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Rupp

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[54] **APPARATUS FOR POLISHING TOROIDAL SURFACES**

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[52] **U.S. Cl.** .... **51/119**; 51/58; 51/124 L; 51/156; 51/284

[51] **Int. Cl.**^{2} **B24B 13/02**

[58] **Field of Search** .... 51/58, 55, 156, 162, 284, 51/71, 119, 120, 124 L, 57, 54

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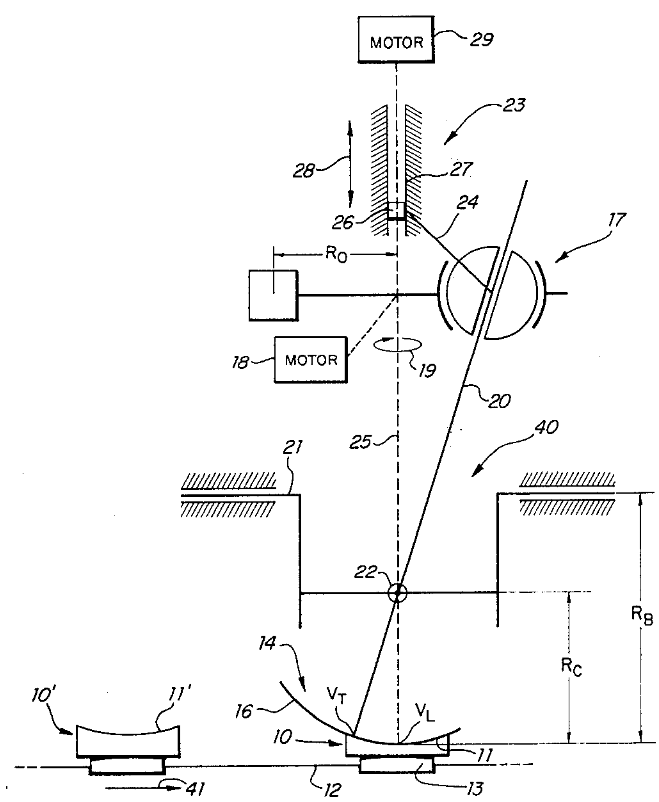
[57] **ABSTRACT**

Apparatus for polishing toroidal surfaces on ophthalmic lenses. In accordance with a preferred embodiment, a toroidal polishing tool is driven in a non-rotating orbital manner while being supported by a gimbal having pivot axes which are vertically displaced from one another so that the lapping surface of the tool will, in its movement, define and always move on a toroidal surface fixed in space. By properly spacing the gimbal axes relative to the vertex of the tool surface, the fixed toroidal surface in space will have the same radial dimensions as the tool surface and the lens surface to be polished. Therefore, by positioning the lens so that its surface will be on the fixed toroidal surface in space, the lens will be effectively polished by the moving tool and can be held stationary throughout the polishing operation. Because the lens can be held stationary, greater machine speeds and polishing rates can be achieved. An improved breakup motion is also provided in the system to prevent the formation of ridges or grooves on the lens surface.

