Aug. 28, 1962 G. O. RAWSTRON 3,050,909

APPARATUS FOR AND METHOD OF POLISHING ASPHERIC SURFACES

Filed Feb. 16, 1960 2 Sheets-Sheet 1

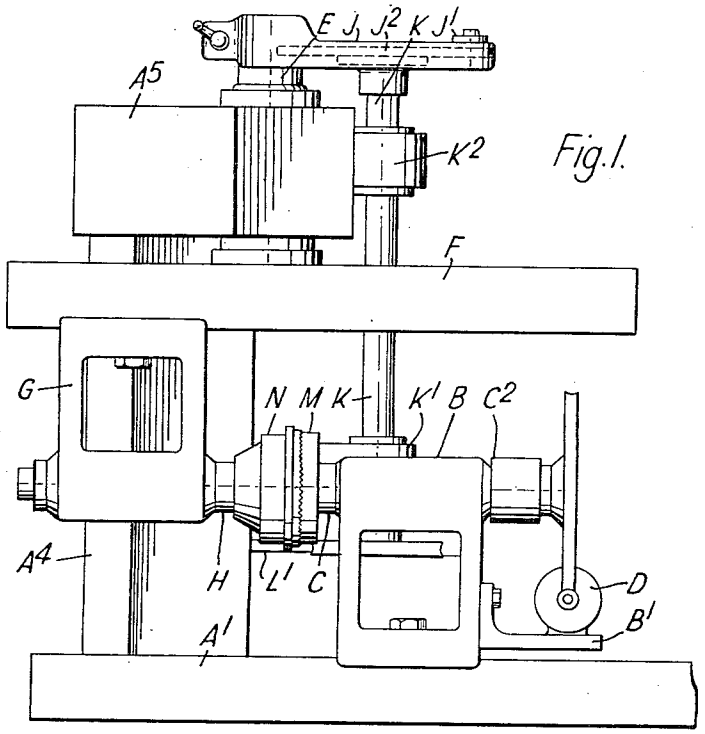
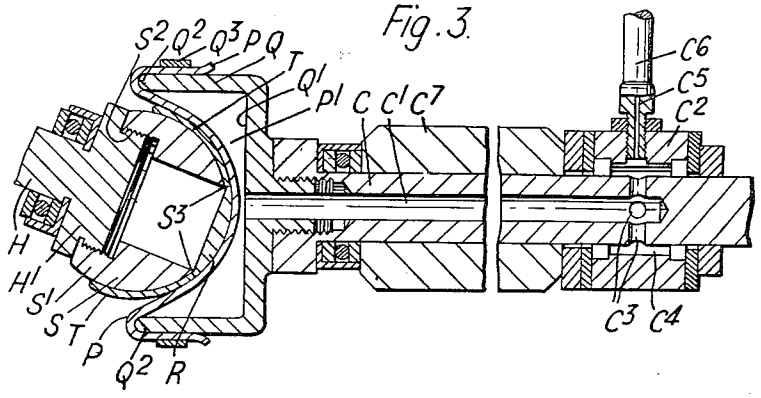



Fig. 1.

Fig. 3.

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Filed Feb. 16, 1960 2 Sheets-Sheet 2

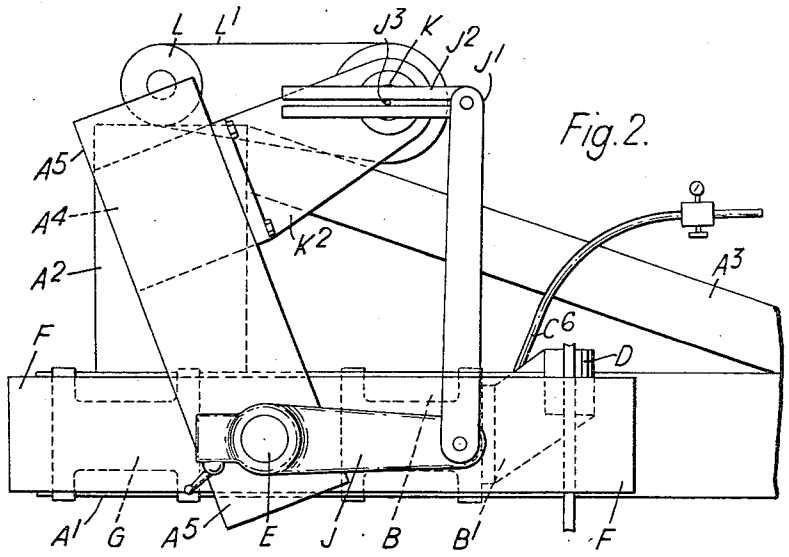
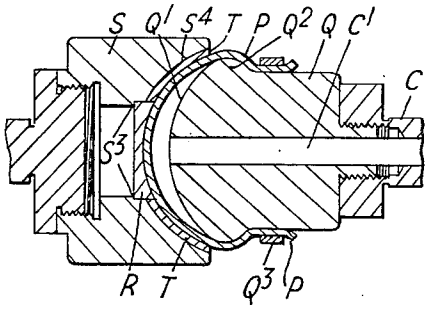



