Nov. 8, 1966 M. S. LIPKINS 3,283,445

METHODS AND APPARATUS FOR SURFACING SPHERICAL OBJECTS

Filed Jan. 2, 1964

FIG. 1

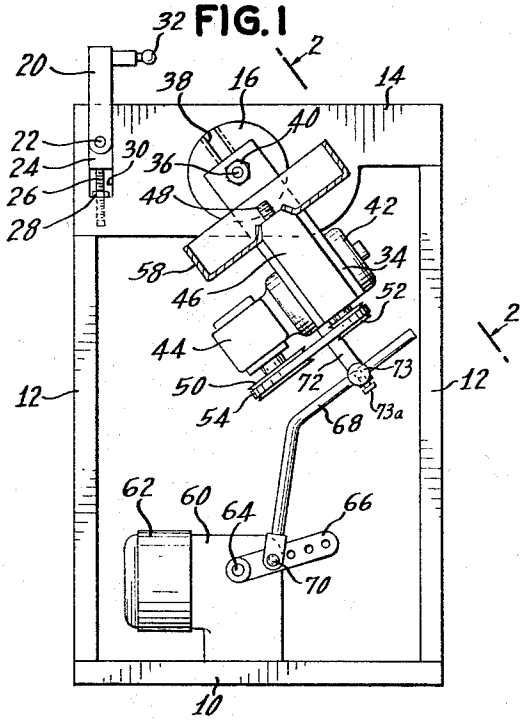


FIG. 2

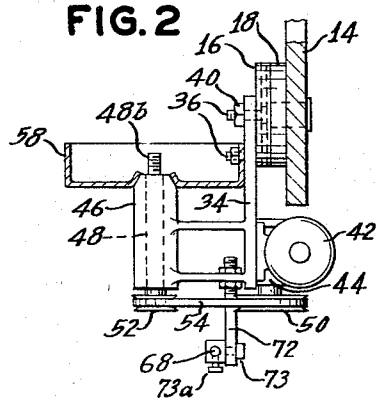


FIG. 3

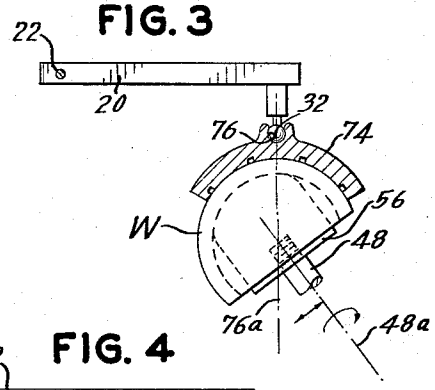


FIG. 4

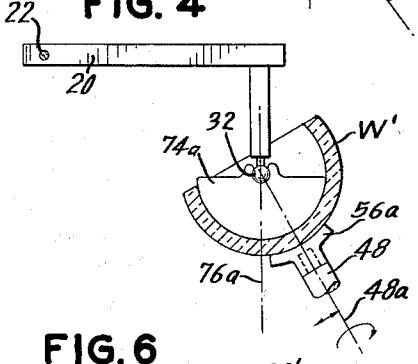


FIG. 5

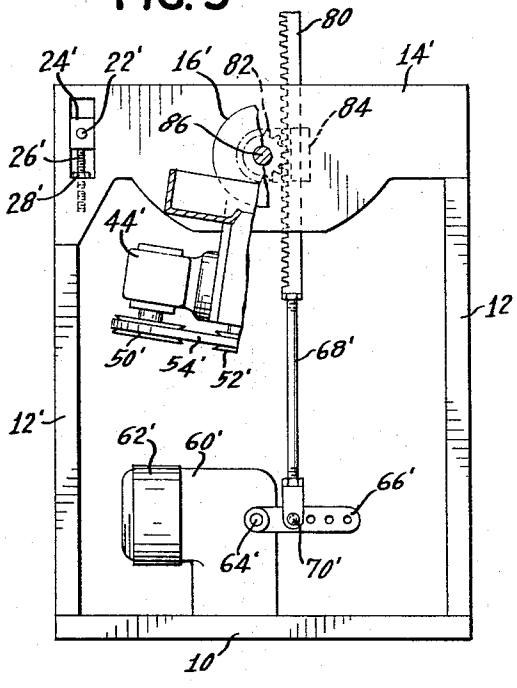
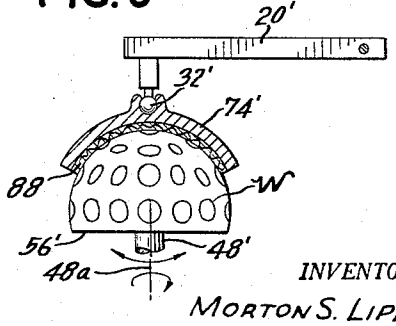


