Jan. 4, 1949. J. H. JEFFREE 2,458,384

GRINDING OF LENSES OR OF DIES THEREFOR

Filed March 9, 1945 3 Sheets-Sheet 1

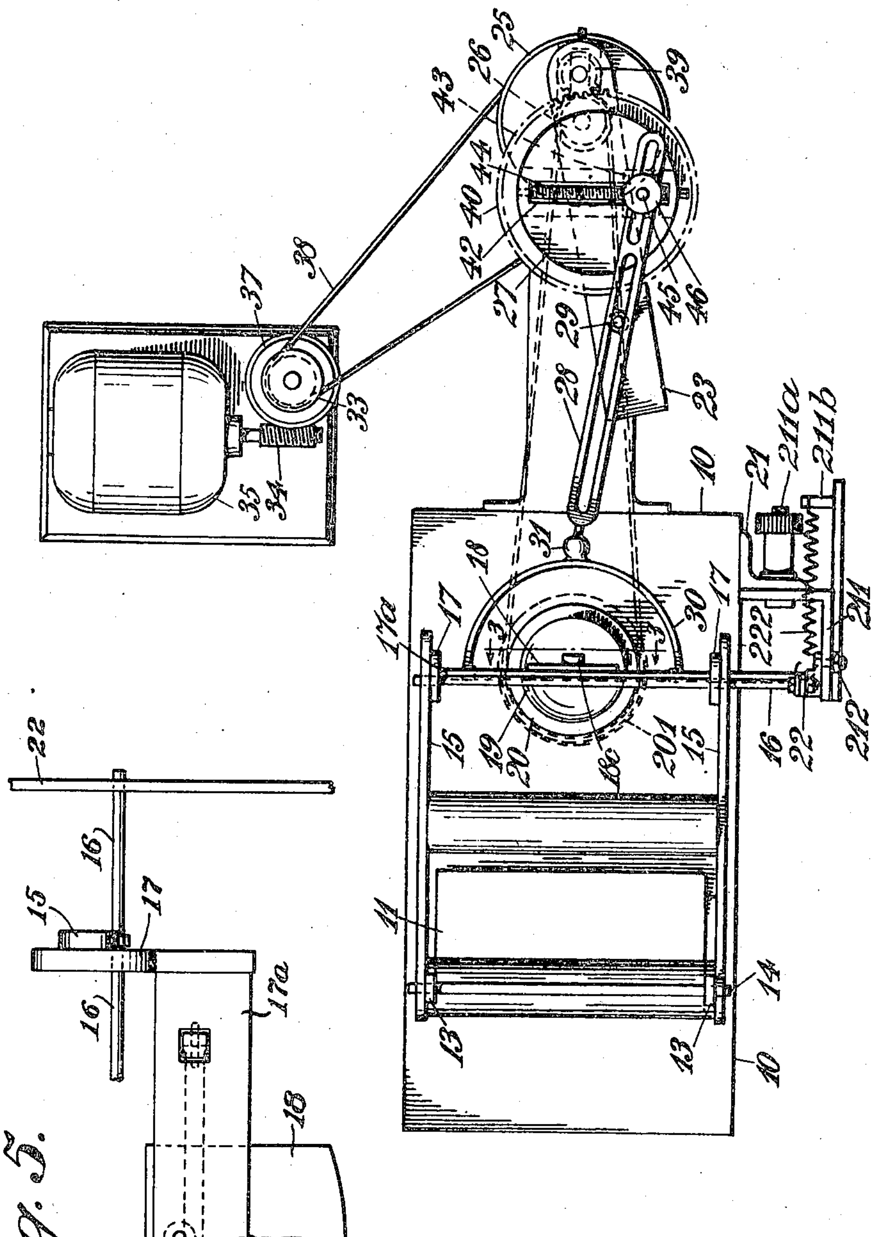

Fig. 1.

Fig. 5.