Fig. 2.

Fig. 4.

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# APPARATUS FOR AND METHOD OF POLISHING ASPHERIC SURFACES

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9 Claims. (Cl. 51—124)

This invention relates to a method of polishing a spherical surface or an aspheric surface approximating to a basic spherical surface and also to apparatus for carrying out such method.

Known methods of polishing an at least approximately spherical surface usually result in a considerable degree of unevenness in polishing, the central portion of the surface more especially often being polished to a greater extent than portions near the edge.

The object of the present invention is to provide an improved method of polishing and apparatus for performing such method whereby the degree of unevenness in polishing an at least approximately spherical surface is appreciably reduced.

In the method of polishing according to the present invention, the element having the surface to be polished and the polishing element are relatively rocked effectively about a pivot axis passing through or at least close to the centre of curvature of the spherical surface to be polished or through or at least close to the centre of curvature of the basic spherical surface approximating to the aspheric surface to be polished, the polishing element having a polishing surface which, in all relative positions of the two elements, extends over the whole area of the surface to be polished.

It will often be convenient for the pivot axis to lie at right angles to the axis of symmetry of the surface to be polished.

Conveniently, simultaneously with the relative rocking of the two elements, either the element to be polished is rotationally driven relative to the polishing element about the axis of symmetry of the surface to be polished at a slow speed such that numerous relative rocking movements are completed during one complete relative revolution, or alternatively the polishing element is rotationally driven relative to the element to be polished about an axis which is collinear with the axis of symmetry of the surface to be polished in one relative position of the two elements, the relative rotation being effected at a slow speed such that numerous relative rocking movements are completed during one complete relative revolution. Preferably, in either of these cases, the undriven element is freely mounted to rotate in the same sense as the rotationally driven element due to frictional drag between the two elements.

For further assisting in the uniformity of polishing, the polishing element may conveniently be caused to press against the surface to be polished with substantially uniform pressure over the whole area of such surface by means of fluid pressure acting on such polishing element.

For facilitating adequate polishing at the edge of the surface, the element having the surface to be polished may conveniently be supported by a workholder carrying an annular surround coming close to the circular edge of the surface to be polished and having a surface which forms a substantially continuous extension of the spherical surface to be polished or of the basic spherical surface approximating to the aspheric surface to be polished around the periphery thereof, such surface extension constituting a surface with which a portion of the polishing element can cooperate while the remainder of such polishing element is in engagement with the surface to be polished.



The polishing apparatus according to the present invention comprises a workholder member for carrying the element having the surface to be polished, a polishing element for cooperation with the surface to be polished, a supporting member for the polishing element, a pivotal mounting for either the workholder member or the supporting member for the polishing element, the axis of such pivotal mounting passing through or at least close to the centre of curvature of the spherical surface to be polished or through or close to the center of curvature of the basic spherical surface approximating to the aspheric surface to be polished, a prime mover, and means for coupling such prime mover to the pivoted member so that such member is caused to rock about its pivotal mounting relatively to the other member, the polishing element having a polishing surface which, in all relative positions of the two members, extends over the whole area of the surface to be polished.

The axis of the pivotal mounting may conveniently lie substantially at right angles to the axis of symmetry of the surface to be polished.