14 Claims, 2 Drawing Figures



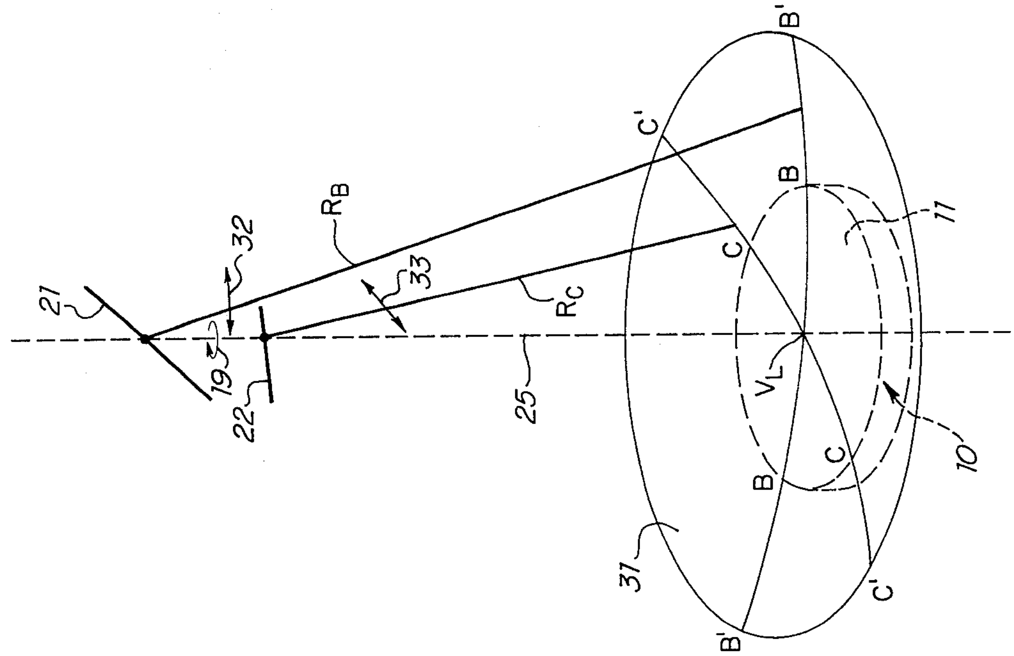


FIG. 2.