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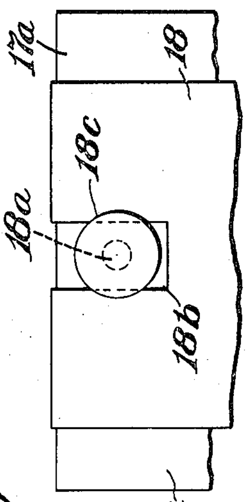

Fig. 3.

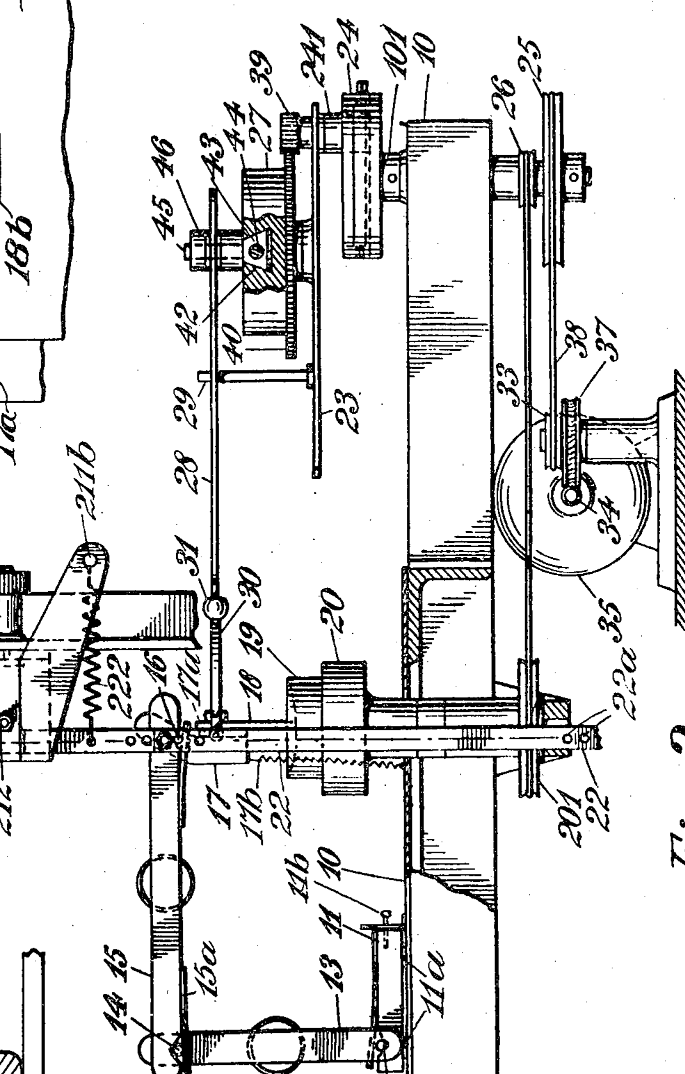

Fig. 2.

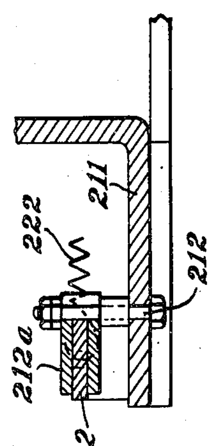

Fig. 4.

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GRINDING OF LENSES OR OF DIES THEREFOR

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Fig. 6.

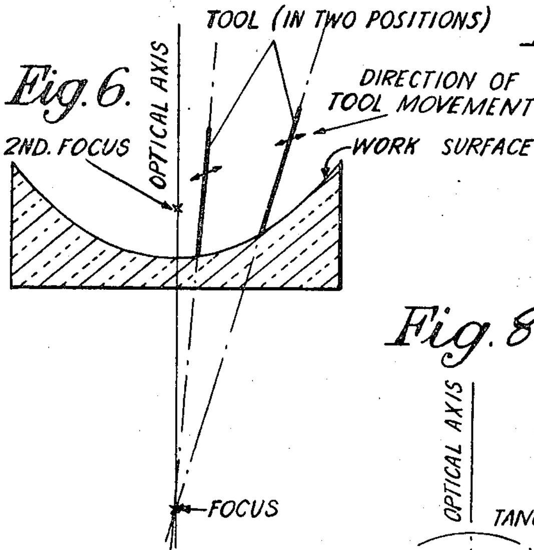


Fig. 7.

