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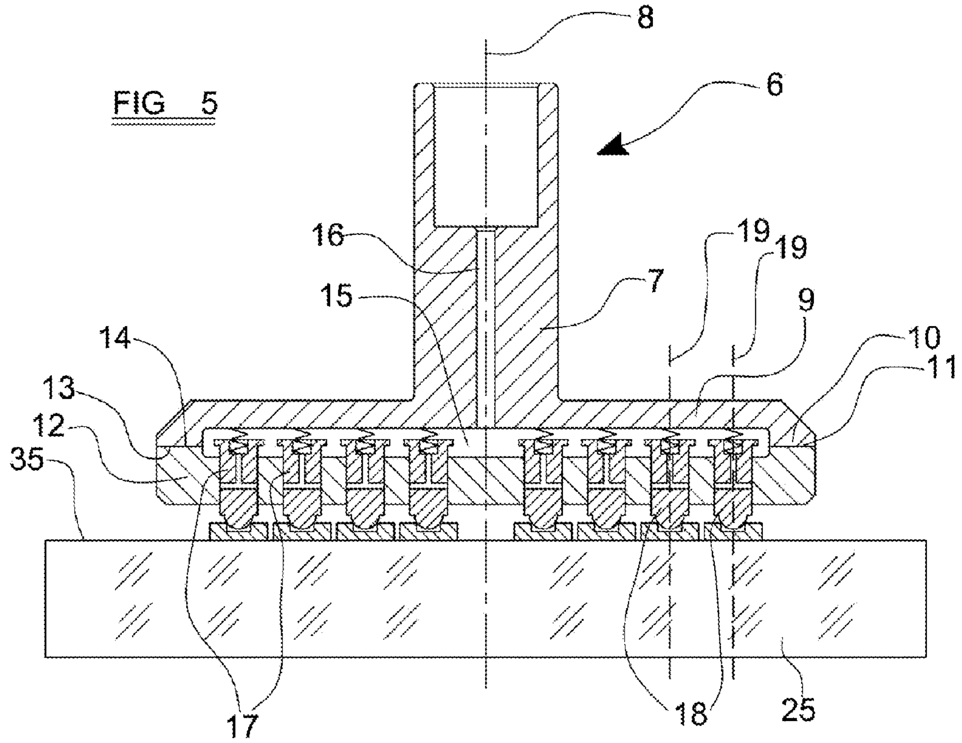
(54) **Tool for smoothing or polishing optical surfaces**

(57) There is disclosed a tool for smoothing or polishing an optical surface. The tool comprises: a body part which is rotatable about an axis of rotation; and a plurality of pads arranged in an array to bear against said optical surface for movement across the surface as the tool is rotated about said axis of rotation, wherein said pads are each mounted: i) for substantially linear movement relative to said body part in a direction substantially normal to said surface in the region where the pad contacts the surface; and ii) universal pivotal movement relative to said body part. The pads are biased towards said optical surface. In a preferred arrangement, a plurality of pistons are mounted for individual reciprocating movement relative to the body part along respective longitudinal axes, each of said pistons having a distal end to which a respective said pad is universally articulated, wherein said pistons are each biased towards said optical surface.

FIG 5



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Description

[0001] The present invention relates to a tool for smoothing or polishing optical surfaces. The invention is particularly suited to smoothing aspheric and freeform optical surfaces.

[0002] The production of high quality optics such as lenses or mirrors requires the creation of extremely smooth and highly polished optical surfaces. Figure 1 illustrates in schematic form a typical chain of process steps used in the production of high quality optics having spherical or flat optical surfaces. Initially, the surface of the lens or mirror is ground so as to conform closely to the desired surface profile. The grinding step is then followed by a smoothing step which is effective to remove surface errors such as ripples or waviness (so-called "mid-spatial" features) arising from the initial grinding step, and to provide a finely smoothed surface preparatory for the next step of polishing.

[0003] Although the prior art method illustrated in figure 1 is well suited to the creation of spherical or flat optical surfaces, it is not well suited to the creation of substantially aspheric or freeform optical surfaces. One of the problems with trying to apply the steps of the method shown in figure 1 to the formation of an aspheric or freeform surface, is that the relatively large smoothing tools typically used commercially for the smoothing step on spherical or flat surfaces cannot be conveniently used to smooth an aspheric or freeform surface without altering the underlying profile of the surface created by the preceding grinding step. In an attempt to avoid this problem, it has therefore been proposed to use much smaller smoothing tools, which present a smaller surface area of smoothing pad. As will be appreciated, however, reducing the effective surface area of the smoothing tool in this way results in a corresponding increase in the amount of time taken by the smoothing step because only a relatively small part of the optical surface can be worked at a time. For this reason, most commercial methods for the production of aspheric or freeform optics tend to omit the smoothing step altogether, as shown schematically in figure 2, which thus places much more importance on the accuracy of the preceding grinding step, and increases the process time of the polishing step.