FIG. 6



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METHODS AND APPARATUS FOR SURFACING SPHERICAL OBJECTS

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11 Claims. (Cl. 51—73)

The present invention relates to methods and apparatus for surfacing spherical objects, more specifically by lapping and polishing such objects. The invention is particularly applicable to surfacing hard materials such as glass, quartz, crystalline silicon, synthetic sapphire, metals, et cetera in making lenses, domes, and other articles having spherical surfaces.

An object of the invention resides in the provision of a novel method and apparatus for surfacing objects that is of particular advantage where the objects are of large spherical extent, approaching or even exceeding a hemisphere. As an example, the invention may be applied in lapping and polishing the inner and outer surfaces of spherical domes in a manner to establish and maintain sphericity with optical standards of precision. Pursuant to the present invention, small parts of spheres such as lenses may be lapped and polished. Each individual lens may be of small spherical extent, but in applying the invention many lenses are cemented to a support so as to present a composite spherical surface of large extent that is to be surfaced.

As will be seen in the detailed description that follows, the illustrative embodiments of the invention that are presently preferred for carrying out the foregoing and other objects includes upper and lower members having confronting spherical surfaces, one being a tool and the other being a support that carries one or more articles to be surfaced. The upper member is constrained to rotate about a substantially vertical axis and the lower member is constrained to rotate at about an inclined axis. The incline of the axis is adjustable, and it is either adjusted from time to time during the treatment of a particular object, or the incline of the axis is oscillated as the surfacing continues. In the preferred arrangement the tool is the upper member, and it is not driven but it is induced to rotate as a result of its contact with the work. The tool is restrained against lateral shift, but it is free to rock into full face-to-face contact with the confronting portion of the work and to apply its weight against the work while the work is rotated about its variably inclined axis. The tool thus applies its weight symmetrically or nearly symmetrically, utilizing its surface with maximum effect and uniformity. The work is of large spherical extent, and it is rotated. The tool ordinarily used represents a much smaller part of a sphere than the work. The entire surface of the work is carried into rubbing engagement with the tool in the course of the operation.

The sphericity of the surface being lapped or polished can be controlled by periodically adjusting the incline of the rotational axis of the work. Alternatively, the angle of incline may be cyclically varied during the surfacing operation. In some instances, it may even be found advantageous to oscillate the axis of the work at a greater frequency than the rotation of the work.

The method and apparatus are highly effective in surfacing objects that represent a large part of a sphere, completing the treatment more easily and with excellent control as to maintaining sphericity and in a shorter time than has been needed heretofore in the surfacing of such objects. As applied to lenses of small spherical angle individually, many such lenses can be mounted on a support so as to represent a large spherical angle. Pursuant to the present invention, a much larger number of lenses can be surfaced at one time than heretofore.

Previous methods have usually been limited to smaller numbers of lenses involving a smaller composite spherical angle of the mounted lenses.

The nature of the invention, and its further objects and novel features will be better appreciated from the following description of the preferred embodiments shown in the annexed drawings.

In the drawings:

FIGURE 1 is a front elevation, partly in section, of a presently preferred embodiment of certain features of the invention, in condition to receive the tool and work support shown in FIGS. 3, 4, and 6;

FIGURE 2 is a fragmentary cross-section of the apparatus viewed from the line 2—2 in FIG. 1;

FIGURES 3 and 4 are fragmentary lateral views, partly in cross-section, illustrating the coaction of a tool and a workpiece in the apparatus of FIGS. 1 and 2;

FIGURE 5 is a fragmentary front elevation, partly in cross-section, of a modification of the apparatus in FIGS. 1–4, inclusive; and

FIGURE 6 is a lateral view, partly in cross-section, illustrating the coaction of the tool and the work in the embodiment of FIG. 5.