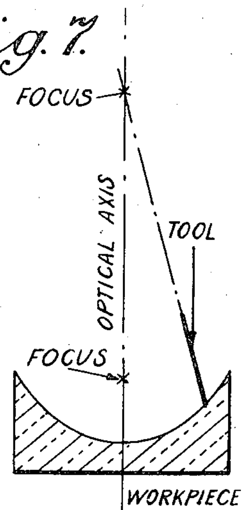


Fig. 8.

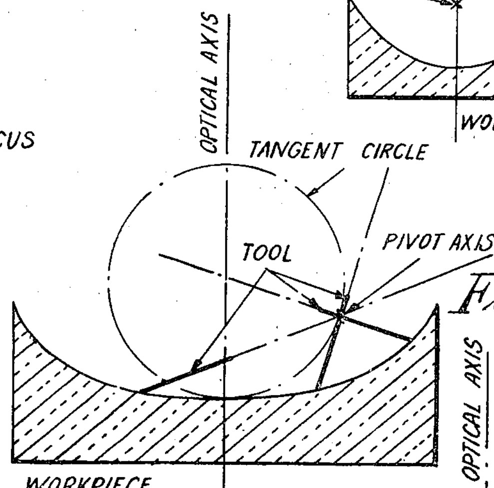


Fig. 9.

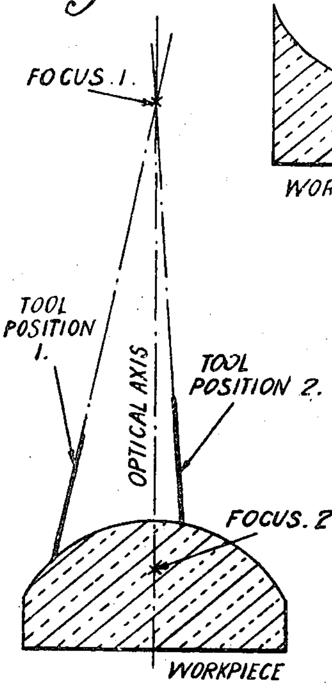


Fig. 10.

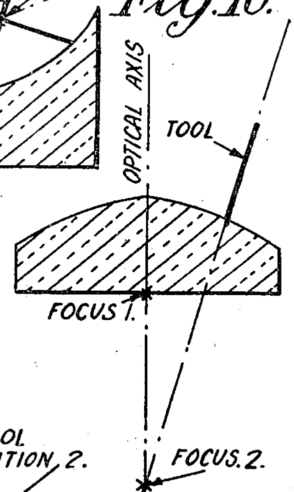
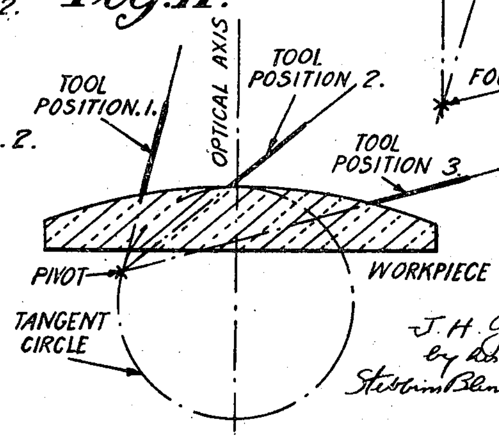


Fig. 11.