[0004] There is thus a need for a smoothing tool which is particularly suitable for use in the production of aspheric or freeform optical surfaces and which can thus be used in a smoothing step intermediate the grinding and polishing steps.

[0005] It is an object of the present invention to provide an improved tool for smoothing or polishing an optical surface.

[0006] According to an aspect of the present invention, there is provided a tool for smoothing or polishing an optical surface, the tool comprising: a body part which is rotatable about an axis of rotation; a plurality of pistons mounted for individual reciprocating movement relative to the body part along respective longitudinal axes, each of said pistons having a distal end to which a respective pad is universally articulated, said pads being arranged in an array to bear against said optical surface for movement across the surface as the tool is rotated about said axis of rotation, wherein said pistons are each biased towards said optical surface along their respective longitudinal axes.

[0007] Conveniently, each said piston is spring-biased towards said optical surface.

[0008] Advantageously, each said piston is biased towards said optical surface by a respective spring.

[0009] Preferably, each said spring is a compression spring.

[0010] Advantageously, the spring constant of each spring is determined in dependence on the radial distance of the respective piston from the axis of rotation of the tool.

[0011] Conveniently, the spring constants of the individual springs are inversely proportional to the radial distance of the respective pistons from the axis of rotation of the tool.

[0012] Preferably, each said piston is mounted for sliding movement within a respective bore, and comprises at least one internal flow conduit in fluid communication with an outlet port provided in the piston to direct lubricating fluid between the piston and the bore.

[0013] Advantageously, the internal flow conduits are all provided in fluid communication with a plenum chamber within the body part.

[0014] Conveniently, the plenum chamber is supplied with lubricating fluid via a flow channel which is substantially coaxial with the axis of rotation of the body part.

[0015] Preferably, said lubricating fluid is compressed air.

[0016] Advantageously, each pad is mounted to the distal end of the respective piston via a ball joint.

[0017] Conveniently, each ball joint comprises flexible adhesive to secure the pad to the piston.

[0018] Preferably, each pad is mounted to the distal end of the respective piston via a spherical bearing.

[0019] Conveniently, said pads are arranged in a substantially planar array.

[0020] Alternatively, wherein said pads may be arranged in either a substantially convex array, or a substantially concave array.

[0021] Preferably, each pad is substantially circular in shape.

[0022] According to another aspect of the present invention, it is proposed to use a tool of the type defined above for smoothing or polishing an optical surface having a predefined surface profile to remove or reduce surface waves, wherein each pad is configured so as to have a diameter which is greater than the wavelength of the surface waves.

[0023] So that the invention may be more readily understood, and so that further features thereof may be appreciated, embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is a schematic block diagram illustrating method steps conventionally used to produce spherical or flat optical surfaces;

Figure 2 is a similar schematic block diagram illustrating a modified method used to produce aspheric or free-form optical surfaces;

Figure 3 is a schematic diagram showing a free-form optical surface profile with a small wavelength surface error;

Figure 4 is a diagram corresponding generally to figure 3, but which shows the surface error having been smoothed out;

Figure 5 is a transverse cross-sectional view through a tool in accordance with the present invention;

Figure 6 is an enlarged cross-sectional view through an individual piston, with associated smoothing pad, of the tool shown in figure 5;

Figure 7 is a schematic diagram, showing two different pads (or alternate positions of the same pad) in use to smooth an optical surface having a surface error feature;

Figure 8 is a transverse cross-sectional view, similar to that of figure 5, but which shows an alternative embodiment of the tool of the present invention;

Figure 9 is a transverse cross-sectional view showing another embodiment of the tool of the present invention; and

Figure 10 is a perspective view, from below, showing a tool in accordance with another proposal.

[0024] Turning now to consider figure 3 in more detail, there is illustrated a surface form measurement plot for a workpiece after an initial grinding step, but before any other processing has been performed. The optical surface is denoted by the plot line 1. As will be noted, the surface 1 has an underlying profile shape on which is superimposed a surface error feature of relatively small wavelength, as represented by the series of closely spaced peaks 2 and troughs 3. The mean wavelength of the surface error is represented schematically at 4.

[0025] It is desirable to remove, or at least substantially remove, the surface error feature 2, 3 via a smoothing step, so as to produce a smoothed surface profile generally similar to that illustrated schematically by line 5 in figure 4 by way of contrast. The tool of the present invention, which is described in more detail below, is effective to produce a surface profile similar to that shown in figure 4, by removing the surface error 2, 3 in the profile shown in figure 3, and is particularly suitable for use on aspheric or free-form surface profiles.