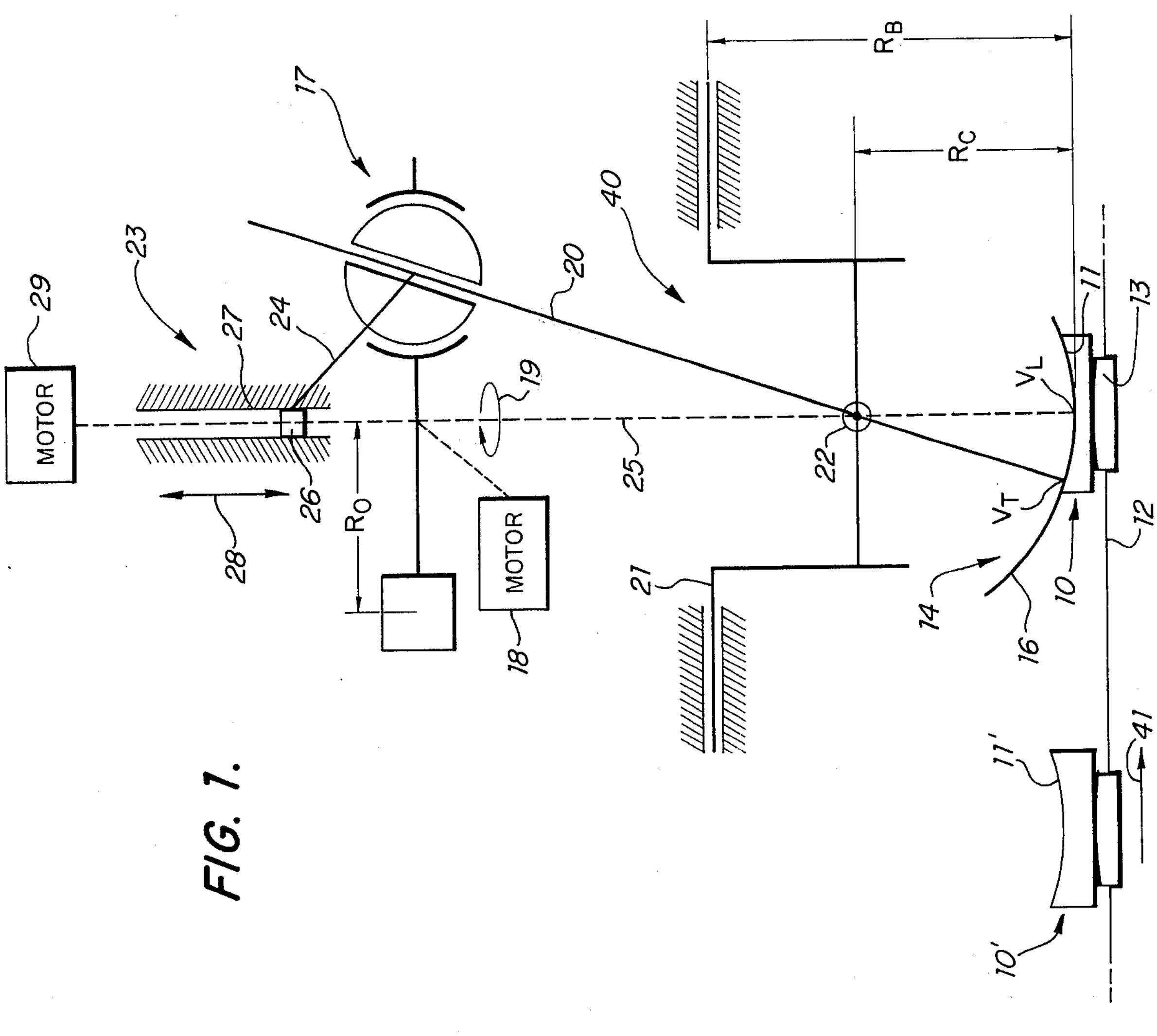


FIG. 1.

APPARATUS FOR POLISHING TOROIDAL SURFACES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a toroidal polishing apparatus and, more particularly, to an apparatus for polishing toroidal surfaces on ophthalmic lenses in a more rapid and efficient manner.

2. Description of the Prior Art

A toroidal surface is a surface of compound curvature in which the circular curvature measured in the direction of a first principal meridian of the surface is of a different radial dimension than the circular curvature measured in the direction of a second principal meridian normal to and passing through the first principal meridian. Such surfaces are important in many areas, but are particularly useful in the ophthalmic field wherein lenses having toroidal surfaces are utilized for the correction of astigmatism.

Because of their importance in the ophthalmic field, a large variety of different systems have been developed to grind and polish such surfaces. The present invention is directed particularly to an apparatus for polishing toroidal surfaces, although, it should be understood that the term "polishing" as used herein is also intended to include "fining" which is an intermediate step sometimes carried out between the grinding and polishing steps.

In the typical toroidal polisher of the prior art, polishing is carried out by moving a lens and a lapping tool, both of which have been provided with the desired toroidal surface, transversely relative to one another in a manner so as to effect polishing of the lens surface. In constructing a system so as to carry out this relative transverse movement, however, there are several design requirements which must be satisfied in order to produce good surfaces. For one thing, because a toroidal surface is not axially symmetrical, it is essential that the tool and the lens be prevented from rotating relative to one another during the polishing operation. Instead, the corresponding principal meridians of the lens and of the tool must be initially aligned and always maintained parallel to one another. Because of this limitation, the practice has been to cause the lapping tool to move relative to the lens in a non-rotating orbital manner such that the meridians of the lens and the tool will remain aligned while still permitting the lens and the tool to move relative to one another to effect polishing.

Also, in order to prevent the formation of ridges or grooves on the lens surface, it has been found necessary to introduce one or more "break-up" motions into the relative movement between the lens and the tool so that the tool will not always move along the same path relative to the lens. These break-up motions may take a variety of forms as long as they do not change the polar alignment of the lens relative to the tool and frequently comprise oscillations or reciprocations of one member relative to the other at different speeds or at different amplitudes. Because of these break-up motions several independent movements of both the lens and the tool usually take place simultaneously during a polishing operation. This tends to make the system quite complex and susceptible to becoming misaligned.

A third important limitation of the polishing system is that the lens surface and the tool surface always be

maintained fully in contact with one another without separating. Because of this requirement, and also because the tool usually is moving in a variety of unrelated and usually irregular paths, it has been found necessary to mount the lens so that it can follow the tool as it is carrying out these multiple motions. Usually this entails mounting the lens on some form of ball joint connection so that the lens can wobble and adjust its position so as to always remain in contact with the tool as the tool is carrying out its several movements. Because of this need for the lens to wobble, the overall polishing speed of the system must be reduced significantly. Specifically, in the typical system where the lens wobbles, the tool can usually be moved only at speeds of about **200–300** r.p.m. and it frequently takes five minutes or more to polish a lens. This greatly slows down the entire lens manufacturing operation and makes it much less conductive to automation.

