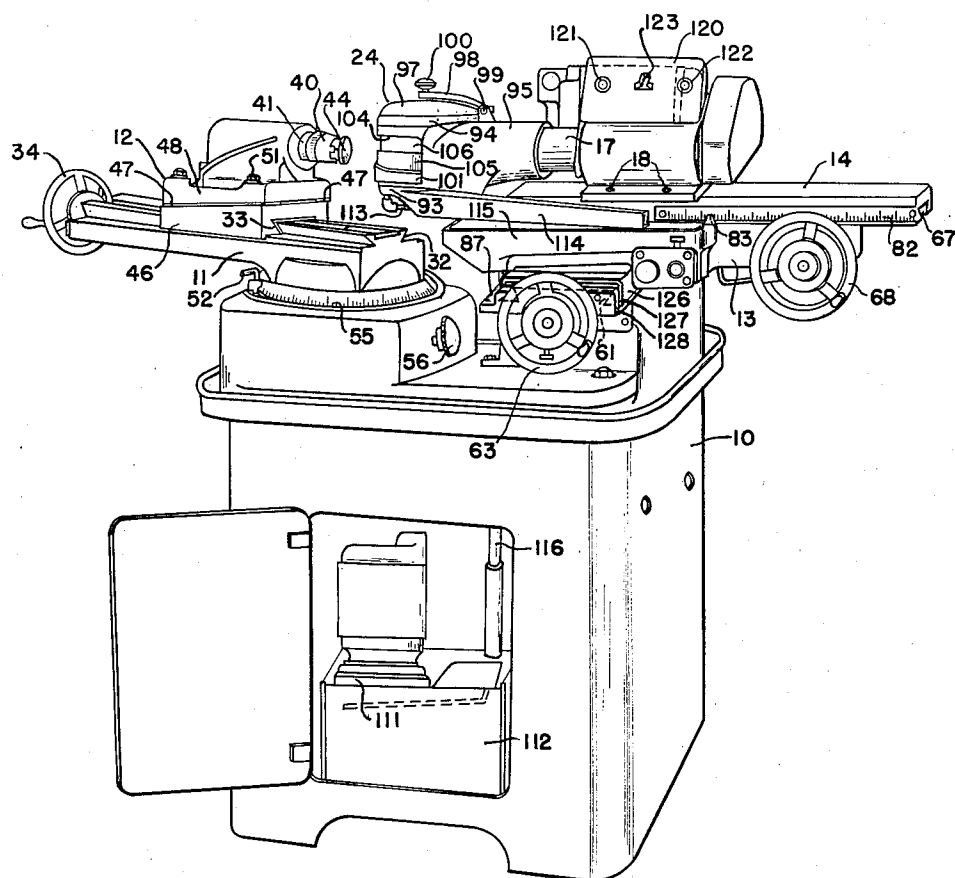
2,589,488

LENS GRINDING METHOD AND MACHINE

Filed Nov. 19, 1948

8 Sheets-Sheet 1

FIG. 1



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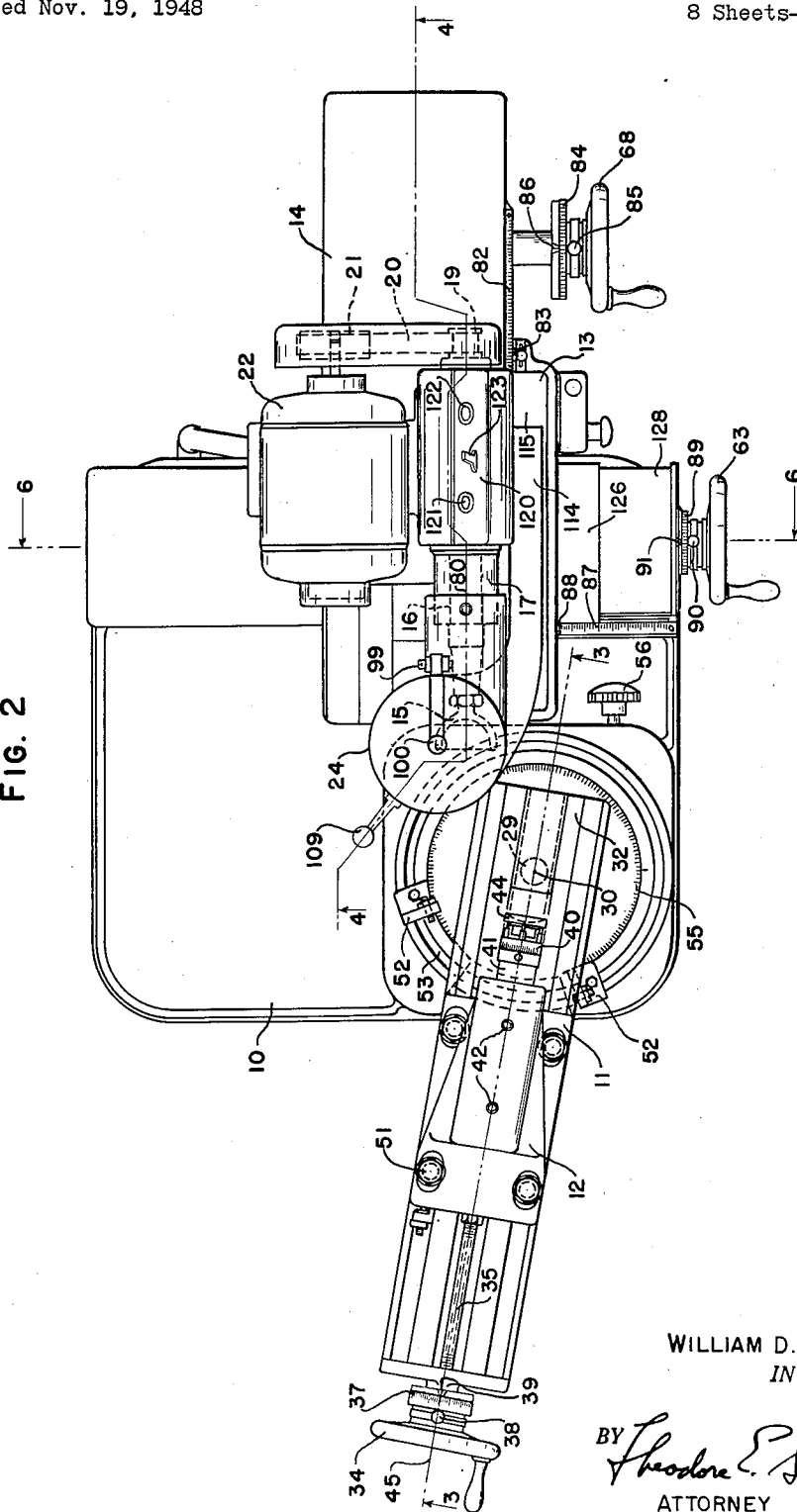
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LENS GRINDING METHOD AND MACHINE

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8 Sheets-Sheet 2

FIG. 2



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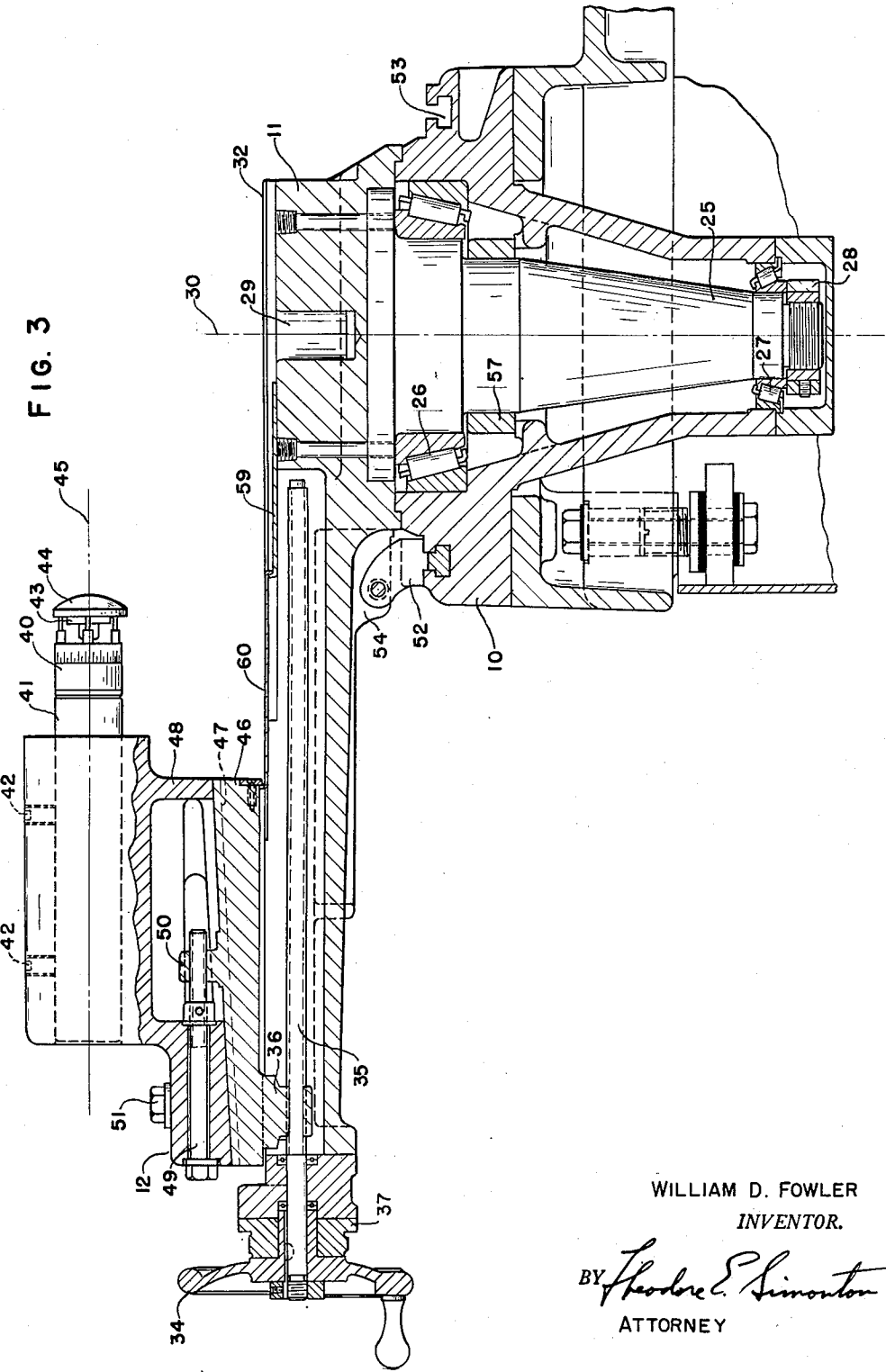
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LENS GRINDING METHOD AND MACHINE