[0026] Turning now to consider figure 5, there is illustrated the head of a tool in accordance with the present invention. The tool head comprises a body part 6 which is preferably formed from stainless steel, and comprises an elongate central shank 7 which is centred on a central axis of rotation 8. At its upper end, the shank 7 is configured to be engaged with an actuating mechanism (not shown) operable to rotate the tool body 6 about the axis 8, and also to move the tool head in an appropriate oscillatory manner generally known *per se* in the field of smoothing and lapping tools.

[0027] An integrally formed circular flange 9 extends radially outwardly from the lower end of the shank 7, and has a small downwardly directed lip 10 formed around its periphery. The lip 10 defines a planar annular engaging surface 11.

[0028] A circular cover plate 12 is provided, which is again preferably formed of stainless steel and which is of substantially equal diameter to the flange 9. The cover plate 12 has a small upwardly directed lip 13 formed around its periphery which defines a planar annular engaging surface 14 configured for mating engagement with the similar surface 11 of the downwardly directed lip 10. The cover plate 12 is affixed to the flange 9 such that the two surfaces 11, 14 are brought into engagement with one another in the manner illustrated in figure 5.

[0029] As will be seen from figure 5, with the cover plate 12 and the circular flange 9 affixed to one another as described, a small circular plenum chamber 15 is defined between the flange 9 and the cover 12. The plenum chamber 15 is provided in fluid communication with a central flow channel 16 which extends along the length of the shank 7 and which is substantially coaxial with the axis of rotation 8. During use of the tool the flow channel is used to feed a supply of lubricating fluid, most preferably compressed air, to the plenum chamber for reasons that will be explained in more detail hereinafter.

[0030] The cover plate 12 is provided with a plurality of substantially cylindrical bores 17, each of which extends fully from one side of the plate to the other. The bores 17 are arranged in a generally circular array so as to cover the major extent of the cover plate 12. Within each bore 17, there is slideably received a respective piston 18. As will be appreciated, each piston 18 is thus mounted for individual reciprocating movement relative to the tool body 6 along a respective axis 19. In the arrangement illustrated in figure 5, the axes 19 of all of the pistons are parallel.

[0031] Figure 6 illustrates a single piston 18 in greater detail. Each piston 18 is generally cylindrical in form, having a proximal end 20 and a distal end 21, and is preferably formed from either phosphorous bronze or brass. The main part of the cylindrical piston has a diameter slightly less than the diameter of its corresponding bore 17, so as to form a close sliding fit within the bore.

[0032] At its proximal end, each piston 18 is provided with a small outwardly directed retaining lip 22 which has a diameter greater than the diameter of the bore 17. As shown in figure 5, the retaining lip of each piston 18 is received within the plenum chamber 15 when the cover plate 12 and the flange 9 are connected, and thus serves to prevent the piston falling out of its respective bore 17, effectively holding the piston captive with respect to the tool body 6.

[0033] Also at its proximal end, each piston is provided with a central recess 23, the recess being of generally cylindrical form and centred on the longitudinal axis 19 of the piston. The recess 23 of each piston receives the lower end of a respective biasing spring 24. In the particular arrangement illustrated, the biasing springs are helically wound compression springs, and are preferably formed from stainless steel.

[0034] As illustrated in figure 5, with each piston 18 received in its respective bore 17, the upper ends of the biasing springs 24 bear against the lower surface of the flange 9. The springs 24 thus act to bias their respective pistons away from the flange 9.

[0035] The distal end 21 of each piston carries a smoothing/polishing pad 26. Each pad 26 is preferably circular in form and comprises a substantially rigid plate (preferably formed of aluminium), and presents a downwardly directed planar smoothing/polishing surface 27. The surfaces 27 of the pads 26 may be provided with a thin coating of polyurethane or similar material for polishing purposes, thereby allowing the tool to be used for polishing. Alternatively, the surfaces 27 may be provided with a thin layer of abrasive material, for example comprising diamond, thereby making the tool suitable for smoothing purposes.

[0036] Each pad 26 is universally articulated to the distal end of its respective piston, so as to be mounted for substantially universal pivotal movement relative to the tool body 6, about the end of the piston. This universal articulation may be achieved in a number of alternative ways, but is most preferably provided by way of a so-called ball joint. For example, in the particular arrangement illustrated, the distal end of each piston is provided with a downwardly projecting ball 28 which is received in a corresponding socket 29 formed on the upper side of the respective pad 26. Each pad 26 is secured to the distal end of its respective piston 18 via an annular fillet 30 of flexible adhesive (such as silicone adhesive) extending around the ball 28, the fillet being sufficiently pliable so as not to interfere substantially with the universal pivotal movement of the pad.

[0037] The size of the pads 26 is carefully selected, in dependence on characteristics of the optical surface on which the tool is to be used. This will be explained in more detail hereinafter.