SUMMARY OF THE PREFERRED EMBODIMENT

By the present invention, the above inadequacies of the prior art have been significantly reduced by providing a polishing system designed to permit the lens to be rigidly mounted in position and held stationary during the entire polishing operation. In accordance with the presently most preferred embodiment, this capability is attained by designing the kinematics of the movable tool in such a manner that its toroidal lapping surface, by its movement, will define and always be positioned on a toroidal surface fixed in space, which toroidal surface will have the same radial dimensions as the lapping surface and the toroidal surface to be polished on the lens. By designing the system in this way, the lens can be rigidly mounted to have its surface aligned on the fixed toroidal surface in space, and, accordingly, as the lapping tool face moves along the surface, it will always be properly oriented and firmly in contact with the lens surface so as to properly polish it.

The above-described tool movement is attained by coupling the tool to an orbital driving means through a gimbal coupling designed such that the tool will be free to pivot about two perpendicular axes which are vertically displaced from one another relative to the lens and lapping tool surfaces. Specifically, one axis of the gimbal is spaced from the vertex of the tool surface by a distance equal to the radius of curvature of the tool surface in the direction of one principal meridian while the second axis is spaced from the vertex by a distance equal to the radius of curvature of the tool surface in the direction of the second principal meridian. Accordingly, as the tool is orbitally driven, its lapping face will automatically define and always move along the proper toroidal surface in space. In prior art systems, the tool is coupled to a gimbal whose axes are in the same plane such that the tool face will not move along a toroidal surface in space, and it is for this reason that the lens must be movably mounted to follow the tool.

The present invention also provides a novel "break-up" motion for the tool to avoid the formation of ridges or grooves on the lens. Specifically, the tool is mounted such that the orbital motion applied to it will continuously change in amplitude between upper and lower limits. This causes the tool to describe a spiral pattern relative to the lens surface which will insure that different parts of the tool will be contacting different parts of the lens at all times. This one break-up motion has been found sufficient to produce good quality lenses without additional movements being necessary. Also, this motion has been designed such that the tool surface will still define and remain on the proper toroidal surface in space at all times.

Bacause of the above described kinematics, the lens can be maintained stationary throughout the polishing operation. This permits much higher polishing speeds and improved surface quality to be obtained. For example, tool speeds of **2,000** c.p.m. and polishing rates of **1–2** minutes per lens are obtainable.

Also, because the lens can be mounted rigidly relative to the tool, the present polishing system is particularly well adapted for automation. For example, the lens can be mounted on a conveyor system that will sequentially feed the lenses into position for polishing one at a time. This cannot readily be done in prior art systems where the lens must be able to wobble relative to the tool. Further features of the invention will be discussed hereinafter in conjunction with the detailed description of the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically illustrates a toroidal polishing system in accordance with a presently preferred embodiment of the invention.

FIG. 2 graphically illustrates the kinematics of the lapping tool in the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 schematically illustrates an apparatus for polishing toroidal surfaces in accordance with a presently preferred embodiment of the invention. In the FIG., reference number **10** refers generally to a lens having a surface **11** to around a be polished. Lens surface **11** has been previously provided with the desired toroidal surface by any conventional procedure and is illustrated more clearly in dotted line in FIG. **2.** Specifically, lens surface **11** has been generated to have a curvature of radius R_B in the direction of a first principal meridian B—B, and a curvature of radius R_C in the direction of a second principal meridian C—C perpendicular to the first principal meridian.

Referring back to FIG. **1,** lens **10** is held on suitable support **12** by means of a lens block **13** to which the lens has been adhered so that when block **13** is inserted in support **12,** lens surface **11** will be properly oriented within the polishing system as is understood by those skilled in the art.

Polishing of lens surface **11** is accomplished by a lapping tool **14** which may be of conventional type and which has been provided with a lapping surface **16** having the same toroidal shape as the lens surface **11.** Although it is not illustrated in the drawings for purposes of clarity, means are also provided in the system to deposit an appropriate polishing mixture over the lens surface **11** so that as the tool **14** is moved thereover, the appropriate polishing action can take place.