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UNITED STATES PATENT OFFICE

2,458,384

GRINDING OF LENSES OR OF DIES THEREFOR

John Henry Jeffree, Cobham, England, assignor to Combined Optical Industries Limited, Slough, England, a British company

Application March 9, 1945, Serial No. 581,730
In Great Britain October 26, 1943

Section 1, Public Law 690, August 8, 1946
Patent expires October 26, 1963

2 Claims. (Cl. 51—58)

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This invention relates to improved methods and apparatus for grinding and/or polishing curved surfaces of various kinds including aspheric surfaces, particularly lenses and the dies used for the moulding of lenses from transparent plastics, as described for example in Kingston United States Patent No. 2,314,838, dated March 23, 1943. The word "lens" in this specification is to be understood to include a mirror, where the context permits.

The production of spherical or cylindrical optical surfaces, and the grinding of lenses which give cylindrical and spherical corrections are well known. While, however, various kinds of optical systems are susceptible of improvement by the inclusion therein of aspheric lens or mirror surfaces, the production of such surfaces of sufficient precision by known methods is so difficult that little use of the same in optical systems has been made hitherto. The objects of this invention comprise the provision of methods and apparatus whereby aspheric as well as spherical surfaces can be ground and polished effectively and with considerable precision. The term "aspheric" as used herein should be understood to include surfaces of revolutions such as paraboloids, ellipsoids and hyperboloids (generally though not exclusively prolate in form) and also to include surfaces having curvatures of third order or of higher orders, which are symmetrically curved relative to an axis, including surfaces which are concave at the middle and convex near the periphery or vice versa. The present invention can be utilized in all such cases, its simplest application however being to the grinding and polishing of prolate surfaces of revolution which can be rotated on their axes of symmetry during the process.

In accordance with the method herein described, the workpiece is first roughly formed to the desired surface (such for example as one of the surfaces of revolution), and this is rotated about its axis of symmetry. This surface is scraped (or, when the polishing stage is reached, it may be polished), by the edge of a lapping tool similar to a profile cutter which is initially shaped roughly to fit the surface. This tool is held under sufficient pressure against the surface acted upon while it is reciprocated back and forth across the surface, being at the same time tilted during its traverse in such manner that its edge tends to describe the desired curve. This is accomplished in the case of prolate surfaces of revolution by causing the tool to swing about a focus (the more distant one) of the surface, while permitting it

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sufficient movement in its own axial direction, i. e., in the direction of the axis of the curve imparted to the tool edge by grinding, to maintain contact between the edge and the surface. In the formation of surfaces other than prolate surfaces of revolution the axis about which the tool is caused to swing will not pass through a focus of the curved surface, but will be otherwise determined, as is later explained.

To render the grinding effective, an abrasive-lubricant composition, such as a suspension of finely divided mineral matter in a viscous liquid such as oil or glycerine is preferably used on the workpiece, and both the surface of the workpiece and the edge of the tool are abraded thereby to attain their final shape appropriate to their initial shape and the relative movements of workpiece and tool. The result of the above is that when the desired shape of workpiece surface is attained the tool edge will continue to fit and make contact therewith, with considerable accuracy at the central portion of the tool edge; and with an accuracy at other portions of the tool edge which, in some cases, is not quite so great.

Other features of the improved method will, preferably, include the variation of the traverse of the tool edge across the workpiece, i. e. the continual displacement of the end positions of the tool edge, back and forth, during its reciprocation, to prevent the possibility of slight ridges being formed on the work, as might happen at the limits of movement of the edge if it always changed its direction from forward to back or vice versa at the same points; and also the carrying out of the desired movement of the tool, in such manner as to cause its edge continually to sweep the abrasive lubricant towards the centre of the workpiece. This can be done, in suitable cases, by causing the traverse of the tool to be slightly off centre, that is, by horizontal adjustment of the tool in its own plane.