[0038] As illustrated most clearly in figure 6, each piston 18 is also provided with a system of internal flow conduits. More particularly, each piston comprises a central flow conduit 31 which runs downwardly from an open end 32 provided within the recess 23, towards the distal end 21. The central flow conduit 31 is coaxial with the longitudinal axis 19 of the piston and terminates approximately mid-way between the two ends of the piston, at which point a pair of oppositely-directed radial conduits 32 extend outwardly, terminating with respective outlet ports 34 provided in the external surface of the piston.

[0039] As can be seen from figure 5, the flow conduits 32, 33 within each piston are provided in fluid communication with the plenum chamber 15, and hence receive a flow of lubricating fluid (preferably compressed air), and direct the lubricating fluid to the outlet ports 34, so as to provide a thin film of lubricating fluid between the outer surface of the pistons 18 and their respective bores 17. It is proposed that during use of the tool, the lubricating fluid will be maintained at an elevated pressure within the plenum chamber, such that there is a substantially constant flow of fluid through the outlet ports, thereby expelling any polishing slurry or machine coolant which may otherwise penetrate the tool.

[0040] As will be appreciated having particular regard to figure 5, the above-described tool presents an array of smoothing/polishing pads 26 to bear against the target optical surface 35 of the workpiece 25. Each pad is mounted for substantially linear movement along a respective piston axis 19, and thus in a direction substantially normal to the optical surface 35 in the region where the pad contacts the surface 35. Each pad is also mounted for universal movement relative to the tool body, and is also biased towards the tool body. The pads are thus arranged so as to move independently of one another and to remain in substantially intimate contact with the surface 35, as the tool is rotated about its axis 8 and moved in an oscillatory manner across the surface 35. Together, the pads thus present a significant area of smoothing/polishing surface to the workpiece.

[0041] Figure 7 illustrates in more detail the articulation of the pads 26 and their size relative to the features of the target surface 35. Two alternate pad positions are shown at a) and b). The diagram also shows the surface error "waviness" as represented by the small peaks 2 and troughs 3, and the underlying surface profile curve 5. As will be seen, each pad has a diameter D which is greater than the wavelength 4 of the surface error pattern. This ensures that the pads 26 always ride over the waves of the surface error feature such that their movement relative to the surface is effective to smooth out the error feature.

[0042] At position b) in figure 7, the pad 26 is shown in a tilted position effective to conform generally to the local curvature of underlying surface profile1. As will be appreciated, because each pad is mounted for individual linear and pivotal movement, all the pads remain substantially in contact with the target surface as the tool head is moved across the surface. However, it is important that each pad 26 has a diameter which is not so large relative to the radius of curvature of the underlying surface profile 1 that its edges impinge on the surface profile through the surface error feature, because if that were to occur, then the tool could change the shape of the profile 1. It is proposed that the maximum permissible pad diameter will be calculated empirically in dependence on factors such as the tightest radius of curvature of the surface profile 1, the grain size of any polishing or smoothing compound used, and other operating factors such as rotational speed, oscillation speed, and pressure.

[0043] As will be appreciated, because the tool head 6 is rotated about its central axis 8 during use, the pads 26 located near the periphery of the tool will move across the optical surface 35 at greater speed than those located nearer to the rotational axis 8. In order to provide a substantially uniform material removal profile across the diameter of the tool, it is therefore proposed that the biasing force of each spring 24 be individually tailored to the relative position of the spring and its associated pad within the overall array of pads. In particular, to avoid to excessive removal of material from the optical workpiece by the peripheral pads 26, it is proposed that the springs 24 biasing the peripheral pads 26 towards the workpiece will have a smaller spring constant than those arranged to bias pads located more centrally within the array. It is therefore proposed that the spring constant of each spring 24 is determined in dependence on the radial distance of the respective piston 18 from the central axis of rotation 8 of the tool. More particularly, it is proposed that the spring constants of the individual springs 24 are inversely proportional to the radial distance of their respective pistons 18 from the axis of rotation 8 of the tool.

[0044] As will be appreciated, the tool of the present invention has been described above with specific reference to an embodiment in which the flange 9 and the associated cover plate 12 are generally planar, and in which the pistons are all arranged for reciprocating movement along parallel axes 19. The pads 26 are thus arranged in a generally planar array. However, it is envisaged that in variants of the invention, the pads may be arranged either in a generally convex array (as illustrated in figure 8), or a generally concave array (as illustrated in figure 9) for use in smoothing or polishing a generally concave or convex workpiece respectively.

[0045] For example, the variant illustrated in figure 8 is configured such that the pistons 18 are mounted for reciprocating movement along axes 19 which are divergent in the sense that they diverge with increasing distance away from the upper end of the spindle 7. This presents a convex array of pads 26 for contact with a concave optical surface 35.

[0046] The variant illustrated in figure is configured such that the pistons 18 are mounted for reciprocating movement along axes 19 which are convergent in the sense that they converge with increasing distance away from the upper end of the spindle 7. This presents a concave array of pads 26 for contact with a convex optical surface 35.