As mentioned above, since toroidal surfaces are not axially symmetrical, it is essential that the tool and lens surfaces be initially aligned with respect to one another and maintained in alignment throughout the entire polishing operation. In other words, it is essential that the principal meridians B—B and C—C of lens surfaces **11** be maintained parallel with the corresponding principal meridians of lapping tool surface **16** at all times. Initial alignment is obtained automatically by the proper mounting of the lens block **13** as mentioned above. Thereafter, to maintain alignment, any movement of the tool relative to the lens must be without rotation, and, to achieve this, it has become the practice in the art to drive the tool in a non-rotating orbital manner over the lens. This technique is also utilized in the present invention, and appropriate structure for establishing this type of motion is schematically illustrated in FIG. **1** and identified by reference number **17.** Specifically, orbital driving means **17** is coupled to tool **14** by a shaft **20** such that as it is driven in an orbital path of radius R_o by a motor **18** as indicated by arrow **19,** the tool will also move in a nonrotating orbital manner relative to the lens **10.** The specific structure of the orbital driving means has not been illustrated for purposes of clarity and because it may take many forms that are known in the art. Examples of such systems, however, are illustrated in U.S. Pat. Nos. **998,101** to Laabs and **3,732,647** to Stith. Orbital driving means **17** is also positioned so that it, and hence the tool, will orbit around vertex axis **25** which extends through the vertex V_L of lens surface **11.**

Supporting tool **14** for orbital movement over the lens surface is a gimbal mount illustrated generally by reference number **40,** which mount forms an important aspect of the present invention. Specifically, in the typical toroidal polisher, the tool is supported by a gimbal having perpendicular axes positioned in the same plane. Accordingly, as the tool is moved orbitally over the lens, its pivotal movement around the gimbal will cause it to describe a spherical surface in space. Because, however, the lens surface is not spherical, but instead is toroidal, to ensure that the lens surface is always in proper contact with the tool surface, it is necessary to mount the lens so that it can wobble and tilt to follow the tool. As mentioned above, this necessitates a reduction in polishing speeds and creates other problems. In the present invention, however, the gimbal has been designed to overcome these inadequacies. In particular, the gimbal **40** is designed to have pivot axes **21** and **22** which are vertically displaced from one another relative to tool surface **16.** Furthermore, axis **21** is spaced from the vertex V_T of the tool surface by a distance of R_B which corresponds to the radius of the curvature of the tool and lens surfaces in the direction of major meridian B—B, while axis **22** is spaced from vertex V_T by a distance of R_C which corresponds to the radius of the curvature of the tool and lens surfaces in the direction of major meridian C—C.

By separating and precisely positioning the pivot axes of the gimbal in this manner, the improved kinematics of the present invention are effectively attained. Specifically, as the tool is being carried around the lens in an orbital manner by orbital driving means **17,** it will be free to pivot in and out of the plane of FIG. **1** aroudn axis **21** such that surface **16** will describe around curved path of radius R_B in that direction. Simultaneously, it will be free to pivot back and forth in the plane of FIG. **1** around axis **22** so as to describe a curved path of radius R_C in that direction. Therefore, it should be apparent that when the tool is driven in one complete orbit around axis **25,** its surface **16** will define a toroidal surface **31** in space (FIG. 2), which toroidal surface will have the same radii of curvature R_B and R_C in the direction of its major meridians B'—B' and C

'—C', respectively, as lens surface **11** and tool surface **16**.

Furthermore, since axes **21** and **22** are fixed in space, the toroidal surface **31** will also be fixed in space and the tool surface **16** will always be positioned on and occupy a portion of it. Accordingly, by positioning lens **10** so that its surface **11** will be aligned and coincide with that toroidal surface in space (i.e. with meridians B—B and C—C coinciding with meridians B'—B' and C'—C'), the lens surface **11** will always be in proper contact with the tool and will be polished by it. Since the fixed toroidal surface in space will be fixed, the lens can also be maintained stationary at all times.