The manner of practising the method will be more clearly understood by the description of apparatus, the operation and adjustment of which may be utilized in the practice. One form of apparatus embodying the invention so far as it relates to apparatus, is illustrated in the accompanying drawings, in which

Figure 1 is a plan view of such apparatus,

Figure 2 is a front elevation thereof, shown partly in section,

Figure 3 is a partial vertical section on line 3—3 of Figure 1, on an enlarged scale,

Figure 4 is a partial section along the plane of line IV—IV of Figure 2;

Figure 5 is a partial elevation looking from the left in Figure 2;

Figure 6 indicates diagrammatically the mounting of the workpiece for grinding a hyperboloid (concave) surface;

Figure 7 indicates diagrammatically the mounting of the workpiece for grinding a concave ellipsoid (prolate) surface;

Figure 8 indicates diagrammatically the mounting of the workpiece for grinding a concave ellipsoid (oblate) surface;

Figure 9 indicates diagrammatically the mounting of the workpiece for grinding a prolate convex hyperbolic surface;

Figure 10 indicates diagrammatically the mounting of the workpiece for grinding a prolate convex ellipsoid surface; and

Figure 11 indicates diagrammatically the mounting of the workpiece for grinding an oblate convex ellipsoid surface.

Referring to the drawings, substantially upright frame members **13** are pivoted at their lower ends on rod **12** mounted on block **11**, which is secured on the fixed horizontal table **10**. Members **13** carry a transverse pivot rod **14** at their upper ends, on which are pivoted two substantially horizontal frame members **15**, these arms **15** being held against this pivot rod, in the form of construction illustrated, by leaf springs **15***a*. Members **15** carry at their opposite ends a transverse pivot rod **16** on which are pivoted arms **17** which have, integral therewith or rigidly secured thereto, a tool-supporting transverse member **17***a*.

The tool **18** is secured to member **17***a*, the tool being, in the form of construction illustrated, a flat metal sheet, the lower edge of which is shaped roughly to fit the curved surface which is to be ground, different tools being provided for the various surfaces such as hyperboloids, ellipsoids, etc., which are to be ground. As is indicated in Figure 3, the tool may be secured to member **17***a* by means of a screw **18***a* passing through a vertical slot **18***b* in the tool, and thence into member **17***c* the slot being wider than the shank of the screw, to permit some horizontal adjustment of the tool in its own plane (for a purpose hereafter explained), before tightening the screw, the head of which **18***c* is wide enough to have a firm bearing on the tool on both sides of the slot. The lower edge of the tool rests on the preformed surface of the workpiece **19**, mounted on a workpiece holder **20** which is rotated about its vertical axis by driving pulley **201**. The workpiece may be, for example, a steel die which is to be ground and polished to a desired curved surface for use in the moulding of optical lenses from plastics, the curved surface shown in the drawings being ellipsoidal.

The tool is supported for the desired movements as follows. An upright standard **21** is secured to the fixed table **10** at one side thereof. This is shown broken away, but may extend down below the level of the table for a required distance of several feet. Bracket **211** is secured to this standard at a desired level above (or below) table **10** by means indicated as the screw **211***a*, the transverse flange of the standard being, conveniently, provided with a vertical slot, or suitably spaced openings, for this purpose. This bracket carries a bolt **212** extending transversely beyond its inner surface, and may be slidably engaged, on one of its lateral surfaces, by a vertical bar **22** having perforations **22***a* extending therethrough at various points. The edge of this bar is in sliding contact with bolt **212**, fitting in a slotted guide **212***a* thereon, with which it is held resiliently in contact, as by means of spring **222**, which may be removably extended from bar **22** to a pin **211***b* on bracket **211**. The pivot rod **16** is extended into one of the perforations **22***a* of bar **22**, so that the arms **15** are approximately horizontal when the lower edge of the tool is resting on the workpiece **19**. The tool **18** is rigidly secured to bar **22** to move therewith, as by securing one of the arms **17** to the bar **22** by a pin extended into another one of the perforations **22***a* of the bar.