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8 Sheets-Sheet 3



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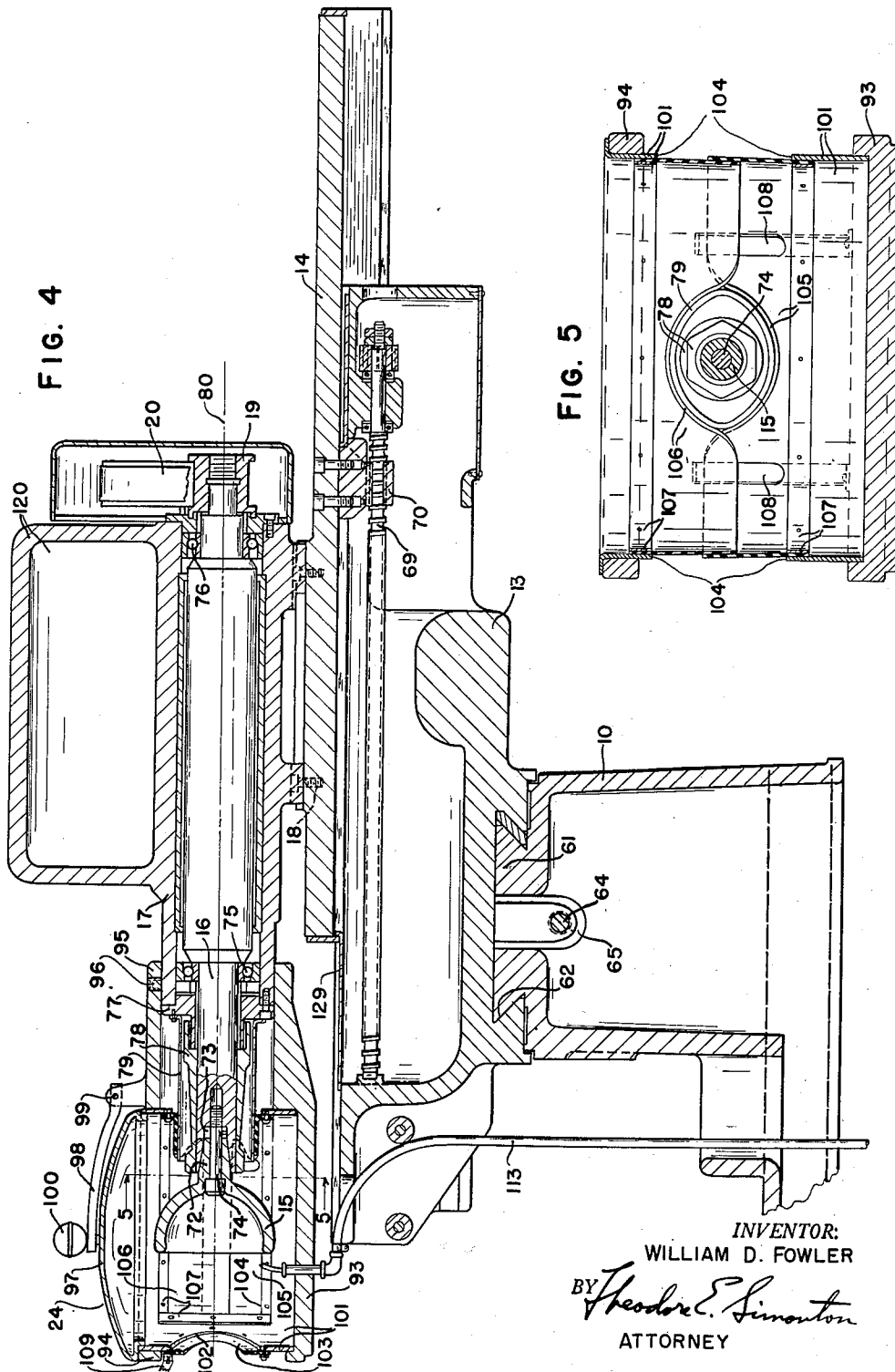
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LENS GRINDING METHOD AND MACHINE

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March 18, 1952

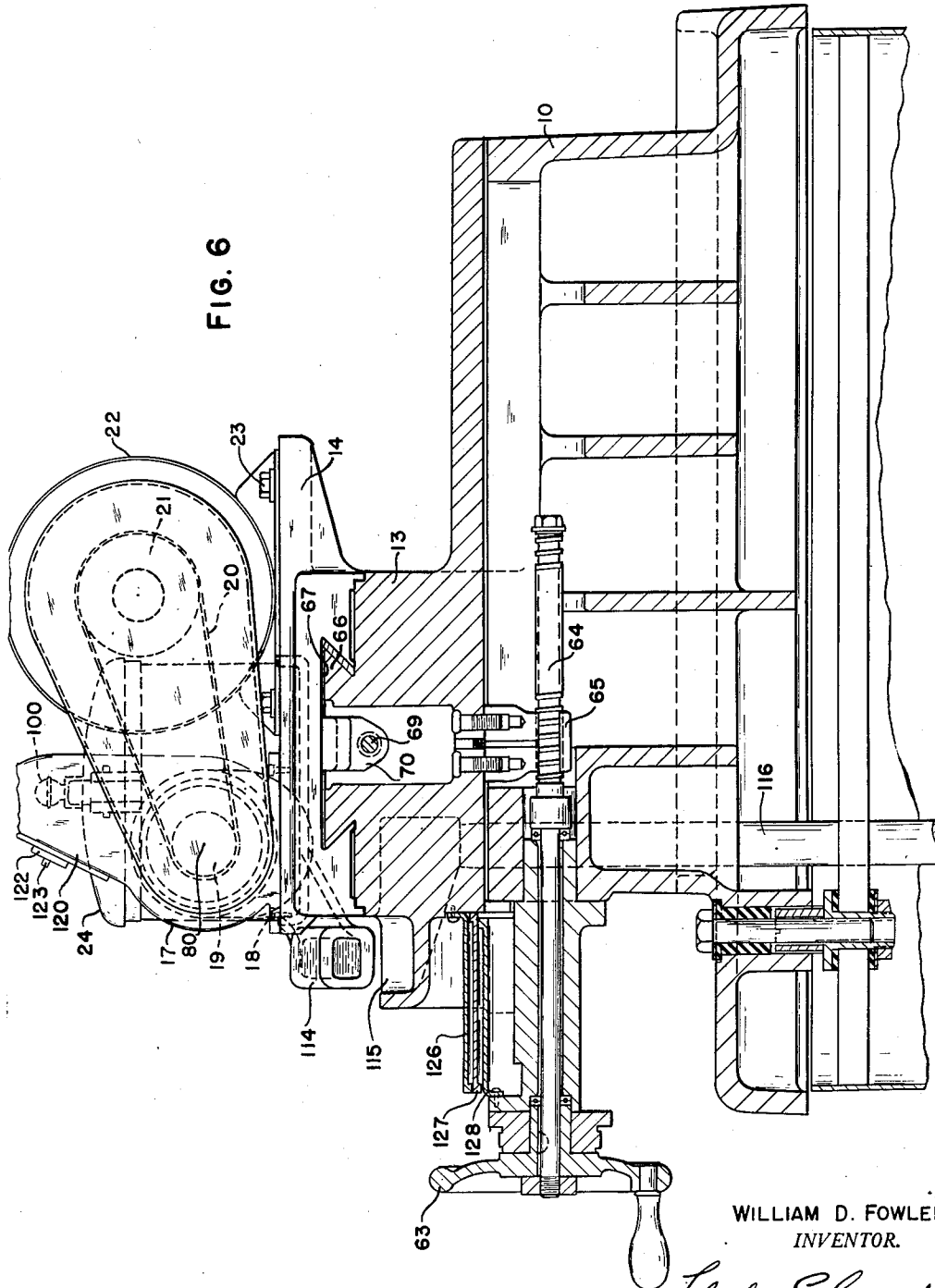
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LENS GRINDING METHOD AND MACHINE