This concept can be better understood with reference to FIG. **2** which graphically depicts the kinematics of the system. Specifically, when the tool (not shown in FIG. **2**) makes a single orbit around the lens **10** while being free to pivot around axes **21** and **22** as indicated by arrows **32** and **33**, respectively, its surface **16** will define toroidal surface **31** in space. Because axis **21** is spaced from the vertex V_L of the lens surface **11** by a distance R_B and because axis **22** is spaced therefrom by a distance of R_C, this generated surface in space will have the same radii of curvature as lens surface **11** and tool surface **16**. Furthermore, because the lens has been properly oriented in the system, the generated surface **31** will have its major axes B'—B' and C'—C' parallel to and coinciding with axes B—B and C—C of lens surface **11**. Therefore, if the lens surface **11**, shown in dotted line in FIG. **2**, is held stationary on surface **31**, as the tools move on that surface it will automatically be on the lens surface at all times and will properly polish it.

Referring back now to FIG. **1**, it was mentioned above, that suitable break-up motions must be superimposed over the basic orbital movement of the tool so as to vary the path of the tool relative to the lens so as to prevent the formation of any ridges or grooves on the lens as might be caused by any imperfections in the tool surface. This is also necessary in the present system and appropriate structure is illustrated schematically by reference number **23**. Specifically, the orbital driving means **17** is coupled by means of a linkage **24** to a plunger **26**. Plunger **26** is, in turn, adapted to be moved up and down within a sleeve **27** as indicated by arrow **28** under control of a suitable motor **29** which may conveniently be a simple pneumatic system. From FIG. **1**, it should be apparent that as plunger **26** is moved back and forth within sleeve **27**, the radius R_O of the orbital driving means **17** will vary. In particular, the radius R_O of the orbit will vary between a first maximum radial dimension and a second minimum radial dimension in a continuous manner. This, in turn, will cause the face of the tool to move in an orbit of continuously varying amplitude and the effect will be that every point on the tool face will move in a spiral path relative to the lens surface. Because of this, every point of the tool face will move over a different part of the lens during every orbital cycle, and this will avoid the formation of grooves or ridges. Inasmuch as this break-up motion does nothing more than vary the amplitude of the orbit, it will not affect the shape of toroidal surface **31** in space. The face **16** of the tool will still always be on that surface and hence, will always be properly mated with the lens surface and, therefore, the lens can still be maintained stationary.

It has also been found that this single break-up motion is adequate to produce good quality surfaces without any further break-up movements being necessary. This results in a substantial simplification of the kinematics over prior art systems where several independent break-up motions are frequently necessary.

In an operative embodiment of the present invention the tool can be orbited at speeds of about **1,000** to about **2,000** c.p.m. while plunger **26** is moved up and down at about **20** cycles per minute to vary the radius R_O between about **0.1** to about **1.0** inches. These operating parameters permit a typical lens to be polished in about **1** to **2** minutes.

In summary, the present invention provides a polishing system capable of polishing lenses more rapidly and effectively than heretofore. This is made possible because the lens can be maintained stationary at all times during the polishing operation. Also, because fewer break-up movements are needed, a somewhat less complex system is made possible. To polish toroidal lenses of differing curvature, it is only necessary to change to the appropriate tool, and adjust the gimbal axes **21** and **22** to be spaced from the lens by new distances corresponding to the radii of curvature of the new lens to be polished. Also, with the present invention, it becomes a relatively simple matter to automate the polishing operation. Specifically, as is illustrated in FIG. **1**, because the lenses can be supported rigidly, a production line system can be set up by which lenses are fed one at a time into position to be polished. After lens **10** has been polished, for example, movable support **12** can be actuated and moved in the direction indicated by arrow **41** to feed the next lens **10'** into position to polish its surface **11'**. Where the lenses must be mounted on a movable support, automation would be much more difficult to achieve.

While what has been described is a presently most preferred embodiment, it should be understood that various additions, changes, and omissions may be made from the invention. For example, it is possible, without departing from the invention, to maintain the tool stationary and move the lens relative to it. Also, the system would find use in polishing workpieces other than lenses. Accordingly, the invention should be limited only insofar as required by the scope of the following claims.