An arrangement is therefore provided whereby the tool rests by gravity on the workpiece **19** and is free to move upwards and downwards in accordance with the curvature of the workpiece, as the bar **22** slides to a sufficient extent over the surface of the pivot bolt **212**. The tool will also swing backwards and forwards about bolt **212** as a pivot, as its lower end is swung backwards and forwards across the workpiece by the means presently to be described. The pivoted frame **13**, **15** serves to restrain movements of the template, and to prevent endwise movements, as will be discussed hereafter. If desired, the tool edge may be held down against the surface of the workpiece by spring pressure in addition to gravity, as by means of the spring **17***b* indicated.

The tool and the work are mutually abraded until, from an original rough form, they reach forms that fit each other at all positions of the working stroke. Since their angular relation to each other varies over the stroke, according to a predetermined law, the curve they acquire is determined by the law of this variation, as well as by the rough curve from which they started. The case is analogous to that of ordinary grinding of spheres together, where the curvature reached depends partly on the initial rough forms of tool and work, but the kind of curve (sphere) is that whereby the tool and work can fit each other in any position. In my machine, however, it is a surface and an edge that must fit, instead of two surfaces, and the conditions under which they fit are restricted by the position of the pivot controlling the angular position of the tool.

The apparatus as shown is arranged for the grinding of a prolate surface of revolution, specifically an ellipsoidal surface. Such a prolate surface, approximating in section to a conic section, concave or convex, may be worked with the edge of a tool so moved that its plane always passes through a point on the axis of the surface at or near a focus (the more distant focus) of the said conic section. The pivot **212** must therefore be positioned approximately at such point. The inclination of the tool to the surface then varies with its traverse, from perpendicular at the central position to oblique at others. Clearly, the only type of curved surface capable of continually fitting an edge of a sheet so moved is a prolate one, that is, one with curvature decreasing away from the centre.

For various types of prolate surfaces, the pivot **212** must be positioned at other points than that shown, to lie approximately at a focus of the desired curvature, and for other types of curvature other adjustments must be made, as will be discussed hereafter.

The driving means will now be described, which provide for traversing the template edge across the workpiece, with the variation of stroke which has been referred to above as desirable. A vertical spindle **101** at the right hand end of table **10** is rotated from motor **35** by worm and wormwheel **34**, **37** and belt **38**, which passes over the pulley 33 on the spindle of the wormwheel and the driven pulley 25 on spindle 101. The workholder 20 is rotated by another belt which passes around pulley 26 on spindle 101 and pulley 201 on the workpiece holder.

Spindle 101 carries at its top a slotted disc 24 in which is secured, at an adjustable distance from its centre, an eccentric or crankpin 241. Horizontal carrier 23 is pivotally mounted on this crankpin.

A second disc 27 is rotatably mounted on a vertical axis extending upwardly from carrier 23, and this disc is rotated by the engagement of a small pinion 39 on crankpin 241 with the large pinion 40 secured to disc 27. Disc 27 is provided with a diametrically-extending slot 42 in which is mounted a screw 44 on which a slider 43 is adjustably mounted. This slider carries a driving pin 45 on which slotted bar 28 is mounted, this bar being secured in adjusted position by two locking washers 46 on pin 45. The traverse of the tool 18 is effected through stirrup 30 secured to template carrier 17*a*, universal joint 31, and bar 28. A vertical pin 29, projecting upwardly from carrier 23 through a slot of bar 28, maintains the correct relationship between these two members.