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8 Sheets-Sheet 5



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LENS GRINDING METHOD AND MACHINE

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FIG. 7

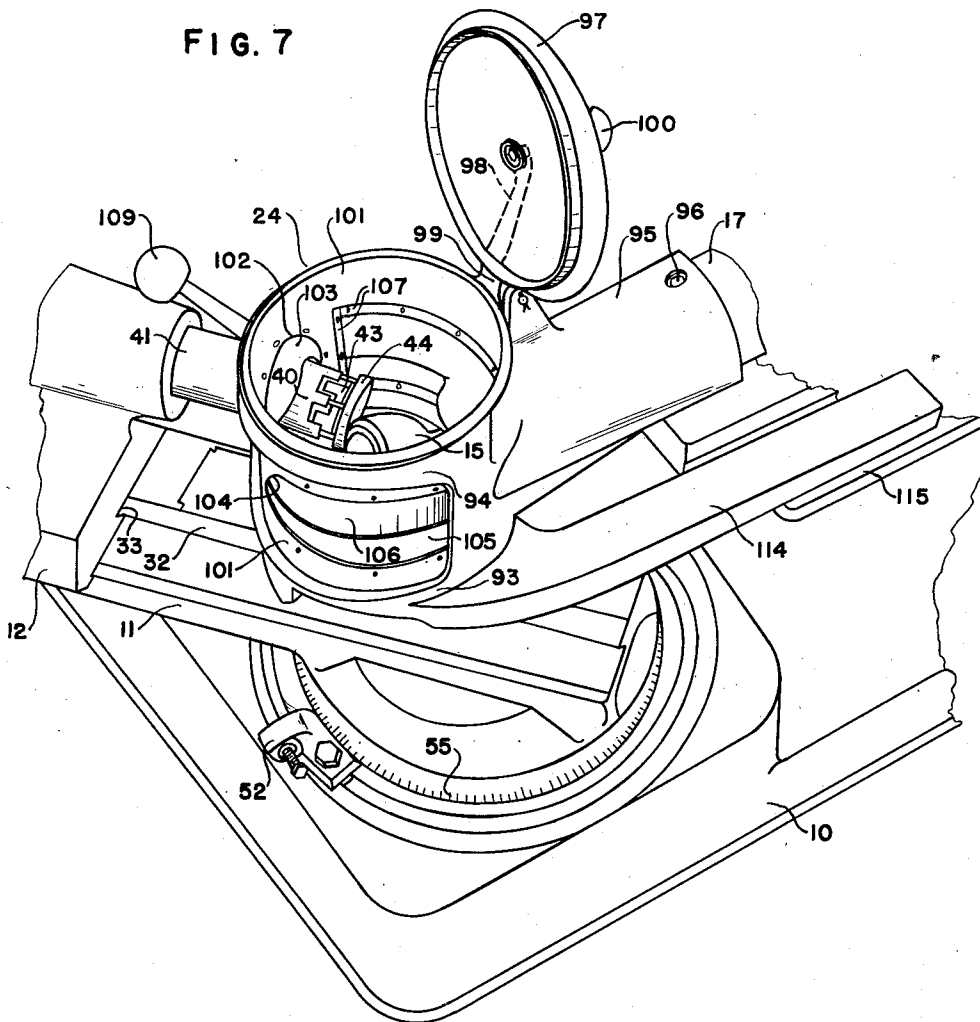
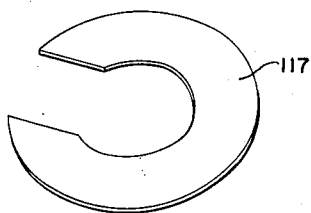


FIG. 8



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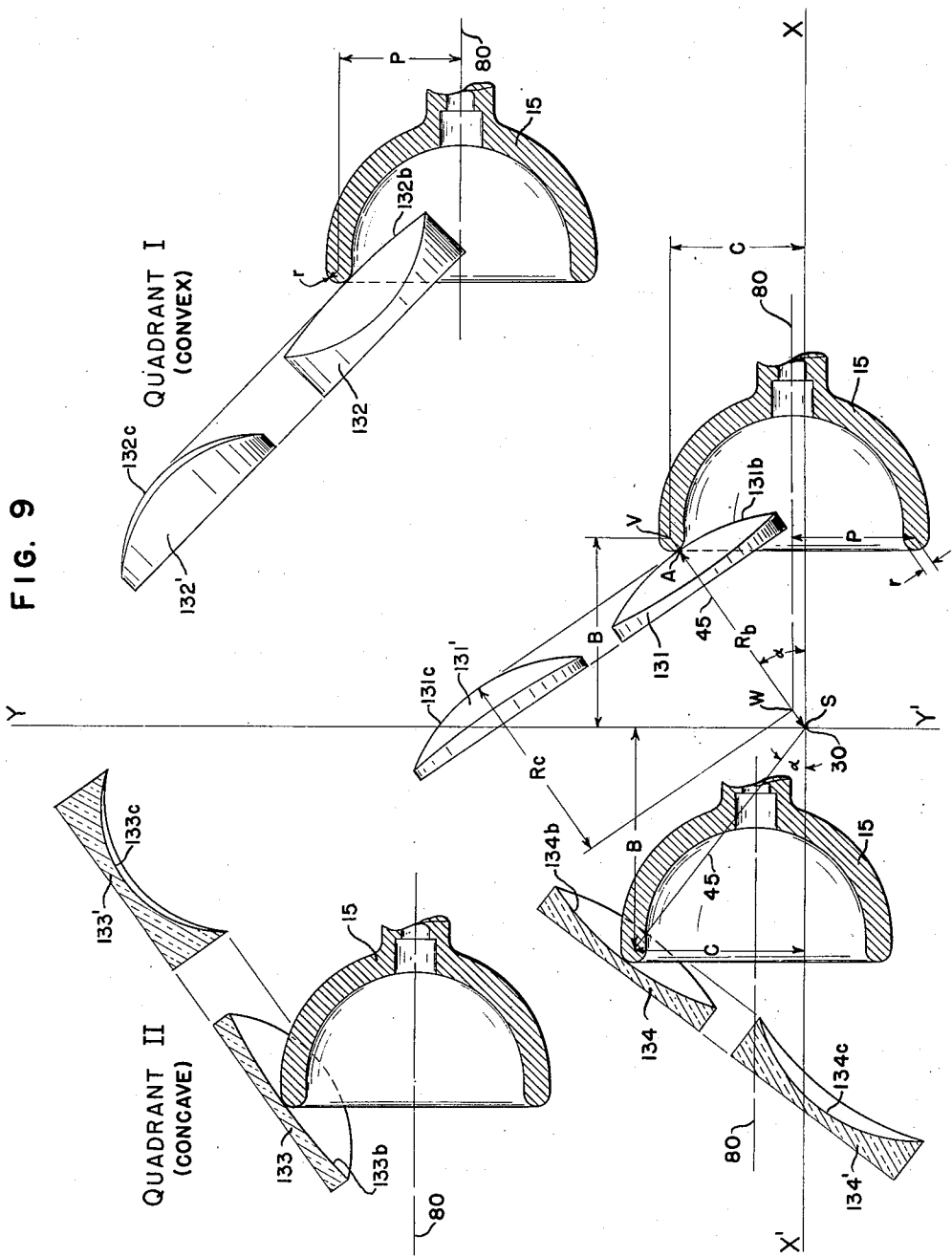
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LENS GRINDING METHOD AND MACHINE