Referring now to FIGURES 1 and 2, base **10** has a pair of uprights **12** that carry a support **14**. A bearing plate **16** is mounted for rotation about a horizontal axis in the bearing **18**.

Arm **20** is carried on a pivot **22** supported by a block **24**. A stud **26** extending downward from block **24** extends through a nut **28** that rests on the bottom of a slot **30** in support **14**. A projection **32** extends from arm **20**, projection **32** being provided for complemental engagement with the socket of a tool to be described in connection with FIGURES 3 and 4. The stud **26** and nut **28** provide for vertical adjustment of the projection **32** in relation to the horizontal axis of plate **16** for adjustment of the tool relative to the workpiece engaged by the tool.

A bracket **34** extends from plate **16**. Bracket **34** is adjustably fixed to plate **16** by means of studs **36** which have respective heads received in an undercut slot **38** in plate **16**, bracket **34** being clamped to plate **16** by nuts **40** on studs **36**.

Bracket **34** support a motor **42** and a reduction-gearing unit **44**. Bracket **34** also carries a bearing **46** containing a drive shaft **48**. Pulley **50** carried by reduction-gearing unit **44** operates pulley **52** on shaft **48** through a belt **54**.

The upper end of shaft **48** has a portion **48***b* that is threaded and is adapted to be secured to the support **56** for a convex workpiece W (FIG. 3) or to a support **56***a* of a workpiece W′ (FIG. 4) having a concave surface to be treated; and it will be appreciated that either workpiece, W or W′, may be in the form of a matrix to which a large number of smaller workpieces *w* (FIG. 6) are united. The bearing **46** supports a combined shield and tray **58** for catching abrasive slurry that is at times used in the operation of the apparatus described.

On base **10** there is a reduction-gearing unit **60** coupled to a motor **62** that drives this gearing. Output shaft **64** of unit **60** carries a crank **66**. A link **68** is connected by a pivot **70** to crank **66**. The point at which rod **68** is connected to crank **66** is adjustable, as by means of a number of holes in crank **66** for receiving pivot **70**. A rod **72** extends rigidly from bracket **34** and carries a pivot member **73**. A bore in member **73** receives rod **68** slidably for adjusting the effective length of rod **68**, and screw **73***a* fixes rod **68** in any adjusted position. Rotation of shaft **64** and crank **66** causes plate **34** and shaft **48** carried thereby to oscillate about the horizontal bearing axis of plate **16**.

Notably, the axis **48***a* of shaft **48** is at a slant angle in FIGURE 1, and this slant angle changes in dependence

on the position of crank **66** and on the adjustments at the ends of rod **68**.

In the course of rotation of crank **66**, the axis of shaft **48** moves between an extreme angle displaced from the vertical, and approaches a vertical position or even swings past the vertical. The angle through which shaft **48** swings depends on the adjustments at the ends of rod **68**.

When support **56** (FIG. 3) is fixed to shaft **48**, and a workpiece W is fixed to support **56** as by means of cement, the external spherical surface of workpiece W is presented to a tool **74**. Tool **74** may take various forms, depending upon the nature of the operation to be carried out. For example, tool **74** may have a concave inner surface engaging workpiece W, where the tool surface is grooved and the tool is made of cast iron. As abrasive material in the form of slurry may be fed between the work and the tool in any suitable manner, as by applying the slurry to the surface of workpiece W where that workpiece extends outside the tool **74**, or the slurry may be fed through a hole through tool **74**. A socket of tool **74** that engages workpiece W is spherical and complemental to the workpiece, and the tool surface represents a large spherical angle which may approach but does not exceed a hemisphere in extent. The solid angle represented by workpiece W, on the other hand, may approach or exceed a hemisphere. The connection **36**, **38**, **40** between bracket **34** and plate **16** is advantageously adjusted so that the spherical center of the surface to be treated lies along the horizontal axis of bearing **18** about which bracket **34** oscillates. The level of pivot **22** may be adjusted so that the axis of symmetry of tool **74** is vertical and passes through the oscillatory axis of bearing **18**.