I claim:

1. Apparatus for polishing toroidal surfaces comprising:

a. a first member and a second member, one of said members comprising a lapping tool having a toroidal lapping surface and the other of said members comprising means for carrying a workpiece having a toroidal workpiece surface to be polished, the toroidal surfaces of both said lapping tool and said workpiece having a curvature of a first radius in the direction of a first principal meridian thereof and a curvature of a second radius different from said first radius in the direction of a second principal meridian thereof perpendicular to said first principal meridian;

b. means for supporting said first member for pivotal movement in first and second curved paths, said first curved path being parallel to said first principal meridian of the toroidal surface thereof and having a radius equal to said first radius, and said second curved path being parallel to said second principal meridian of the toroidal surface thereof and having a radius equal to said second radius;

c. drive means for driving said first member in a non-rotating orbital manner, said support means causing the toroidal surface of said first member to define and always move in a fixed toroidal surface in space, said fixed toroidal surface in space having the same radial dimensions as the toroidal surfaces of said first and second members; and

d. means for positioning the toroidal surface of said second member on said fixed toroidal surface in space such that during the movement of said first member thereon said workpiece surface will be polished by said lapping tool.

2. Apparatus as recited in claim **1** wherein said support means comprises gimbal means having first and second axes which are perpendicular to each other and perpendicular to said first and second principal meridians, respectively, and wherein said first and second axes are spaced from the vertex of the toroidal surface of said first member by distances equal to said first and second radii, respectively.

3. Apparatus as recited in claim **2,** and further including means for maintaining said second member substantially stationary relative to said first member with the first and second principal meridians of the toroidal surface thereof parallel to the first and second principal meridians of said fixed toroidal surface in space.

4. Apparatus as recited in claim **3,** wherein said first member comprises said lapping tool, and wherein said second member comprises said means for carrying said workpiece.

5. Apparatus as recited in claim **3** and further including means for introducing a breakup motion into the movement of said first member to vary the path of movement of said first member relative to said second member.

6. Apparatus as recited in claim **5** wherein said breakup motion introducing means comprises means for continuously varying the amplitude of the orbit of said first member.

7. The apparatus as recited in claim **6** wherein said drive means drives said first member at an orbital speed of between about **1,000** and **2,000** c.p.m.

8. Apparatus as recited in claim **6** wherein said first member comprises said lapping tool and wherein said second member comprises said means for carrying said workpiece.

9. Apparatus as recited in claim **8** wherein said workpiece comprises a lens.

10. Apparatus as recited in claim **9** wherein said means for carrying said lens comprises conveyor means carrying a plurality of lenses to be polished, said conveyor means including means for positioning said plurality of lenses, one at a time, on said fixed toroidal surface in space to be polished by said lapping tool.

11. Apparatus for polishing toroidal surfaces comprising:

a. a lapping tool having a toroidal lapping surface, said toroidal lapping surface having a curvature of a first radius in the direction of a first principal meridian thereof and a curvature of a second radius different from said first radius in the direction of a second principal meridian perpendicular to said first principal meridian;

b. means for supporting said lapping tool for pivotal movement in first and second curved paths, said first and second paths being parallel to said first and second principal meridians, respectively, and having radii equal to said first and second radii, respectively;

c. drive means for driving said lapping tool in a non-rotating orbital manner whereby said support means will cause the toroidal surface of said lapping tool to define and always move on a fixed toroidal surface in space, said fixed toroidal surface in space having the same radial dimensions as said toroidal lapping surface; and

d. means for positioning a workpiece having a toroidal surface to be polished on said fixed toroidal surface in space such that the movement of said lapping tool thereon will effect polishing of said workpiece.

12. Apparatus as recited in claim **11** wherein said workpiece positioning means comprises means for maintaining the surface thereof stationary on said toroidal surface fixed in space.

13. Apparatus as recited in claim **12** wherein said support means comprises gimbal means having first and second axes which are perpendicular to each other and perpendicular to said first and second principal meridians, respectively, and wherein said first and second axes are spaced from the vertex of the toroidal lapping surface by distances equal to said first and second radii, respectively.

14. Apparatus as recited in claim **13** and further including means for introducing a breakup motion into the movement of said lapping tool to vary the path of movement of said lapping tool relative to said workpiece.

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