In one arrangement, one of the two relatively rocked members constituted by the workholder member and the supporting member for the polishing element consists of a rotatable shaft whose axis is substantially collinear with the axis of symmetry of the surface to be polished at least in one relative position of the two members, driving means being provided for rotating such shaft at a slow rate such that numerous relative rocking movements are completed during one complete revolution of such shaft. Preferably, with this arrangement, the second of the two members constituted by the workholder member and the polishing element supporting member is freely mounted to rotate in the same sense as the rotationally driven shaft due to frictional drag between the elements carried by such members.

Conveniently, means may be provided for adjusting the position of the element carried by the pivoted member towards or away from the axis of the pivotal mounting for such member so as to vary the radius of the arcuate movement of such element when its supporting member is rocked, the element carried by the other member also being movable to maintain cooperation of such two elements.

The polishing element may conveniently form part of the polishing device claimed and described in the present applicants' copending U.S. patent application No. 9,086, filed February 16, 1960, such polishing device comprising a piece of flexible sheet material which constitutes the polishing element, and means for applying fluid pressure to such piece of flexible sheet material to cause such flexible piece to press against the surface to be polished with substantially equal force at all points of contact therewith. The flexible piece may conveniently constitute the wall or part of the wall of a chamber to which fluid under pressure can be admitted.

The workholder member may conveniently constitute the main workholder body of an arrangement of workholder within the scope of that claimed and described in the present applicants' copending U.S. patent application No. 9,086, filed February 16, 1960. In such workholder arrangement, the workholder body, in addition to carrying means for supporting the element to be polished, also carries an annular surround coming very close to the circular edge of the surface to be polished and having a surface which forms a substantially continuous extension of the spherical surface to be polished or of the basic spherical surface approximating to the aspheric surface to be polished around the periphery thereof. Such an-

nular surround, in one arrangement, is constituted by a mass of resinous material on which the extension of the surface to be polished is formed.

The invention may be carried into practice in various ways, but a preferred method of polishing and apparatus for effecting such method according thereto will now be described by way of example with reference to the accompanying drawings, in which:

FIGURE 1 is a front view of the preferred polishing apparatus,

FIGURE 2 is a plan view of the preferred polishing apparatus,

FIGURE 3 shows in detail the preferred arrangement of workholder and polishing device forming part of the preferred polishing apparatus and applied to the polishing of a convex surface, and

FIGURE 4 shows a modification of the arrangement of workholder and polishing device of FIGURE 3 applied to the polishing of a concave surface.

For convenience such preferred method and apparatus will be described with reference to a workpiece constituted by an optical lens element having a concave or convex surface to be polished which constitutes a segment of an at least approximately spherical surface.

The preferred polishing apparatus (see FIGURES 1 and 2) comprises a fixed base consisting of three members arranged generally in the form of a right-angled triangle, the shortest member $A^2$ of the three members extending rearwardly from near one end of the member $A^1$ constituting the front of the base whilst the third member $A^3$ connects the other end of the front member $A^1$ with the rear end of the shortest member $A^2$. The front member $A^1$ constitutes a generally horizontal guide along which can move, for adjustment purposes, a framework member B carrying above the base a rotatable shaft C whose axis extends in the direction of the length of the guide $A^1$. The framework member B carries a bracket $B^1$ on which is mounted an electric motor D coupled with a large reduction ratio, to the rotatable shaft C.