It will be seen that the throw of the eccentric or crankpin 241 determines the length of stroke of the working edge of the template back and forth over the workpiece, this length varying as crank-pin 241 is adjusted nearer to, or further away from, the centre of disc 24. Also, the adjusted position of pin 45 lengthwise of the slot in link 28, through which it extends, determines what may be called the mean mid-position of the tool strokes in relation to the axis of the workpiece, which may, or may not, coincide with that axis in different cases. And the throw of the eccentric driving pin 45 determines the variation of displacement of the tool stroke. That is to say, the rotation of pin 45 about its centre causes the whole stroke to be displaced in the lengthwise direction of the stroke, so that its extreme positions at both ends will continuously vary, a series of such variations being completed each revolution of the disc 27. Also, the adjustment of slider 43 on its screw 44 determines the maximum extent to which the stroke of the tool will be displaced in reference to the constant stroke which it would have if actuated solely by crankpin 241. It will be seen that such variation of movements prevents imperfections of the surface ground, which might be caused by the change of direction of the tool stroke always taking place at fixed points in its travel.

It will be seen that the function of the hinged frame 13, 15, 17, connected to the tool, is to prevent or restrain undesired movements thereof during operation. Thus, unless permitted to a small extent by looseness of bearings, rotation of the tool about the axis of the workpiece, or about any vertical axis, is prevented, as well as its rotation in its own plane. The one rotation which is permitted, during operation, is that about the axis of pin 212, this being an axis normal to the axis of the workpiece, by which the correct inclination of the tool edge is determined at all times. As to movements of translation of the tool edge, the hinged frame permits vertical movement thereof, in accordance with the curved contour of the surface traversed by the edge. It also, of course, permits movement of the tool normal or nearly normal to its own plane, which constitutes its working stroke. A third possible movement of translation, a horizontal movement of the tool in its own plane, is prevented by the construction as shown, during operation.

As to initial adjustments, however, or adjustments when the apparatus is stopped, the tool may be shifted horizontally in its own plane, by suitably adjusting the position of screw 18*a* in slot 18*b* of the tool, as described above in connection with Figure 3, so that the tool may be maintained somewhat off centre in this plane, to enable it to sweep the abrasive-lubricant continuously towards the centre of the workpiece. A slight rotation of the tool in its own plane, for adjustment, is also permitted by the screw and slot construction described, and such adjustment by tilting in this plane may be required in connection with the lineal adjustment referred to, or because of faulty alignment of other parts. A further possibility of adjusting the tool position by tilting it in its own plane may, if desired, be given by pivotally connecting the member 11 to the base 10, as indicated at 11*a*, along a horizontal axis normal to the pivot 12, suitable provisions being made, as indicated at 11*b*, for locking the parts in adjusted position.

The tool is shown in the drawings as a flat sheet, but it may, if desired, be curved so that its working edge is curved not only in the plane of its own axis, but also in a plane normal thereto, that is, in the direction of its travel over the workpiece. Such a construction is not required in the case illustrated in the drawings, but may be found useful for properly forming the extreme edge portions of the curved work surface, in cases in which such edge portions differ markedly from the curvature of the remainder of the surface. The utility of this expedient in particular cases can be determined readily by test.

As has been stated above, correct inclinations of the tool edge for the grinding of, and maintaining contact with, various prolate surfaces of revolution are obtainable by locating the pivot 212 at the distances from the surface of the workpiece, along the optical (i. e., the symmetrical) axis of the surface acted upon (or closely adjacent thereto), which represent in each case the position of a focus of the curvature in question. In the case illustrated an ellipsoid is ground, with the pivot 212 in about the relative position shown, the tool tilting symmetrically with respect to the axis of the workpiece. If a hyperboloidal surface is to be ground, the pivot 212 must be positioned some distance below the surface of the table 10, bracket 211 being secured to the lower part of the upright frame member 21, and the arms 15 and 17 then being connected to vertical bar 22 at perforations 22*a*, which are shown in the drawing as being at the upper end of the bar. If, on the other hand, a paraboloidal surface is to be ground, the focus at which pivot 212 should be located is, theoretically, at an infinite distance above the workpiece, and the tool, the edge of which is roughly formed to a corresponding parabola, should be substantially upright, i. e. parallel to the axis of the workpiece, at all times. In practice, sufficiently accurate results can be obtained in grinding small dies or lenses by locating the pivot 212 at a height of about 2 feet above the surface of the work, or, say, about four times the relative height shown in the drawings. If the device be used for grinding or polishing a spherical surface the pivot 212 must, of course, be placed at the centre of curvature, the tool thereby being kept radial, that is, normal to the surface, at all times.