[0047] Whilst the invention has been described above with reference to specific embodiments, it is to be appreciated that certain modifications or alterations can be made to the tool without departing from the scope of the claimed invention. For example, it is envisaged that variants of the tool could use spherical bearings rather than ball joints to mount the pads 26 to the pistons in order to provide the necessary universal articulation.

[0048] Whilst it is considered preferable to use a supply of compressed air or other gas as the above-mentioned lubricating fluid, it is envisaged that the tool may alternatively be used with a liquid lubricant.

[0049] Although the tool body 6 has been described above as preferably being made from stainless steel, other materials are also suitable. For example, it is envisaged that the body may be made from aluminium, or even plastics materials. Similarly, the pistons 18 need not necessarily be made from phosphorous bronze or brass, and could instead be made from other convenient materials such as low friction or self-lubricating materials (e.g. Nylon or PTFE).

[0050] Figure 10 illustrates a tool in accordance with another proposal, as viewed from below showing the array of individual smoothing/polishing pads 26. In this arrangement, there are provided no pistons. Instead, the cover plate 12 of the embodiment described above has effectively been replaced with a circular membrane or diaphragm 36 formed of resiliently deformable material such as an elastomer. The membrane is affixed to the flange 9 so as to define a similar plenum chamber between the diaphragm and the flange. The pads 26 are affixed directly to the outer surface of the membrane. In its relaxed condition, the membrane can either be: substantially planar as illustrated in figure 10 (thereby presenting a planar array of pads similar to the arrangement of figure 5); convex (thereby presenting a convex array of pads similar to the arrangement of figure 8); or concave (thereby presenting a concave array of pads similar to the arrangement of figure 9).

[0051] Because the membrane is resiliently deformable, and has a degree of flexibility, it effectively serves the function of the individual pistons of the previously described arrangements by biasing the pads 26 towards the target optical surface and supporting the pads 26 for i) substantially linear movement relative to the body part 6 of the tool in a direction substantially normal to the target optical surface in the region where the pad contacts the surface, and ii) universal pivotal movement relative to the body part.

[0052] When used in this specification and claims, the terms "comprises" and "comprising" and variations thereof mean that the specified features, steps or integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or integers.

[0053] The features disclosed in the foregoing description, or in the following claims, or in the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for obtaining the disclosed results, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

[0054] While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure. Accordingly, the exemplary embodiments of the invention set forth above are considered to be illustrative and not limiting. Various changes to the described embodiments may be made without departing from the spirit and scope of the invention.

Claims

1. A tool for smoothing or polishing an optical surface, the tool comprising: a body part which is rotatable about an axis of rotation; a plurality of pistons mounted for individual reciprocating movement relative to the body part along respective longitudinal axes, each of said pistons having a distal end to which a respective pad is universally articulated, said pads being arranged in an array to bear against said optical surface for movement across the surface as the tool is rotated about said axis of rotation, wherein said pistons are each biased towards said optical surface along their respective longitudinal axes.

2. A tool according to claim 1, wherein each said piston is spring-biased towards said optical surface.

3. A tool according to claim 2, wherein each said piston is biased towards said optical surface by a respective spring.

4. A tool according to claim 3, wherein the spring constant of each spring is determined in dependence on the radial distance of the respective piston from the axis of rotation of the tool.

5. A tool according to claim 4, wherein the spring constants of the individual springs are inversely proportional to the radial distance of the respective pistons from the axis of rotation of the tool.

6. A tool according to any preceding claim, wherein each said piston is mounted for sliding movement within a respective bore, and comprises at least one internal flow conduit in fluid communication with an outlet port provided in the piston to direct lubricating fluid between the piston and the bore.

7. A tool according to claim 6, wherein the internal flow conduits are all provided in fluid communication with a plenum chamber within the body part.

8. A tool according to claim 7, wherein the plenum chamber is supplied with lubricating fluid via a flow channel which is substantially coaxial with the axis of rotation of the body part.

9. A tool according to any one of claims 6 to 8, wherein said lubricating fluid is compressed air.

10. A tool according to any preceding claim, wherein each pad is mounted to the distal end of the respective piston via a ball joint.

11. A tool according to claim 10, wherein each ball joint comprises flexible adhesive to secure the pad to the piston.

12. A tool according to any one of claims 1 to 9, wherein each pad is mounted to the distal end of the respective piston via a spherical bearing.

13. A tool according to any preceding claim, wherein said pads are arranged in a substantially planar array; or a substantially convex array; or a substantially concave array.

14. A tool according to any preceding claim, wherein each pad is substantially circular in shape.

15. Use of a tool according to claim 14 for smoothing or polishing an optical surface having a predefined surface profile to remove or reduce surface waves, wherein each pad is configured so as to have a diameter which is greater than the wavelength of the surface waves.