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8 Sheets-Sheet 7

FIG. 9



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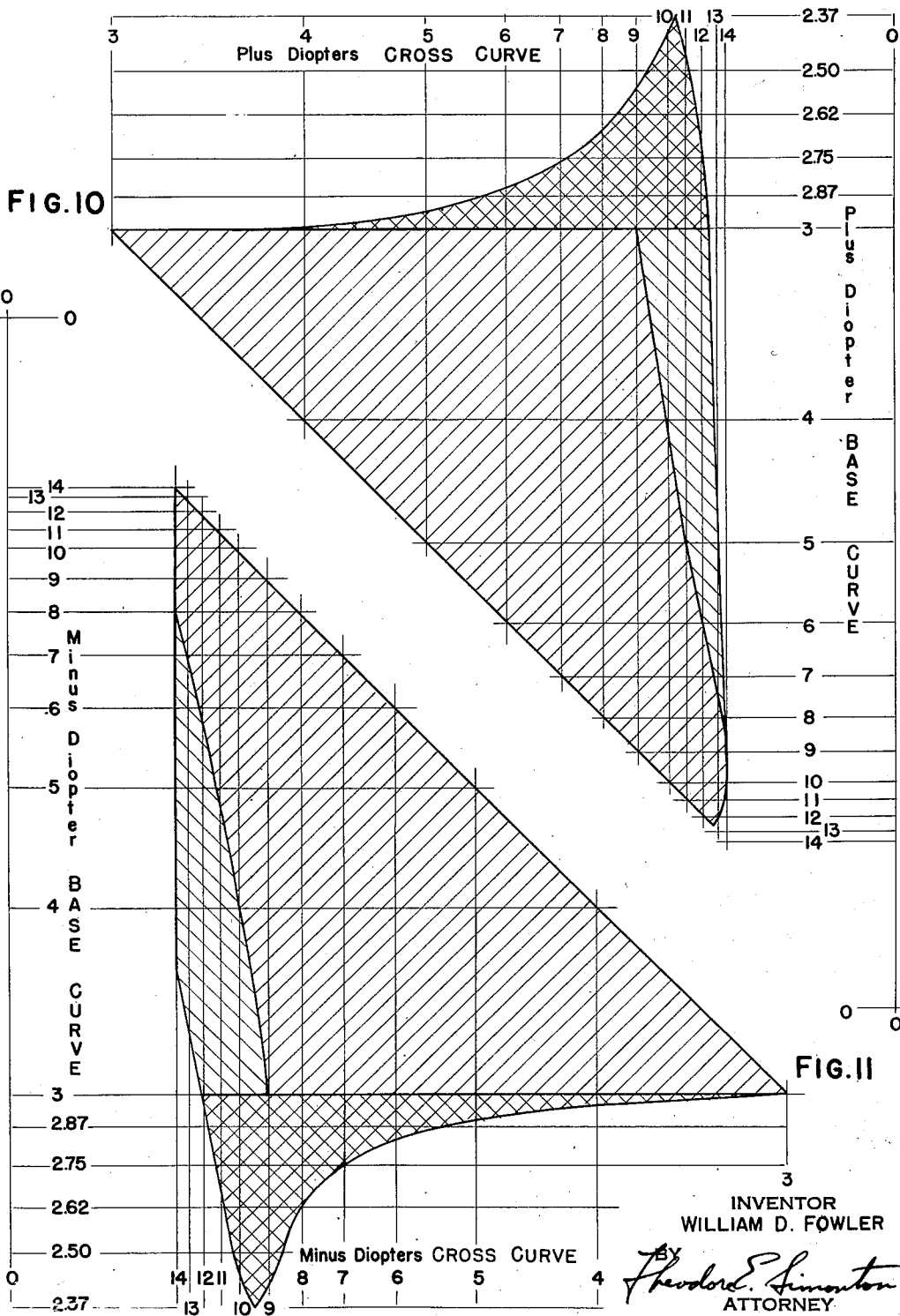
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LENS GRINDING METHOD AND MACHINE

Filed Nov. 19, 1948

8 Sheets-Sheet 8



UNITED STATES PATENT OFFICE

2,589,488

LENS GRINDING METHOD AND MACHINE

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7 Claims. (Cl. 51—124)

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This invention relates to lens grinding methods and machines and particularly to a method and machine for generating toric lenses by surface grinding, although, as a special case, spherical lenses may also be generated with the method and machine of this invention.

Toric lenses are lenses having at least one surface which is a portion of the equatorial zone of a torus. Such a surface, in two selected mutually perpendicular planes, presents two distinct curves constituting circular arcs of different radii of curvature. The intersection of said two planes is the line hereinafter referred to as the lens axis. One of these curves is called the base curve, and the other, at right angles to the base curve, is called the cross curve. A spherical lens surface is obviously a special case of a toric lens surface, in which special case the two radii of curvature are equal. The curvatures of the base curve and the cross curve are ordinarily given in diopters (the reciprocal of the focal length in meters), and the base curve is usually taken as the one of smaller diopter value (larger radius of curvature).

The accepted method of generating toric lens surfaces by grinding involves the use as the generating tool of an abrasive wheel of the annular ring type, commonly called a cup wheel. Usually, a diamond charged cup wheel is employed. The axis of the tool and the axis of the lens blank are located in the same plane, which is called the base plane, since it contains the base curve. The generation of the toric surface is accomplished by relative bodily swinging movement between the rotating tool and the non-rotating lens blank; the axis of swing being normal to the base plane. Either the lens blank is swung past the cup wheel rotating about a stationary axis, or the rotating cup wheel is swung past the stationary lens blank. In either case, the radial distance in the base plane between the axis of swing and the point of tangency of the lens blank and the arcuate working face of the tool determines the base curve. The cross curve is dependent upon the diameter of the cup wheel, but is primarily determined by the angle between the lens axis and the tool axis when, in the course of their relative swinging movement, the lens axis passes through the center of curvature of the arcuate working face of the wheel. With this method of generation, the cross curve is not a true circular arc, but approximates a circular arc quite closely. The difference between the desired true circular arc and the generated curve is commonly called the elliptical error, and this elliptical error is usually corrected in a lapping operation following the generating operation and performed on a separate lapping machine.

A number of ingenious machines have heretofore been developed for generating toric surfaces

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on ophthalmic lens blanks by grinding in accordance with the foregoing principles, employing a cup wheel and a lens chuck with their axes located in the base plane. These prior machines have included two pivotal axes normal to the base plane, one being the above-described axis of swing, and the other being what may be called the axis of angulation. The desired base curve is obtained by varying the distance between the axis of swing and the axis of angulation. Adjusting means are provided for bringing the center of curvature of the arcuate working face of the wheel into alignment with the axis of angulation, and for adjusting the wheel axis angularly with respect to the axis of angulation to obtain the desired cross curve. The desired lens thickness is secured by axial adjustment of the lens chuck.

The commercial machines of the foregoing type have incorporated rather complicated mechanical arrangements for obtaining the described adjustments. They are therefore difficult to set to generate a desired toric surface, and are especially difficult to adjust to minimize the elliptical error and to compensate for wheel wear. Other common disadvantages are excessive size and weight, and lack of adequate provision for confining the necessary liquid coolant. This coolant becomes contaminated with ground glass and particles from the abrasive wheel, and, unless properly confined, is apt to damage the working parts of the machine, as well as being dangerous to the health of the operator. These machines are therefore expensive to make, to keep in good repair, and to operate, and the accuracy of the lenses produced often leaves much to be desired.

The present invention, which is hereinafter described in detail, utilizes principles which are not broadly novel, but which, so far as I am aware, have never before been applied in the art of grinding toric lenses, and the application of which to that art has resulted in a method and machine that are startlingly new in simplicity, speed of setting, and accuracy. Only one pivotal axis is employed, the above-described axis of swing, and this is fixed in position in the machine frame, so that large and rugged bearings may be effectively used. The relatively light lens and lens chuck are swung on this pivotal axis about the heavier cup wheel and its driving mechanism, which results in lower machine cost and longer efficient machine life than the reverse arrangement of parts. In setting the machine for any desired combination of base curve and cross curve within the range of the machine, only two simple rectilinear adjustments at right angles to each other are made, one an axial movement of the cup wheel and the other a transverse movement of the cup wheel axis, both movements being in the base plane. The cup wheel is thus positioned in a definite linear

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and angular location with respect to the axis of swing of the lens. The cup wheel may therefore also be supported and adjusted in a simple and rigid manner. The lens chuck is axially advanced toward the cup wheel to bring the lens blank surface into contact with the cup wheel and to control the depth of cut and hence the thickness of the finished lens. As in prior machines, this thickness adjustment has no effect upon the machine settings which produce the desired base and cross curves.

The primary objects of this invention are to provide a method of lens grinding which generates both convex and concave toric lenses simply, efficiently and accurately, and to provide a toric lens grinder for carrying out that method, which can be economically manufactured, and which is simple to adjust and to operate.

A further object is to produce a toric lens grinder in which the simplicity of adjustment for base and cross curves is such as to permit easy and accurate compensation for elliptical error and for wear of the arcuate working face of the cup wheel.

Still further objects are to effectively confine the liquid coolant used in the grinding machine, and to locate and protect the working parts so as to enhance the efficient working life of the machine.

Other objects and advantages will appear from the following description, taken in conjunction with the accompanying drawings, in which:

Figure 1 is a perspective view of the complete machine;

Figure 2 is a top plan of the machine;

Figure 3 is a vertical section through the turntable and work slide, taken on the line 3—3 of Figure 2, and showing the lens chuck and associated parts in front elevation;

Figure 4 is a vertical section through the tool slide and associated parts, taken on the line 4—4 of Figure 2, with a few parts adjacent the section line shown in front elevation;

Figure 5 is a sectional view of the grinding chamber on the line 5—5 of Figure 4;

Figure 6 is a side elevation of the machine, partly in section on the line 6—6 of Figure 2;

Figure 7 is a perspective view of the grinding chamber and associated parts;

Figure 8 is a perspective view of a baffle plate which may be used in the grinding chamber;

Figure 9 is a diagram illustrating the method of this invention and showing various curved lens surfaces produced at different settings; and

Figures 10 and 11 are diagrams showing the range of curve combinations produced by the machine for convex and concave lenses, respectively.

Referring more particularly to the drawings, Figures 1 and 2 show the complete machine mounted upon a frame or supporting base 10. A turntable 11 is rotatably mounted on the base 10 and a work carriage 12 is slidably mounted on the turntable 11. A cross-feed slide 13 is slidably mounted on the base 10, and a tool carriage 14 is slidably mounted on the slide 13 for movement in a direction perpendicular to the movement of the slide 13. A grinding wheel 15 (shown in broken lines in Figure 2) is secured to one end of shaft 16 rotatably supported in a housing 17 secured to the tool carriage 14 by bolts 18. The outer end of shaft 16 is provided with a pulley 19 driven by means of belt 20 and

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pulley 21 by an electric motor 22 secured to tool carriage 14 by bolts 23 (Figure 6). A grinding chamber 24, mounted on the tool carriage 14, encloses the grinding wheel 15.