On the rearwardly extending base member $A^3$ is carried a supporting framework in the form of a rectangular sectioned column $A^4$ oblique to the front and on top of which is mounted an elongated supporting block $A^5$ which extends obliquely forwards over the front base member $A^1$. Over such front base member $A^1$, the supporting block $A^5$ carries a vertical pivot shaft E itself carrying at its lower end a generally horizontal arm F along which can move, for adjustment purposes, a second framework member G. The second framework member G carries a freely rotatable shaft H whose axis lies in the horizontal plane containing the axis of the above-described driven horizontal shaft C. The upper end of the vertical pivot shaft E, above the supporting block $A^5$, carries a generally horizontal crank J connected through a coupling arm $J^1$ to a generally horizontal crank arm $J^2$ carried by a rotatable vertical shaft K supported near its upper and lower ends by means of brackets $K^1$ and $K^2$ projecting from the supporting framework $A^4$ and $A^5$, such rotatable shaft K being driven at or near its lower end by means of a belt drive $L^1$ from a second electric motor L. The action of this mechanism due to operation of the second electric motor L is such that a swinging movement is imparted to the crank J through the crank arm $J^2$ and coupling arm $J^1$, and the movement of such crank J causes the pivot shaft E, together with the generally horizontal arm F, the second framework member G and the freely rotatable horizontal shaft H, to rock about the axis of such pivot shaft E. The axis of the freely rotatable horizontal shaft H therefore swings about such pivot axis E in a horizontal plane containing the axis of the first horizontal shaft C, and the arrangement is such that, substantially in the middle position of such swinging movement, the axes of the two horizontal shafts C and H are collinear. Means are provided, such for example as the pin and slot coupling shown at $J^3$, for adjusting the effective length of the crank arm $J^2$ carried by the rotationally driven vertical shaft K so that the amplitude of the swinging movement can be varied.



The two above-described horizontal shafts C and H which can be relatively rocked are used to carry a polishing device for engagement with the surface to be polished and the workpiece constituted by the optical lens element having such surface. For convenience it will be assumed herein that the polishing device is carried by the rotationally driven shaft C whilst the workpiece is carried by a workholder carried by the freely rotatable horizontal shaft H. A preferred arrangement of polishing device and workholder is later described with reference to FIGURE 3, but in FIGURE 1 the polishing device is indicated at M and the workholder at N.

In use, the position of the second framework member G on the swinging horizontal arm F is adjusted so that the centre of curvature of the spherical surface to be polished, or the centre of curvature of the basic spherical surface approximating to the aspherical surface to be polished, lies on the axis of the vertical pivot shaft E carrying such arm F and such framework member G. The position of the first framework member B on the guide $A^1$ constituted by the front base member is then adjusted to bring the polishing device M into engagement with the surface of the workpiece to be polished, such workpiece being carried by the workholder N. Operation of the second electric motor L therefore causes a relative rocking motion between the workpiece carried by the workholder N and the polishing device M about an axis passing through the centre or effective centre of the surface to be polished. Further, operation of the first electric motor D causes the polishing device M to rotate at a slow speed about its axis, which is collinear with the axis of its supporting shaft C. The lens element constituting the workpiece, together with its supporting shaft H, will then rotate in the same sense as the polishing device M about the axis of such supporting shaft H, due to frictional drag between the lens element and the polishing device N. Such rotation of the lens element and shaft H will in practice be somewhat irregular and at an average speed less than that of the polishing device N. The speed of rotation of the polishing device N is such that numerous rocking movements of the workpiece in the workholder M are completed during one complete revolution of such polishing device N. The polishing is effected almost entirely due to the relative rocking of the workpiece and the polishing device.

A polishing device is employed, for example of the kind described below, which in all relative positions of such device and the workpiece completely covers the surface to be polished when the amplitude of the rocking motion is appropriately adjusted. This is of great importance in achieving a relatively even degree of polishing, and in practice it is found that sufficiently even polishing is achieved even when the solid angle subtended by the surface to be polished at its centre of curvature is quite large. The slow rotation of the polishing device and free rotational mounting of the lens element also help to reduce any unevenness in polishing due to variations of the polishing surface carried by the polishing device or of the polishing slurry with which such surface is impregnated. It is important, however, that such rotation shall be slow so that the contribution towards actual polishing afforded by such rotational movement is at least very small, since a greater degree of polishing is effected near the edge of the workpiece due to such rotational movement than near the centre of the workpiece.

The achievement of evenness in polishing is also assisted by the use of a polishing device which is caused to press against the surface to be polished with substantially equal force at all parts of contact therewith. Conveniently, the polishing device claimed and described in the present applicant's copending United States patent application Serial No. 9,086, filed February 16, 1960, may be used

for this purpose. Such preferred polishing device, in combination with a preferred arrangement of workholder to be later described, is shown in FIGURE 3 applied to the polishing of a convex at least approximately spherical surface and in FIGURE 4 applied to the polishing of a concave at least approximately spherical surface. FIGURE 3 also shows details of the preferred rotatably driven shaft C for carrying the preferred polishing device.