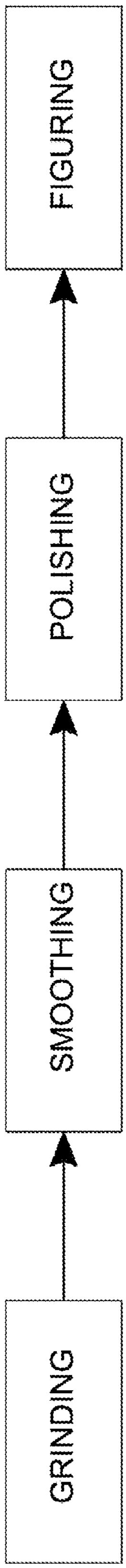
GRINDING
SMOOTHING
POLISHING
FIGURING

FIG 1

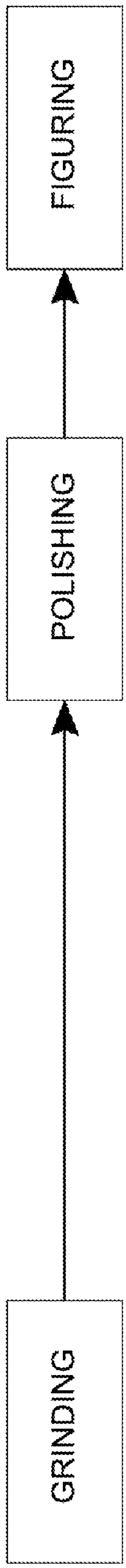
GRINDING
POLISHING
FIGURING

FIG 2

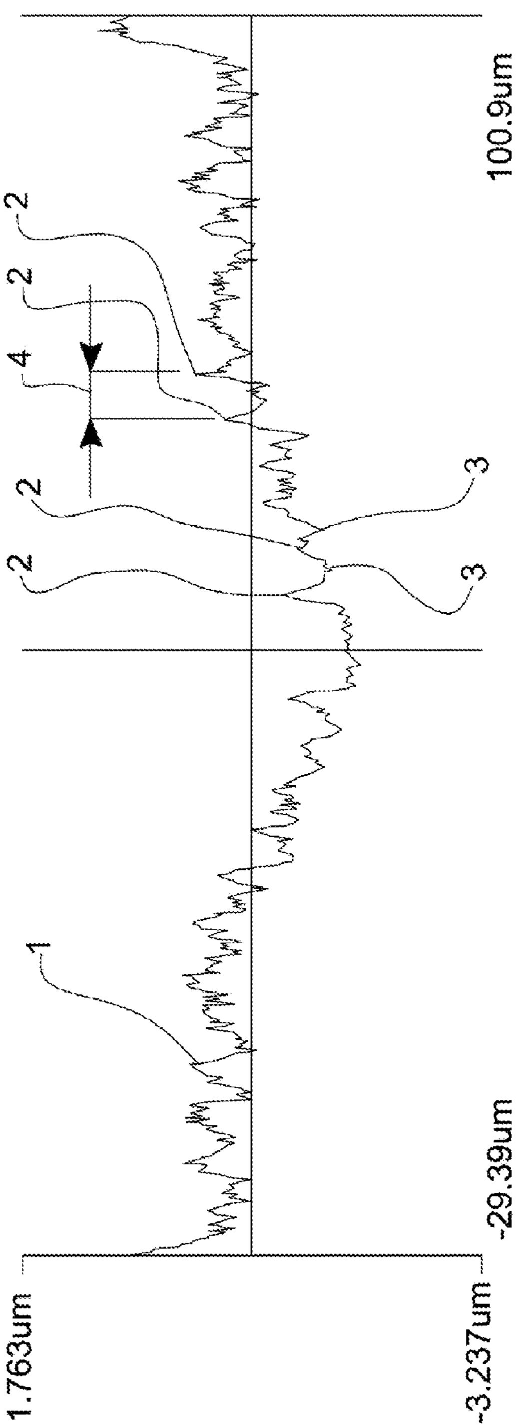
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FIG 3