The construction of the turntable 11 and its associated parts is best shown in Figure 3. The turntable 11 is secured to a vertical shaft 25 rotatably mounted in base 10 by means of upper and lower roller bearings 26 and 27, the upper bearing 26 being supported by the base 10 and the lower bearing 27 being held in position by the retaining assembly 28 threaded on the lower end of shaft 25. A gauge hole 29, for a purpose presently to be described, is provided at the upper side of the turntable 11 in exact alignment with the axis 30 of the turntable shaft 25, which is the axis previously referred to as the axis of swing.

The work carriage 12 is mounted to slide radially with respect to the turntable axis 30 by means of the conventional dovetail ways 32 on the turntable 11 and channel 33 in the work carriage. The work carriage 12 may be moved along the ways 32 by means of handwheel 34, screw 35 and nut 36. For accurately determining the movement of the work carriage, a graduated circular scale or dial 37 is rotatably mounted on the hub of the handwheel 34 and is normally locked thereto by the thumb screw 38 (Figure 2). An index pointer 39 on the turntable 11 cooperates with the dial 37.

The lens blank holder or chuck 40 is secured to a chuck shaft 41 which in turn fits snugly in a suitable bore in the work carriage 12 in which it is locked in position by means of set screws 42. The construction of the chuck 40 is no part of the present invention, and it will therefore not be discussed in detail herein. It will suffice here to say that the chuck 40 is adapted to hold in proper alignment a conventional lens block 43 to which a lens blank 44 has been blocked in the usual manner with pitch or other adhesive, so that the axis of the lens coincides with the axis of the block. The chuck in turn clamps the lens block in such manner that the lens blank, the lens block, the chuck and the shaft 41 have a common axis 45. It will be evident to those skilled in this art that direct chucking of the lens blank could be used, if desired, in lieu of first blocking the lens and then chucking the lens block.

In order properly to position the axis 45, the work carriage 12 is made in four pieces. The lower piece 46 contains the channel 33 and has an inclined upper surface, provided with a similarly inclined central rib. Two guide plates 47 fit snugly on either side of the central rib, and are dowelled to the under side of the work carriage upper piece 48 during the manufacture of the machine. As will be understood by those skilled in the art of machine design, the guide plates are precisely located on the upper piece 48 before dovelling them thereto, and the turntable ways 32 are precisely leveled, so as to cause the axis 45 to intersect the axis 30 at a right angle. The upper piece 48 carries a screw 49 cooperating with a nut 50 on the lower piece 46. Turning the screw 49 permits the lens axis 45 to be adjusted to the desired height without disturbing its perpendicular relationship to the axis of swing 30. Lock bolts 51 may then be tightened to secure the upper piece 48 to the lower piece 46 at the desired height adjustment.

To limit the arc of swing of turntable 11, movable stops 52 (Figure 2) are provided which can be clamped at any desired position in the

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circular inverted T-shaped groove 53 (Figures 2 and 3), located in supporting base 10. The movable stops 52 limit movement of turntable 11 by contact with fixed stop 54 (Figure 3) attached to turntable 11. To facilitate accurate setting of stops 52, a graduated circular scale 55 (Figures 1 and 2) is provided on turntable 11 adjacent said stops. Turntable 11 may be locked in any desired position by tightening knob 56 (Figures 1 and 2), which operates a brake shoe 57 (Figure 3) in conventional manner. The brake knob 56 and brake shoe 57 may also be used if desired, to create a slight drag to retard the swinging movement of turntable 11 and assist in moving the lens blank past the cup wheel at a constant rate. It has been found, however, that an operator soon develops an accurate sense of touch which enables him to swing turntable 11 at a proper rate of speed without requiring the use of brake shoe 57 to retard the swinging movement of the turntable.

To protect gauge hole 29 and screw 35 from dirt and other foreign matter, cover plates 59 and 60 (Figure 3) are provided, which slide one over the other in conventional telescope fashion as the work carriage 12 is run back and forth on ways 32.

Figures 4, 5 and 6 show the details of construction of the cross-feed slide 13, tool carriage 14 and associated parts. The base 10 is provided with dovetail ways 61 cooperating with a channel 62 in cross-feed slide 13. Transverse movement of slide 13 along the ways 61 is obtained by means of handwheel 63, screw 64 and nut 65. The slide 13 is provided with dovetail ways 66 along which tool carriage 14 slides guided by cooperating channel 67, under the control of handwheel 68 (Figures 1 and 2), screw 69 and nut 70. The movement of tool carriage 14 is exactly at right angles to that of cross-feed slide 13.

As best seen in Figure 4, the grinding wheel 15 is of the annular ring type, commonly called a cup wheel, having an arcuate working surface on its annular edge. The cup wheel 15 may be secured to its shaft 16 by means of a taper shank 72 on the cup wheel fitting snugly into a taper recess 73 in the end of shaft 16, and held in place by bolt 74. The shaft 16 is mounted in bearings 75 and 76 secured in shaft housing 17. To protect the bearings from entry of foreign material, the left end of housing 17 is substantially closed by a cover plate 77 having a hub projecting into and cooperating with a tubular sealing member 78 secured to the shaft 16 to rotate therewith. A guard sleeve 79, preferably oval in cross section as shown in Figure 5, is spaced from and surrounds seal 78 and is secured to cover plate 77.

The parts are so constructed and assembled that the axis 80 of the cup wheel 15 and shaft 16 is precisely parallel to the direction of movement of tool carriage 14. Adjustment of the tool carriage by handwheel 68 therefore produces axial adjustment of the cup wheel, and transverse adjustment of the cup wheel in a direction perpendicular to its axis 80 is obtained by means of handwheel 63 and cross-feed slide 13. The assembly is likewise such that cup wheel axis 80 lies in a plane precisely normal to turntable axis 30. No adjustment for the height of axis 80 is provided, but the lens axis 45 is adjusted for height as above described so that the axes 45 and 80 lie in a common plane normal to the axis of swing 30.

During the operation of the machine, it is

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necessary to adjust the cup wheel 15 axially and transversely as above described to a desired position with respect to the axis of swing 30 of turntable 11. As shown most clearly in Figure 2, suitable scales and index pointers are provided to assist in locating the cup wheel 15 precisely at the desired position. To aid in the axial setting, a linear graduated scale 82, appropriately divided for coarse adjustment in turns of handwheel 68, is secured to tool carriage 14 and its cooperating index pointer 83 is secured to cross-feed slide 13. For finer adjustment, a micrometer dial 84 is releasably secured to the hub of tool carriage handwheel 68 by set screw 85, and cooperates with the index pointer 86. The dial 84 is preferably graduated in fractions of a turn of handwheel 68. Normally, the dial 84 rotates with handwheel 68, but for "zeroing" the dial as later described, set screw 85 may be loosened and the dial 84 rotated with respect to the handwheel 68. To aid in the transverse setting, a linear coarse scale 87, preferably graduated in turns of handwheel 63, is secured to supporting base 10 and cooperates with index pointer 88 secured to cross-feed slide 13. A micrometer dial 89 is releasably locked to rotate with the cross-feed slide handwheel 63 by set screw 90, likewise permitting "zeroing" of the dial 89, which cooperates with an index pointer 91 and is preferably graduated in fractions of a turn of the handwheel 63.

The details of the grinding chamber 24 are shown in Figures 4, 5 and 7, the latter figure illustrating the parts in operative position for grinding a concave toric lens surface. The grinding chamber 24 is shown as a substantially cylindrical receptacle with an open top and with its cylindrical side wall cut away, leaving a bottom side wall band 93 and a top side wall band 94. It is provided at one side with a laterally projecting substantially cylindrical supporting sleeve 95, preferably cast integrally with the main receptacle portion of the grinding chamber. The supporting sleeve 95 slips over the end of shaft housing 17, and is secured thereto by set screw 96. The open top of the grinding chamber 24 may be closed by a cover 97, preferably made of a tough, transparent plastic material, which is shown rotatably supported by an arm 98 hinged to sleeve 95 at 99. A knob 100 is provided on arm 98 for operating the cover.

Closely fitting within bands 93 and 94 and rotatable therein is a cylindrical inner body 101 with hole 102 therethrough of sufficient size to permit introduction of lens blank and lens chuck within the grinding chamber. About the edge of hole 102 is affixed the annular flexible seal 103, made of rubber or like material, with an orifice therethrough of such size as to fit tightly about lens chuck 40 or shaft 41. Commencing on either side of hole 102 at a little distance therefrom, a slot 104 through the wall of the cylindrical inner body 101 runs completely around the remainder of said cylindrical inner body wall. Slot 104 is of sufficient width to permit entry of grinding wheel shaft 16 and guard sleeve 79, the cup wheel 15 being assembled on shaft 16 after grinding chamber 24 is in place on housing 17. At the bottom and top edges respectively of slot 104 are flexible strips or aprons 105 and 106, made of rubber or like material, which project up and down respectively so as to overlap and cover said slot. Aprons 105 and 106 may be fastened to the inner wall of inner body 101 by screw-fastened metal strips 107. Projecting vertically up from bottom band

93 just outside of apron 105 are two flat finger-like guides 108 (Figure 5), one on either side of and close to guard sleeve 79. Guides 108 extend to the upper edge of lower apron 105 and then bend inward and downward over the edge of said flexible apron and project downward along its inside almost to the bottom edge of slot 104. Guides 108 thus form narrow inverted U-shaped passages which hold apron 105 erect along the wall line of inner body 101 on either side of sleeve 79 but allow the apron to slide through said passages as inner body 101 is rotated. Between guides 108, however, the apron 105 is allowed to ride down under the oval guard sleeve 79 (Figure 5). Guides 108 also serve to keep the inner and upper apron 106 from bulging outwards on either side of sleeve 79, over the top of which said apron 106 rides. A handle 109 (Figures 2 and 7) is attached to inner body 101 by which it may be rotated.