In some cases other than the prolate surfaces of revolution, the inclination of the tool will not vary symmetrically with respect to the axis of the workpiece as described above. When acting upon oblate surfaces of revolution the template in its mid position will be inclined to the vertical, and may remain so throughout its traverse. In such cases the position of the pivot will be found to lie on the periphery of a circle tangent to the central portion of the curvature to be traced, which circle has a radius equal to one half the radius of the central portion of the oblate surface. Considerations indicating the position of the pivotal point upon such periphery need not be given here. The correct position will be found to be the one which, when used as a pivot as described, will cause the tool edge always to maintain contact (at least as to its central portion), with the surface to be ground, and this point can always be found, either by theoretical considerations checked up by trial, or by trial and error, or empirical, methods, until the correct position is ascertained. In all such cases, brackets similar to the bracket **211**, shown in the drawings, but carrying a pivot pin similar to the pin **212** at the required distance from the axis of the workpiece, will be provided.

Among other modifications of the apparatus to fit different cases, it may be said that astigmatic surfaces having different curvatures in different directions may, if symmetrically curved relative to an axis, be worked while rotating the workpiece on this axis, by making the inclination of the tool depend on the angle of rotation of the workpiece as well as on the extent of traverse of the tool. In all such cases the principle holds good that a point must be found through which the pivot **212** is extended, about which the bar **22** will swing, this being so located that the tool edge will always incline at such angles to the surface of the workpiece as to continue to fit the same when the desired final shape of the surface is attained.

Reference has been made to the abrasive-lubricant composition. In the case where an aspheric surface of great precision is imparted to a steel die the abrasive-lubricant composition may be changed during the grinding operation. A suspension of carborundum in oil may first be used, then a suspension of finely divided alumina in oil or glycerine and finally a suspension of diamantine in oil or glycerine. Polishing may be effected in the same machine, the tool in that case having a flexible edge or an edge of leather or soft fabric.

I claim:

1. In apparatus for grinding or polishing optical surfaces, including aspheric surfaces, the combination of a workpiece holder, means for rotating it about an axis of symmetry of a workpiece thereon, a pivot member, a tool carrier, means for supporting said carrier in sliding engagement with said pivot member, to swing thereabout, with the edge of a tool carried thereby pressed against the surface of a workpiece on said workholder, and means for swinging said edge across said surface with a varied stroke, comprising, a rotatable eccentric pin, a carrier pivoted thereto, a disc journalled on said carrier and rotated by driving connection from said pin, a pin eccentrically mounted on said disc, and driving connections between said last named pin and said tool carrier.

2. In a method of forming oblate conicoidal surfaces of revolution on workpieces, the steps which consist in forming a workpiece surface roughly to the required curvature, shaping a tool edge roughly to fit the same, rotating the workpiece about the optical axis of the said surface, swinging the tool back and forth over said surface about an axis passing through a point on one side of said optical axis and on the periphery of a circle tangent to the centre portion of said surface and having a radius of curvature half that of the surface to be formed on the said central portion of the workpiece, while maintaining the shaped edge of the tool pressed into contact with the surface, and permitting the tool to move in its axial direction in conformity with the form of the curved surface engaged by its edge, the said second-mentioned axis being at such a distance along said periphery from said optical axis that the tool in swinging will tilt at various angles of inclination to the surface of the workpiece during its travel across the same, such that the tool edge will tend to fit the surface of the workpiece when the inaccuracies of the latter have been removed.

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