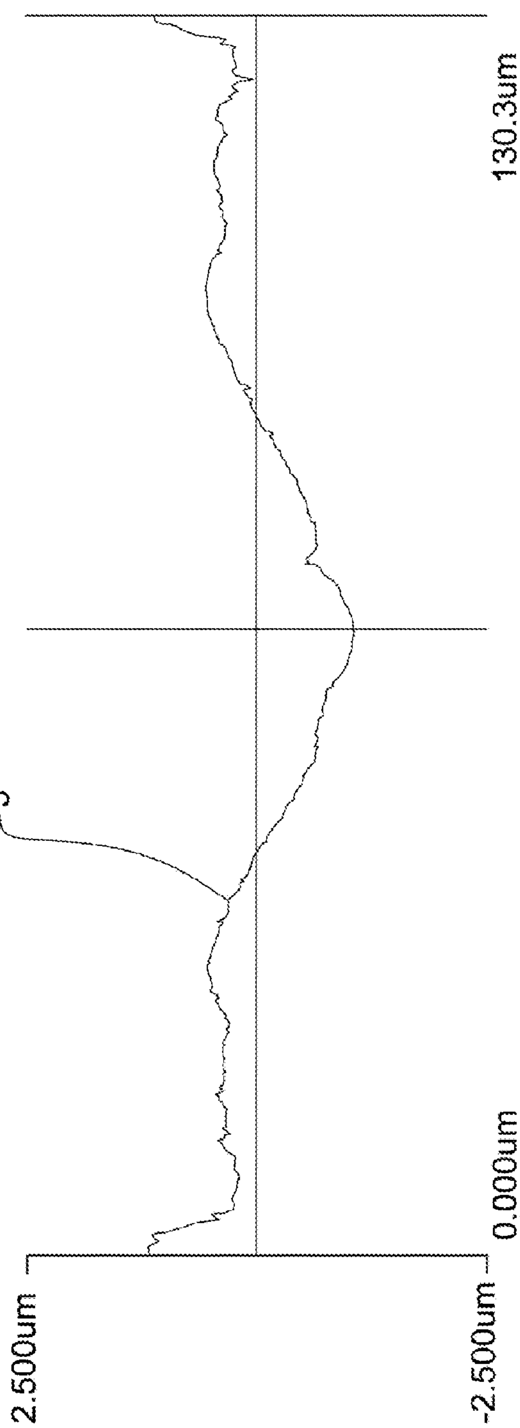
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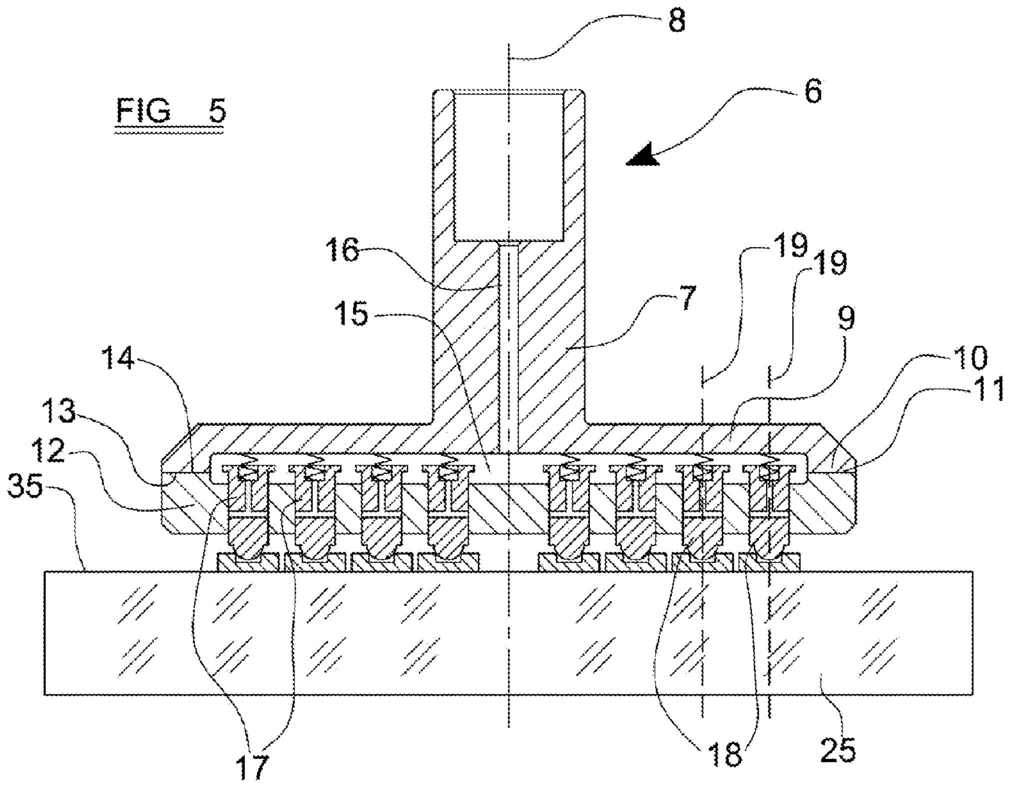
FIG 4