Such preferred polishing device comprises a piece of flexible sheet material preferably formed in two layers, consisting for example of canvas-type material of the kind commonly known as Rexine, which is impregnated with pitch and can be used with a suitable abrasive slurry for polishing purposes, having a lining of plastic sheet material impervious to air, for example thin sheet polythene. For clarity, this flexible piece P is shown in the drawings as a single layer only. The flexible piece P having the air-impervious lining is fastened over the end face $Q^1$ of a cylindrical fitting Q carried at the end of the driven horizontal shaft C adjacent to the workpiece, such shaft C and fitting Q being provided with a central bore $C^1$ through which air under pressure can be admitted to an air pressure chamber $P^1$ formed between the flexible piece P and such operative end face $Q^1$ of the end fitting Q on the shaft C. For admitting the air to the bore $C^1$ in such driven rotatable shaft C, a portion of such shaft C near its end remote from the workpiece is surrounded by a fixed sleeve $C^2$, the shaft C having radial inlet ports $C^3$ each connecting with an annular air inlet chamber $C^4$ formed within the sleeve $C^2$ around the shaft C and the sleeve having a radial inlet port $C^5$ connecting such air inlet chamber $C^4$ with the air supply pipe $C^6$. Over its central portion the driven rotatable shaft C is surrounded by a supporting fixed sleeve $C^7$ itself mounted in the framework member B of the polishing apparatus.

In order to make the air pressure chamber $P^1$ airtight, the flexible piece P near its periphery passes over a peripheral edge $Q^2$ formed on the end fitting Q adjacent to such chamber $P^1$ and is tightly secured to the fitting Q beyond such peripheral edge $Q^2$ by means of a securing ring $Q^3$. The actual arrangement of the fitting Q on the end of the driven horizontal shaft C varies according to the nature of the surface to be polished.

Thus in the case shown in FIGURE 3 of the convex surface to be polished, the fitting Q is in the form of a thin-walled cup-shaped extension of the shaft C and the flexible piece P is passed over the circular end edge $Q^2$ thereof.

In the modified polishing device of FIGURE 4 for a concave surface to be polished, the end face $Q^1$ of the fitting Q is made convex with a curvature somewhat less than that of the concave surface to be polished, and the outside wall of such fitting Q is provided with a peripheral projection $Q^2$ immediately adjacent to the periphery of such end face $Q^1$, the flexible piece P passing over such peripheral projection $Q^2$ and being fastened to the outside wall of the fitting Q immediately beyond such projection $Q^2$.

In each of these cases, the diameter of the cylindrical fitting Q at the point having the peripheral edge $Q^2$ is large enough to secure in position a flexible piece P of sufficient area to extend completely over the surface to be polished in all relative positions of the workpiece and the polishing device.

In use, the flexible piece presses uniformly against the surface to be polished over the whole area thereof notwithstanding any small irregularities or deviations from smoothness in such surface.

It will be clear that during any polishing operation in which the above-described device is employed it is important to ensure that the flexible piece P does not at any time during its movement relative to the surface to be polished, project appreciably beyond the edge of such surface without an abutment for such projecting portion, for in this case the air pressure may cause the flexible piece P to burst at its projecting region or at least to bulge out in a manner which may give rise to uneven polishing. It is, however, difficult to obtain as adequate and even polishing at the edge of the surface as over its central portion unless the polishing flexible piece P is permitted to pass, at least in part, beyond the edge of such surface. It is therefore preferred, in conjunction with the polishing device, to use a special form of workholder for the workpiece having the surface to be polished, such workholder having a surface portion which forms a substantially contiunous extension of the surface to be polished around the periphery thereof.