In preparing for a lapping operation, a spherical workpiece W or W′ is cemented to to support **56** or **56***a* on the threaded end **48***b* of shaft **48**, and a spherical tool **74** or **74***a* that is at least nearly complemental to the shape of the workpiece is disposed on the workpiece. Projection **32** is received in socket **76**. Using adjustments **26–28** and **36–38–40** (as well as others that may be found desirable) the axis **76***a* of symmetry of the tool and the rotational axis **48***a* of the workpiece are caused to intersect at a point vertically below projection **76**. In this way, the tool rests stably on the workpiece and its bearing force on the workpiece is distributed symmetrically about the vertical axis. The workpiece is rotated about its axis by drive means **42**, **44**, **48**, **50**, **52**, **54**. The surface of tool **74** may be abrasive, and for example tool **74** may be of metal loaded with diamond particles. In a modified application, abrasive slurry is fed to the engaged surfaces of the tool and the workpiece. As the workpiece rotates, the tool is caused to rotate, but at a lower speed, so long as the axis of the work is inclined in relation to the tool axis; and as a result, the surface of the workpiece is lapped.

Accurate control of sphericity is achieved by varying the angle of incline of shaft **48**. This is accomplished in either of two ways, either by indexing crank **66** from time to time during the rotation of shaft **48**, or by rotating crank **66** continuously. Both techniques are useful in succession, in completing the lapping treatment quickly and in correcting for distortions that may exist initially and those that may occur as the treatment progresses. The oscillation of axis **48***a* may be made rapid and the rotation about axis **48***a* be relatively slow. Experience will show that each of these motions is useful in quickly lapping the nearly spherical surface of the workpiece to the desired smoothness, radius, and spherical uniformity. Thereafter, the same motions may be used in polishing the lapped surface, as with rouge and with a clothfaced tool such as that shown in FIG. 6.

Depending on the proportions of the tool and the workpiece, the range of oscillation of shaft **48** may be varied to advantage, by adjusting the length of rod **68** between pivots **70** and **73**, and by adjusting the radial position of pivot **70** on crank **66**. At its maximum angle of inclination, the shaft **48** will ordinarily cause the circular edge of the tool to be tangent to the circular edge of the work, although a somewhat greater angle of inclination is permissible as illustrated in FIG. 4.

The method and the apparatus described are useful in surfacing convex spherical objects W and concave objects W′. The method and apparatus are also used to special advantage where the spherical angle of the object is large so as to approach or even exceed a hemisphere. The method and apparatus are also of special merit where many objects *w* (FIG. 6) are to be lapped and/or polished in one operation. By virtue of the large spherical angle of the surface treatment, a relatively large number of lenses can be surfaced in one operation, a larger number than would be possible in surface-treating arrangements limited to smaller spherical angles. The treatment proceeds rapidly and with excellent control by virtue of the symmetry of pressure distribution of the tool, and the varied incline of the work (whether by successive adjustments or by continuous variation) provides control that helps the attendant to correct errors initially present and to maintain sphericity to a high degree of accuracy.

FIGURE 5 is a modification of the apparatus in FIGURES 1 and 2, in providing a modified mechanism for oscillating the axis of plate **16**, and for accordingly swinging the rotational axis of shaft **48** in a vertical plane. The parts in FIGURE 5 which correspond to those in FIGURES 1 and 2 bear primed numerals and in the interest of brevity their description is not repeated here. Rod **68′**, which is operated by crank **66′**, carries a rack **80** that meshes with a pinion **82** at the back of support plate **14′**, rack **80** being held in mesh with pinion **82** by a guide **84**. Pinion **82** operates a shaft **86** that is rigidly fixed to plate **16′**. The mechanism illustrated in FIGURE 1 provides for limited oscillation of the axis of shaft **48** between angular limits from a maximum slope toward the vertical axis (and to some limited extent across the vertical axis in some conditions of adjustment). The apparatus of FIGURE 5 includes a modified form of oscillating mechanism that provides for a wider angle of oscillation of shaft **48**. The oscillation of shaft **48** has a range that is as far to one side of the vertical as the other.