Liquid coolant may be supplied to the grinding chamber 24 by a motor-operated pump 111 shown in Figure 1 located within the supporting base 10. The coolant is pumped from the reservoir 112, also located in the base, to the grinding chamber 24 through pipe 113 shown in Figures 1 and 4, whence it flows onto the arcuate working face of cup wheel 15 and thence over the work. After use, the coolant, which has been spattered within the inner body 101 of grinding chamber 24, collects in the bottom of the grinding chamber and flows through outlet channel 114 (Figures 1, 2, 6 and 7) and the trough 115 on the side of cross-feed slide 13, and thence through pipe 116 (part of which is seen within the open base of Figure 1) through suitable settling tanks or filters (not shown) back to reservoir 112.

Figure 8 illustrates a C-shaped disk or baffle plate 117 which may advantageously be used in grinding chamber 24. It is placed in the grinding chamber so as to rest on the upper metal strip 107, and rotates with the inner body 101 as the lens is swung across the cup wheel 15. The baffle plate 117 eliminates any spatter of coolant if cover 97 is slightly ajar, and even permits the cover to be opened while the machine is operating for inspection of the grinding with little or no loss of coolant.

The shaft housing 17 also carries a chamber 120 which contains the operating mechanism and associated wiring for the push button switches 121 and 122 and the toggle switch 123 (Figure 1). Switch 121 is a start switch and 122 a stop switch for the grinding wheel motor 22, and switch 123 controls the motor of coolant pump 111.

The cross-feed slide ways 61 on base 10 and the tool carriage ways 66 on cross-feed slide 13 may also be protected from dirt and other foreign material. Cover plates 126, 127 and 128 (Figures 1, 2 and 6) protect ways 61 and slide over one another in conventional telescope fashion as cross-feed slide 13 is run back and forth. Cover plate 129 (Figure 4) lies between ways 66 on the cross-feed slide 13 and protects screw 69 and other interior parts when the tool carriage 14 is run away from the axis of swing 39.

The operation of the machine, once it has been properly installed in the laboratory or shop where it is to be used and "zeroed" as described below, is extremely simple. The operator is usually furnished with a blocked lens blank, and with a work sheet giving instructions as to the base curve and cross curve of the lens surface to be generated thereon and as to the amount of glass

to be removed to give the desired finished thickness of the lens. The operator should have available a chart, supplied with the machine, telling the proper position of the cup wheel 15 for generating any lens surface within the range of the machine. This chart gives the above described longitudinal setting of the cup wheel 15 in terms of the sum of the readings of the coarse linear scale 82 and the micrometer dial 84 associated with the hand wheel 68 of tool carriage 14, and the transverse setting in terms of the sum of the readings of the linear scale 87 and the micrometer dial 89 associated with the hand wheel 63 of cross-feed slide 13. The operator then adjusts the hand wheel 68 to give the longitudinal setting indicated by the chart, and the hand wheel 63 to give the corresponding transverse setting. The blocked lens is then centered in the chuck and securely clamped in position. The operator then turns the hand wheel 34 associated with the work carriage 12 to advance the lens toward and introduce it into the grinding chamber 24, using the handle 109 to put the opening 102 in line, and brings the high point of the lens blank gently into contact with the arcuate working face of the cup wheel 15, at its rear side. This may readily be accomplished by swinging the turntable back and forth a little while slowly turning the hand wheel 34. The thumb screw 38 is then loosened; the dial 37, which is preferably calibrated in one-tenth (0.1) millimeters, is rotated until its reading with the index pointer 39 is zero; and the thumb screw 38 is tightened. The operator then backs the lens slightly away from the cup wheel; makes a trial swing of the lens past the cup wheel to determine an arc long enough to insure complete surfacing of the lens, but short enough to prevent the lens from striking the wall of the cup wheel; and sets the adjustable stops of the cup wheel; and sets the adjustable stops 52 to limit the arc of swing of the turntable 11 accordingly. This completes the settings that are needed preparatory to generating the desired lens surface.

The operator first positions the turntable at one extreme of its swing, with the fixed stop 54 engaging one of the adjustable stops 52. He then starts the grinding wheel motor 22 by means of the start switch 121 and the coolant pump by means of the switch 123, and turns the hand wheel 34 until the dial 37 indicates the desired depth of cut. The entire amount of glass to be ground away may be removed in a single pass, but where a considerable amount of glass is to be removed, it is preferable to make a number of passes taking off about one mm. per pass. The operator then manually swings the turntable 11 until the fixed stop 54 engages the other adjustable stop 52. The turntable is then swung back, the hand wheel 34 advanced for the next cut, and the swinging operation repeated. One final pass of the lens blank across the wheel with only 0.1 or 0.2 mm. of glass being removed insures a super-smooth surface on the lens blank.

The generation of the lens surface is now completed, and the operator stops the motors, retracts the lens blank from the grinding chamber and removes it from the chuck. A skilled operator can carry out the entire setting and generating above described in two or three minutes. The generating time averages less than one minute.

It will be apparent that a locking device may be provided to lock hand wheel 34 in any desired position and also that a stop, with or without a

graduated scale device, may be provided to limit the movement of work carriage 12 along its ways on turntable 11 in order to obtain correct lens thickness. Neither of these devices is essential to the proper operation of the machine and hence they are not shown.

A diamond impregnated cup wheel of the type described is very durable, and should generate many thousands of lens surfaces before replacement is required. Nevertheless, some wear does take place on the cup wheel 15, and the machine should accordingly be "zeroed" from time to time to compensate for this wear. Such "zeroing" is also necessary when the machine is first put into service and when a new cup wheel is installed.

In order to reset the zero reading of dial 84 on hand wheel 68 of tool carriage 14, governing the longitudinal setting, a special gauge is provided having a cylindrical shank which fits snugly into the above-described gauge hole 29. The upper end of this shank carries a C-shaped extension, the upper free side of which forms a laterally directed arm that may conveniently be introduced into grinding chamber 24 through the slot 104. The end of said free arm is formed with a plane gauging surface wide enough to engage both sides of the cup wheel and parallel to the axis of the cylindrical shank. This plane gauging surface is located at a predetermined distance to the left of the axis of the shank and hence of axis 30, equal to the hereinafter described radius of curvature of the arcuate working face of cup wheel 15 plus an arbitrary feeler gauge thickness. The cup wheel 15 is then manipulated by means of the hand wheels 63 and 68 so as to bring both sides of its arcuate working face just tangent to said plane gauging surface, thus aligning the gauge. The wheel is then backed away until the feeler gauge can just be inserted, thus taking up backlash and bringing the center of curvature of the wheel working face exactly over the axis of swing 30. The set screw 85 is then loosened, dial 84 set to zero, and again locked by the set screw.

In order to reset the zero reading of the transverse dial 89 associated with the hand wheel 63 of cross-feed slide 13, the following procedure may be followed. A lens blank is chucked in the lens chuck, introduced into the grinding chamber, and any convenient surface, preferably with a fairly strong cylindrical curve, is generated. In order to prevent interference by the grinding chamber, the lens is then backed out and reintroduced into the grinding chamber through the slot 104. The cup wheel 15 is then adjusted transversely by means of the hand wheel 63, until the generated lens surface, when oscillated by swinging the turntable 11, just touches both the front and the rear sides of the arcuate face of the cup wheel. At this point, the adjustment of the cup wheel 15 is stopped, the set screw 90 loosened, the dial 89 set to zero, and again locked in position by the set screw.

When both of these simple "zeroing" operations have been completed, the cup wheel 15 is positioned with great precision so that, when the scales 82 and 87 and the dials 84 and 89 all read zero, the center of curvature in the base plane of the arcuate working face of the cup wheel is located exactly over the axis of swing 30. Because the axis of swing 30 is fixed in position, this "zeroing" operation can be performed with greater precision than is practicable with prior machines in which the zero position of the cup

wheel must be established with reference to a point which is itself variable.

In commercial machines manufactured in accordance with this invention, I have used cup wheels having a pitch radius of 1.34375" and a radius of curvature of the arcuate working face of 0.1250". I have found that, in normal use in generating lenses of various sizes, both convex and concave, the wheel wear takes place quite uniformly, so that said radius of curvature remains substantially constant, while the center of curvature moves back axially of the cup wheel. Under these conditions, a "zeroing" operation such as above described not merely compensates for wheel wear, but restores the machine to practically the same degree of accuracy that it initially possesses with a new wheel.

Figure 9 is a diagram illustrating the method of this invention and also the manner of arriving at the above described longitudinal and transverse settings of the machine. The mutually perpendicular coordinate axes $X-X'$ and $Y-Y'$ lie in the base plane and intersect at the point S, which is the intersection of the axis of swing 30 with the base plane. The axis $X-X'$ is so chosen as to be parallel to the cup wheel axis 80, and hence the axis $Y-Y'$ is perpendicular to the axis 80. These relationships hold true regardless of the position at which the cup wheel 15 may be located.