One arrangement of workholder described in the present applicant's U.S. patent application No. 9,085, filed February 16, 1960, is especially suitable for this purpose. Such workholder arrangement is shown in FIGURE 3 for a workpiece R having a convex spherical surface to be polished and comprises a main workholder body S having a generally hemispherical surface $S^1$ whose curvature is approximately equal to that of the surface to be polished, such workholder body S having a screwthreaded recess $S^2$ in its flat face by means of which it can be attached to the appropriate end of the freely rotatable shaft H for supporting such workholder, such shaft being provided with an appropriately screwthreaded boss $H^1$ for this purpose. At the centre of its generally spherical surface $S^1$, the main workholder body S is provided with a cylindrical recess $S^3$ of just sufficient diameter to receive the workpiece R, and of depth less than the thickness of such workpiece. The lens element R is thus located in such recess $S^3$ with the surface to be polished exposed and standing out from the generally spherical surface $S^1$ of the main body S owing to the relatively small depth of the recess $S^3$, which may conveniently be equal to about one half of the axial thickness of the lens element R. Over its generally spherical surface $S^1$, the main workholder body S carries a moulded annular layer T of resinous material closely surrounding the workpiece R and having a surface flush with the surface to be polished, the spherical curvature of such surface of the resinous layer T being substantially equal to that of the surface to be polished. It will be appreciated that the thickness of the resinous layer T will be of the order of one half of the thickness of the lens element R but that such thickness may not be uniform, the degree of uniformity depending on the difference between the curvature of the generally spherical surface $S^1$ of the main holder body S and the curvature of the surface to be polished.

The above-described workholder is shown in FIGURE 4 modified to suit a workpiece P having a concave spherical surface to be polished. Thus, in this case, the main body of the workholder S may be provided with a generally hemi-spherical internal surface $S^4$ having a central recess $S^3$ for receiving the workpiece P whilst the mould used for producing the annular layer T of resinous material will have an external spherical surface of curvature substantially equal to that of the concave surface to be polished.

As has been previously mentioned, the above-described polishing device in use presses uniformly against the surface to be polished notwithstanding any small irregularities or deviations from smoothness in such surface. The polishing device is thus especially useful for the polishing of an aspheric surface, i.e. a surface approximating to a basic spherical surface.

It has usually been necessary hitherto, in the production of an optical element having an aspheric surface, to form a rough approximation to such surface and then to carry out accurate expert figuring during the polishing stage in order to produce the desired asphericity accurately. It has now been found possible, for example by the method described in the present applicants' copending U.S. patent applications Nos. 9,087 and 9,088 filed February

16, 1960 to produce the desired asphericity accurately without the need for such figuring during polishing, the accurate aspheric surface produced by such method being left with a "grey" surface finish requiring uniform polishing for which the above-described polishing device is especially useful.

The workholder above-described is also especially useful for a workpiece having an approximately spherical surface to be polished, for example an aspheric surface approximating to a basic spherical surface. In this case, the surface of the annular surround constituted by the resinous layer T is arranged to form an extension of the basic spherical surface to which such aspheric surface approximates. Thus, such surface of the annular surround T will form part of a surface at least approximating to the spherical surface having, in the case of a generally convex surface, the largest radius and in the case of a generally concave surface the smallest radius, which contacts the surface to be polished at its circular edge only.

The above-described workholder may be modified in various ways and in fact it will be appreciated that it is not essential to use a mass of resinous material on which to form the generally spherical surface portion thereof, such surface being formed for example on a metal or glass member surrounding the workpiece, such member being carried by or forming part of the main workholder body.

With the above-described arrangement of polishing device and workholder, shown in FIGURES 3 and 4 respectively for a convex and a concave surface to be polished, it is arranged that the area of flexible piece P enclosed by the peripheral edge $Q^2$ over which it passes is slightly greater than the area of contact of such flexible piece P in use with the work surface formed by the workpiece R and the annular surround T of the workholder. To ensure this, the area of flexible piece P enclosed by the edge $Q^2$ is made appropriately greater than the plane area enclosed by such edge $Q^2$, the actual amount greater clearly depending also on the curvature of the surface to be polished. Thus, the whole of the flexible piece P enclosed by the peripheral edge $Q^2$ is pressed against the work surface except for a narrow annular strip adjacent to such peripheral edge $Q^2$ on the fitting Q carrying such flexible piece P, the framework member B carrying the rotatably driven shaft C being moved along its guide $A^1$ so that the operative end of the fitting Q on such shaft C is slightly spaced from such work surface.