The tool shown in FIGURE 6 rests on a number of small workpieces *w* such as lenses which are united in a cement or matrix as of pitch on the work support **56′**. In FIGURE 6, the surface of tool **74′** has a cloth or felt covering **88**, and is suitable for use with polishing agents such as rouge.

The foregoing description of the presently preferred but illustrative embodiments of the invention in its various aspects is evidently susceptible of modification and the novel features may be utilized in other analogous applications by those skilled in the art. Consequently, the invention should be construed broadly in accordance with its full spirit and scope.

What is claimed is:

1. The method of subjecting a spherical object to a surfacing treatment, comprising the steps of supporting the object for rotation about an axis that passes symmetrically through said object, resting an at least approximately complemental spherical tool on said surface with surface-treating material interposed, restraining the center of said tool against displacement from a vertical axis through the spherical center of said surface, oscillating said axis repeatedly across a significantly inclined mean position about a horizontal axis that passes through said spherical center, and, concurrently, rotating said object about said axis.

2. The method set forth in claim **1**, wherein said axis is oscillated many times during each rotation of the object about its axis.

3. The method set forth in claim **1**, wherein the object is rotated many times during each oscillation of the axis of rotation.

4. The method of subjecting a spherical object to a surfacing treatment, comprising the steps of supporting

the object for rotation about an axis that passes symmetrically through the object and driving said object about said axis, resting an at least approximately complemental spherical tool on said surface with surface-treating material interposed, the tool having the shape of a spherical sector and having an object-treating surface over substantially the whole sector, the tool being induced to rotate by rotation of the object, and for the duration of the treatment maintaining the axis of rotation of the object at positions varying from one side to the other of a substantially inclined mean position.

5. Apparatus for surface-treating an object having a large-angle spherical surface, said apparatus including a tool having a spherical-sector work-treating surface, a spindle having a work support at the upper end thereof for supporting an object whose surface is to be treated, first drive means for rotating said spindle, means for locating said tool over the object while allowing free rotation about a vertical axis and free seating gravitationally on a spherical-surfaced object, means supporting said spindle for oscillation about a horizontal axis through the spherical center of the object, and second drive means for oscillating said spindle about said horizontal axis to opposite sides of a substantially inclined mean position.

6. Apparatus in accordance with claim **5** wherein the locating means includes means for arresting the center of the tool along a fixed vertical axis.

7. Apparatus in accordance with claim **5** wherein said first and second drive means are coordinated to effect plural oscillations of said spindle for each rotation thereof.

8. Apparatus in accordance with claim **5** wherein said first and second drive means are coordinated to effect plural rotations of said spindle for each oscillation thereof.

9. The method of subjecting a spherical object to a surfacing treatment wherein the object and a substantially complemental spherical-sector surfacing tool are members held in contact with each other while being moved relative to each other about a common spherical center, including the steps of supporting one of said members from below as a lower member for rotation about an axis through said common spherical center, resting the other or upper member on said lower member, and rotating one of said members about an axis through said common spherical center and inducing rotation of the other member about an axis through said common spherical center, and for the duration of the treatment maintaining the axis of said lower member in positions varying to opposite sides of a substantially inclined mean position.

10. The method set forth in claim **9** wherein said axis of said lower member is oscillated about said mean position during the surfacing treatment.

11. Apparatus for surface-treating an object having a spherical surface with a complemental spherical surfacing tool, where said object and said tool are spherical members held in mutual contact one above the other and moved relative to each other about a common spherical center, said apparatus including a spindle having at the upper end thereof a support for the lower one of said members, means locating the upper member above the lower member while allowing free seating of the upper member on said lower member, means for rotating one of said members and thereby inducing rotation of the other of said members, and means for oscillating said spindle about a substantially inclined mean position.

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