Following conventional nomenclature, the quadrant at the right of axis $Y-Y'$ is designated as quadrant I, and the quadrant at the left is designated as quadrant II. The cup wheel 15 is shown in four illustrative positions, two with its active rear side located in quadrant I and two in quadrant II, and is shown in section taken in the base plane. Lenses 131, 132, 133 and 134 are shown respectively engaging the cup wheel in each of these four positions. Each of these lenses is illustrated as having a curved face in contact with the cup wheel at the lens axis and of the appropriate curvature for generation by the cup wheel; and the opposing face is, for convenience, shown plane.

The lenses 131 and 132 are shown in top plan, and the lenses 133 and 134, for clarity, in section in the base plane. Connected with each of the lenses 131 and 132 by projection lines is a side elevation of the lens, indicated, respectively, by the reference characters 131' and 132'. Similarly connected with each of the lenses 133 and 134 is a sectional view of the lens, indicated by the reference characters 133' and 134', and taken in a plane at right angles to the base plane and passing through the lens axis.

It will be noted that the lenses 131 and 132 are convex, and the lenses 133 and 134 are concave. As will be understood by those skilled in the art, all lenses generated in quadrant I are convex, and all lenses generated in quadrant II are concave, with the exception of the saddle-back lenses discussed below.

The base curve of lens 131 is indicated by the reference numeral 131b, and the cross curve by the reference numeral 131c; and similar designations are applied to the base and cross curves of the other three lenses.

The base curve 131b is a true circular arc, and its radius, indicated as R_b , is the distance between the point S (axis of swing 30) and the point, marked A, of tangency between the lens and the arcuate working face of the cup wheel. It will be evident that the radius SA, when extended, will pass through the center of curva-

ture of the arcuate working face of the cup wheel, this center point being marked V. The distance VA is thus the radius of curvature of the working face of the wheel, and is denoted by "r."

The point V lies on what may be called the pitch circle of the cup wheel, and its perpendicular distance from the cup wheel axis 80 is equal to the pitch radius of the cup wheel, indicated as P. The point V is thus the intersection of the cup wheel pitch circle with the base plane. The distances marked "B" and "C" in Figure 9 are, respectively, the distances of the point V from the axes Y—Y' and X—X'.

The cross curve 131c as generated is not a true circle, and the cross radius R_c indicated in Figure 9 is correct only where the generated cross curve intersects the lens axis. The axis of the cup wheel intersects the line SV at point W, and the cross radius R_c is the distance WA. It will thus be seen that the cross curve is dependent upon the pitch radius P of the cup wheel.

It will be evident that precisely similar considerations apply to the base curves 132b, 133b and 134b, and to the cross curves 132c, 133c and 134c, as well as to all toric lens surfaces capable of being generated by my method and machine.

When the cup wheel 15 is set with its axis 80 coinciding with the axis X—X', and hence intersecting the axis of swing 30, the cross radius R_c will equal the base radius R_b , and a true spherical lens surface will be generated. The distance C will then of course be equal to the pitch radius P of the cup wheel 15. It will be evident that this is a special case of the generation of a toric lens surface.

It is also to be noted that the machine herein described may be used for the generation of saddleback lenses. Such lenses have a surface which is convex in one plane and concave in the other, and while they are not often used, there is nevertheless some demand for them. By having the lens blank make contact with the front side the arcuate working surface of the cup wheel 15 instead of the rear side as described above, a lens with a convex base curve and a concave cross curve may be produced in quadrant I and a lens with a concave base curve and convex cross curve may be produced in quadrant II.

The angle between the axis X—X' and the line SV from the axis of swing passing through the point of tangency of the cup wheel 15 and lens, is denoted in Figure 9 as α . It is evident that, knowing the size of the angle α , the distances B and C may be computed from the following equations:

For convex lenses:

$$B = (R_b + r) \cos \alpha \quad (1)$$

$$C = (R_b + r) \sin \alpha \quad (2)$$

And, for concave lenses:

$$B = (R_b - r) \cos \alpha \quad (3)$$

$$C = (R_b - r) \sin \alpha \quad (4)$$

It has been customary in this art to determine the value of α from the following equations:

For convex lenses:

$$\sin \alpha = \frac{P}{R_c + r} \quad (5)$$

And, for concave lenses:

$$\sin \alpha = \frac{P}{R_c - r} \quad (6)$$

The values of "P" and "r" are of course known from the dimensions of the cup wheel, and the

values of R_b and R_c are determined by the toric lens surface which it is desired to produce, so that the foregoing six equations permit a complete solution of any toric lens generating problem. Unfortunately, however, this solution is inaccurate, and furnishes only a very rough approximation, because it assumes that a circular cross curve is generated, whereas, as pointed out above, the generated cross curve actually is not circular, but approximates an ellipse. Equations (5) and (6) are thus correct only for the value of R_c where the generated cross curve intersects the lens axis.

With prior art toric lens generating methods and machines, it has been common practice to apply a rule-of-thumb compensation for this elliptical error. One such rule-of-thumb, used for convex toric lenses, is to subtract $\frac{1}{8}$ of a diopter from the desired cross curve in diopters for each diopter of cylinder power of the desired lens, and use this lower figure in making the cross curve setting of the generating machine. The cylinder power of a lens is the difference between the cross curve and the base curve, both expressed in diopters. Such a rough compensation was satisfactory with prior machines, because the machines were only intended to produce an approximate toric surface, that is to say, to do rough generating. Nor could they do any better, because the unavoidable inaccuracies of the angular settings employed as above described, made precise machine settings and precise compensation practically impossible.

With the method and machine of the present invention, much more accurate work is readily obtainable, because the only adjustments are two mutually perpendicular rectilinear movements of the cup wheel axis. It is well known in machine tool practice that rectilinear adjustments can easily be made to a much higher degree of precision than can angular adjustments, given equal care in both cases.

It is therefore possible, with my method and machine, to carry out precise generation of toric lens surfaces which are of such perfection that they may be directly finished by a lapping operation using fine abrasive, and then polished, without first employing the heretofore necessary coarse lapping operation. This of course greatly reduces the total time required for producing a finished lens. In order to do this, it is necessary to have compensated machine settings of much greater accuracy than can be obtained by applying any rule-of-thumb to the settings resulting from the use of equations (5) and (6).

Compensated settings for use with my method and machine can be obtained in several ways. One way, requiring a good deal of time but giving wholly satisfactory results, is by a process of trial and error. With this process, large numbers of lenses are ground with different cross curve settings, the base curve being held constant since it is an exact circle; the corresponding fining times are determined, and the cross curve setting that gives the minimum fining time for a given lens is selected for future use when making such a lens. Another way is by mathematical solution of the problem. This is feasible, but the precise mathematical equations I have thus far succeeded in obtaining, are extremely complex, and their solution is correspondingly long and difficult. The most practical way appears to be by a combination of experimental results obtained by trial and error and a graphical analysis based on these experimental results.

The manner of obtaining the compensated settings forms no part of the present invention, and need not be discussed further. What is important here is that this invention permits an accuracy of setting heretofore unobtainable, and thus justifies the compilation and permits the use of a chart of compensated settings, resulting in a wholly new degree of precision of toric lens surface generation by a cup wheel grinding operation.

Regardless of the method employed for determining the compensated settings, it will now be apparent that these may be expressed in terms of the correct distances B and C for each desired combination of base and cross curves within the range of the machine. It is contemplated that such settings will be furnished with each machine, in chart form and expressed in terms of the graduations on scale 82 and dial 84 for the axial or longitudinal setting "B," and of the graduations on scale 87 and dial 89 for the transverse setting "C." For any desired combination of base and cross curves, it will then only be necessary for the operator to look up on this chart the corresponding machine settings, and set the machine as above described.

The range of base and cross curve combinations which may be produced in my above-mentioned commercial machine, constructed as herein described, is graphically represented in Figures 10 and 11, which range is determined, of course, by the usual limitations such as lens diameter, wheel dimensions and lens chuck and chuck shaft diameters. Figure 10 shows the range of possible curve combinations for convex lenses, and Figure 11, the range for concave lenses. The radii of curvature of the base curves are represented by the ordinates, and the radii of curvature of the cross curves are represented by the abscissas, of each diagram. All measurements are in diopters. The cross-hatched areas all represent lens combinations that are within the capabilities of my machine as it is currently being commercially marketed. The largest similarly cross-hatched area in each diagram, approximately triangular in outline, represents and includes the toric lens sizes ordinarily encountered in ophthalmic shops. The areas cross-hatched in the opposite sense and shaped approximately like smaller acute triangles, represent lens sizes that are seldom, if ever, encountered. The curved areas cross-hatched in both senses, represent lens sizes that are occasionally required.

It will be apparent to those skilled in the art that my method permits a single machine to handle an unusually wide range of lens sizes, covering all of the commonly used convex and concave toric lens surfaces. Of particular importance to the prescription shop is the fact that this is accomplished with no change of brackets, mountings, scales, grinding wheels and like paraphernalia, in changing over from convex to concave work or vice versa.

To those skilled in the art, it will also be apparent that the method and machine herein disclosed, while using known principles and structures, is wholly novel in the art of toric lens grinding. Two simple adjustments by means of hand wheels 63 and 68 enable the operator to set the machine for any desired combination of base and cross curves, within wide limits. There is no complicating angular adjustment such as is found in the methods and machines heretofore known in the art. In prior machines, an angular

adjustment of the tool axis has been required to fix the angle at which the lens blank is to meet the arcuate working face of the cup wheel. The herein-disclosed method and machine obtains this angular adjustment as an inherent result of fixing the two rectilinear dimensions B and C (Figure 9).