It will be appreciated that the above-described arrangement of polishing apparatus and method of use thereof to effect polishing may be modified in various ways within the scope of the invention. For example, instead of mounting the worksholder on a freely rotatable shaft, such shaft may be fixed and the workholder mounted to rotate freely on bearings carried by such shaft. Again, the rocking motion may be produced in ways other than that described, for example by means of a cam which acts to rock the workpiece and the polishing device effectively about an axis passing through the centre or effective centre of the surface to be polished. Further, if desired, both the rocking movement and the rotating movement may be imparted to one of the two members respectively carrying the workpiece and the polishing device, the other of such two members being fixed or rotatable but undriven.

What I claim as my invention and desire to secure by Letters Patent is:

1. A method of uniformly polishing an aspheric surface of revolution which deviates only by small amounts from a basic spherical surface by means of a flexible polishing element having a cooperating polishing surface, which method comprises the steps of imparting a relative reciprocating movement to said flexible polishing element and the surface to be polished, said movement being directed along a great circle of said basic spherical surface, maintaining the polishing element in contact with the entire area of the surface to be polished throughout said relative reciprocating movement, and varying the orientation of the reciprocating movement with respect to the surface to be polished by imparting a relative rotational movement to said surface and polishing element by rotationally driving one of them about its axis of symmetry, the relative displacement per unit of time caused by said reciprocating movement being greater than that caused by said rotational movement.

2. A method of polishing as claimed in claim 1, according to which the surface other than that driven rotationally is left free to rotate in the same direction as the rotationally driven surface under the action of the frictional drag between the two.

3. A method of polishing as claimed in claim 1, according to which fluid pressure is used to press the flexible polishing element into contact with the surface to be polished to maintain uniform polishing pressure over the whole area of contact with the surface to be polished.

4. Apparatus for polishing an aspheric surface of revolution which deviates by only small amounts from a basic spherical surface, comprising a workholder member for carrying the element having the aspheric surface to be polished, a flexible polishing element cooperating with the surface to be polished and having a polishing surface area greater than that of the surface to be polished, a supporting member for such polishing element, a pivotal mounting for one of such two members having the center of its pivot axis at the center of the basic spherical surface, means for imparting a reciprocating movement to such pivoted member about its pivot axis relatively to the other member with an amplitude of reciprocation such that the polishing surface of the polishing element remains in contact with the whole of the surface to be polished throughout the whole of the reciprocating movement, thereby maintaining a uniform polishing effect over the whole of the surface to be polished, and means for varying the orientation of such reciprocating movement relatively to the surface to be polished, such means consisting of means for rotating one of the two members about its axis of symmetry at a speed at which the relative displacement due to such rotation is less than that caused by said reciprocation.

5. Polishing apparatus as claimed in claim 4, including means whereby that one of the two members which is not driven rotationally is mounted to rotate freely about its axis of symmetry, whereby the frictional drag between the polishing element and the surface to be polished will cause such undriven member to rotate in its mounting in the same sense as the driven member.

6. Polishing apparatus as claimed in claim 4, including means for adjusting the position of the element carried by the pivoted member in a direction towards or away from the pivot axis thereby varying the radius of the arcuate reciprocating movement, and means for effecting corresponding adjustment of the position of the element carried by the other member to ensure cooperation between the two elements in the position of adjustment.

7. Polishing apparatus as claimed in claim 4, in which the polishing unit constituted by the polishing element and the supporting member therefor includes a piece of flexible sheet material carrying the polishing surface, means for anchoring such flexible sheet at its edge to the supporting member and thereby forming a chamber between the flexible sheet and the supporting member, and means for supplying fluid under pressure to such chamber whereby the flexible sheet is pressed against the surface to be polished with equal pressure at all points of contact with such surface.

8. Polishing apparatus as claimed in claim 7, in which the workholder member includes a part having an annular spherical surface substantially conforming to the said basic spherical surface, such annular spherical surface having its inner edge portion closely adjacent to the peripheral edge portion of the surface to be polished and form-

ing a substantially continuous extension thereof, whereby the polishing surface on the flexible sheet engages not only with the surface to be polished but also with such extension thereof.

9. Polishing apparatus as claimed in claim 4, in which the workholder member includes a part having an annular spherical surface substantially conforming to the basic spherical surface, such annular spherical surface having its inner edge portion closely adjacent to the peripheral edge portion of the surface to be polished and forming a substantially continuous extension thereof, whereby the flexible polishing element engages not only with the surface to be polished but also with such extension thereof.




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