As pointed out above, the foregoing simplicity of adjustment is of extreme importance when regarded in the light of compensation for the elliptical error, and it is also of prime importance in connection with the matter of cup wheel wear. Referring back to the description of the "zeroing" operation, it will be evident that the point V of Figure 9 is the point that is brought exactly over the axis of swing 30, to point S, when "zeroing." Since the point V is also the point from which the dimensions B and C are taken, my method and machine provides a single reference point for all settings, adjustments and computations, permitting a maximum of precision to be easily obtained.

Although the method and machine disclosed herein provide a lens blank holder adapted to swing about the axis 30 during the generating operation, and an abrasive cup wheel which is mounted for longitudinal and transverse adjustments with respect to the said axis of swing and to remain stationary during the generating operation, it is to be understood that the invention includes the reverse arrangement in which the lens blank holder remains stationary while the cup wheel swings about a fixed axis of swing during the generating operation. The preferred arrangement, however, permits mounting the relatively light lens blank holder for swinging motion about the axis 30 while the heavier rotating cup wheel with its motor needs provision for adjustment in rectilinear paths only.

Although I have thus described my invention in its preferred form, as required by the patent statutes, I desire to be limited only by the scope of the appended claims.

I claim:

1. In the method of generating a toric lens surface by the interaction of a non-rotating lens blank with a rotating cup type grinding wheel having an arcuate working surface on its annular edge, wherein said lens blank and cup wheel members have their axes in a common plane and one member is swung past the other about an axis of swing perpendicular to said common plane; the improvement which consists in fixing said axis of swing of said one member; adjusting said other member, while maintaining its axis in said common plane, to a predetermined position relative to said fixed axis of swing, by moving said other member longitudinally of its axis and by moving said other member transversely of its axis in a direction perpendicular to its axis, said longitudinal and transverse movements being wholly independent of one another; moving said one member to a predetermined radial distance from said axis of swing to determine the depth of cut; and swinging said one member about said axis of swing in contact with and across the face of said other member; whereby the shapes of both the base curve and the cross curve of said toric lens surface are determined solely by said longitudinal and transverse adjustments and the dimensions of said cup wheel.

2. In the method of generating a toric lens surface by the interaction of a non-rotating lens blank with a rotating cup type grinding wheel having an arcuate working surface on its annular edge, wherein said lens blank and cup wheel

members have their axes in a common plane and said lens blank is swung past said cup wheel about an axis of swing perpendicular to said common plane; the improvement which consists in fixing said axis of swing of said lens blank; adjusting said cup wheel, while maintaining its axis in said common plane, to a predetermined position relative to said fixed axis of swing, by moving said cup wheel longitudinally of its axis and by moving said cup wheel transversely of its axis in a direction perpendicular to its axis, said longitudinal and transverse movements being wholly independent of one another; moving said lens blank to a predetermined radial distance from said axis of swing to determine the depth of cut and the generated lens thickness; and swinging said lens blank about said axis of swing in contact with and across the face of said cup wheel; whereby the shapes of both the base curve and the cross curve of said toric lens surface are determined solely by said longitudinal and transverse adjustments and the dimensions of said cup wheel.

3. A lens grinding machine adapted for the generation of toric lens surfaces, comprising a supporting base, a turntable mounted on said base for oscillatory movement about an axis of swing fixed with respect to said base, a carriage mounted on said turntable for rectilinear movement radially toward and away from said fixed axis of swing, a second carriage adjustably mounted on said base for rectilinear movement in two mutually perpendicular longitudinal and transverse directions, a cup type grinding wheel having an arcuate working surface on its annular edge mounted for rotation on one of said carriages, driving means for rotating said cup wheel, and a lens blank holder non-rotatably mounted on the other of said carriages, said cup wheel and said lens blank holder having their axes located in the same plane normal to said fixed axis of swing, whereby the shapes of both the base curve and the cross curve of the generated toric lens surface are determined solely by said longitudinal and transverse adjustments and the dimensions of said cup wheel.

4. A lens grinding machine adapted for the generation of toric lens surfaces, comprising a supporting base, a turntable mounted on said base for oscillatory movement about an axis of swing fixed with respect to said base, a carriage mounted on said turntable for rectilinear movement radially toward and away from said fixed axis of swing, a lens blank holder non-rotatably mounted on said turntable carriage, a tool carriage adjustably mounted on said base for rectilinear movement in two mutually perpendicular longitudinal and transverse directions, a cup type grinding wheel having an arcuate working surface on its annular edge mounted for rotation on said tool carriage, and driving means for rotating said cup wheel, said lens blank holder and said cup wheel having their axes located in the same plane normal to said fixed axis of swing, whereby the shapes of both the base curve and the cross curve of the generated toric lens surface are determined solely by said longitudinal and transverse adjustments and the dimensions of said cup wheel.

5. A lens grinding machine adapted for the generation of toric lens surfaces, comprising a supporting base, a turntable mounted on said base for oscillatory movement about an axis of swing fixed with respect to said base, a carriage mounted on said turntable for rectilinear move-

ment toward and away from said fixed axis of swing along a line passing through said axis of swing perpendicular thereto and extending on either side thereof, a lens blank holder non-rotatably mounted on said turntable carriage, a cross-feed slide adjustably mounted on said base for rectilinear movement along a fixed line spaced from said axis of swing at one side thereof and lying in a plane normal thereto, a tool carriage adjustably mounted on said cross-feed slide for rectilinear movement in a direction perpendicular to the movement of said cross-feed slide, a cup type grinding wheel having an arcuate working surface on its annular edge mounted for rotation on said tool carriage, and driving means for rotating said cup wheel, said lens blank holder and said cup wheel having their axes located in the same plane normal to said fixed axis of swing, and said tool carriage being so constructed and arranged with reference to said turntable as to be capable of positioning said working surface of the cup wheel either on the same side of said fixed axis of swing as said cross-feed slide line or on the opposite side, whereby either convex or concave toric lens surfaces may be generated and the shapes of both the base curve and the cross curve of the generated toric lens surface are determined solely by said cross-feed slide and tool carriage adjustments and the dimensions of said cup wheel.

6. In a lens grinding machine adapted for the generation of toric lens surfaces, of the type having a non-rotating lens blank holder and a cup type grinding wheel with their axes located in a common plane, one of said lens holder and cup wheel members being mounted for swinging movement across the face of the other member about an axis of swing normal to said common plane, and said cup wheel being secured to a shaft mounted for driving rotation on a tool carriage, in combination, a grinding chamber for enclosing said cup wheel and confining a supply of liquid coolant, comprising a receptacle having portions of its side wall cut away, means for securing said receptacle to said tool carriage, a cylindrical inner body rotatably mounted within said receptacle and having a hole in its cylindrical wall adapted to admit said lens blank holder within said inner body, an annular flexible seal affixed to the edge of said hole and having an orifice therethrough of substantially the diameter of said lens blank holder, a slot extending completely around said inner body from points on either side of said hole and spaced therefrom, said slot being of sufficient width to admit said cup wheel shaft within said body, two flexible aprons affixed one along the upper edge and the other along the lower edge of said slot, said aprons conforming closely to the cylindrical wall of said inner body and being of sufficient width to overlap and close said slot, and finger-like guides secured to said grinding chamber on either side of said cup wheel shaft and adapted to hold said flexible aprons overlapping to keep said slot closed during rotation of said inner body with respect to said cup wheel shaft and said grinding chamber.

7. In a lens grinding machine adapted for the generation of toric lens surfaces, of the type having a non-rotating lens blank holder and a cup type grinding wheel with their axes located in a common plane, one of said lens holder and cup wheel members being mounted for swinging movement across the face of the other member about an axis of swing normal to said common

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plane, and said cup wheel being secured to a shaft mounted for driving rotation on a tool carriage, in combination, a grinding chamber for enclosing said cup wheel and confining a supply of liquid coolant, comprising a substantially cylindrical receptacle having the major portion of its side wall cut away to leave a cylindrical lower band extending upward and a cylindrical upper band extending downward toward and around said cup wheel, a sleeve projecting laterally from said receptacle and adapted to slip over said cup wheel shaft and be secured to said tool carriage, a cylindrical inner body rotatably mounted between and within said upper and lower bands and having a hole in its cylindrical wall adapted to admit said lens blank holder within said inner body, an annular flexible seal affixed to the edge of said hole and having an orifice therethrough of substantially the diameter of said lens blank holder, a slot extending completely around said inner body from points on either side of said hole and spaced therefrom, said slot being of sufficient width to admit said cup wheel shaft within said body, two flexible

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aprons affixed one along the upper inner edge and the other along the lower inner edge of said slot, said aprons conforming closely to the cylindrical wall of said inner body and being of sufficient width to overlap and close said slot, and finger-like guides secured to said grinding chamber on either side of said cup wheel shaft and adapted to hold said flexible aprons overlapping to keep said slot closed during rotation of said inner body with respect to said cup wheel shaft and said grinding chamber.

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REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
20 1,401,832	Taylor -----	Dec. 27, 1921
1,800,308	Maynard -----	Apr. 14, 1931
1,984,074	McCade -----	Dec. 11, 1934
2,000,216	Carlson -----	May 7, 1935
2,065,103	Simpson -----	Dec. 22, 1936