FIG 5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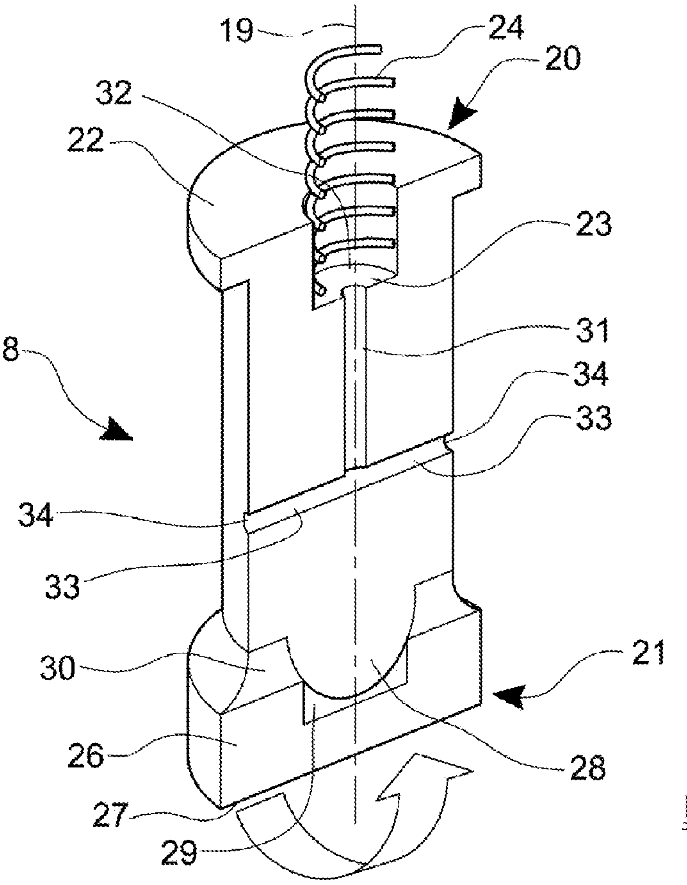
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FIG 6

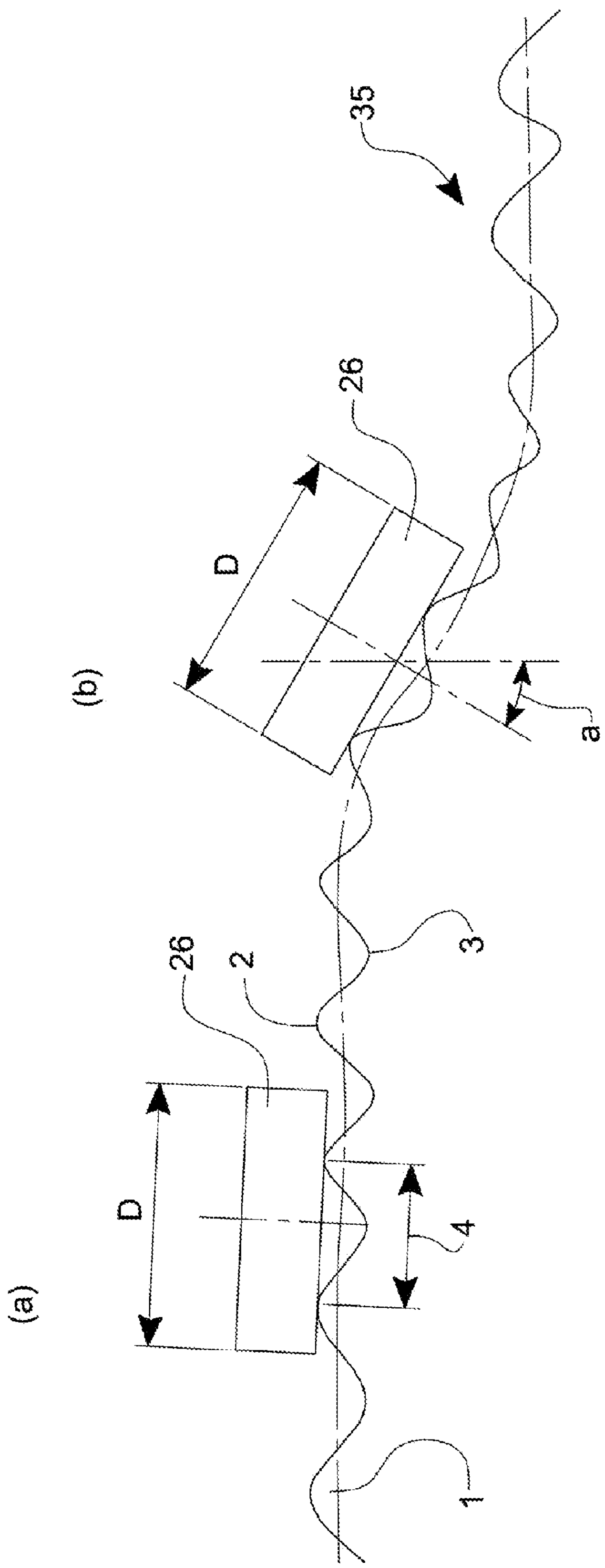

FIG 7

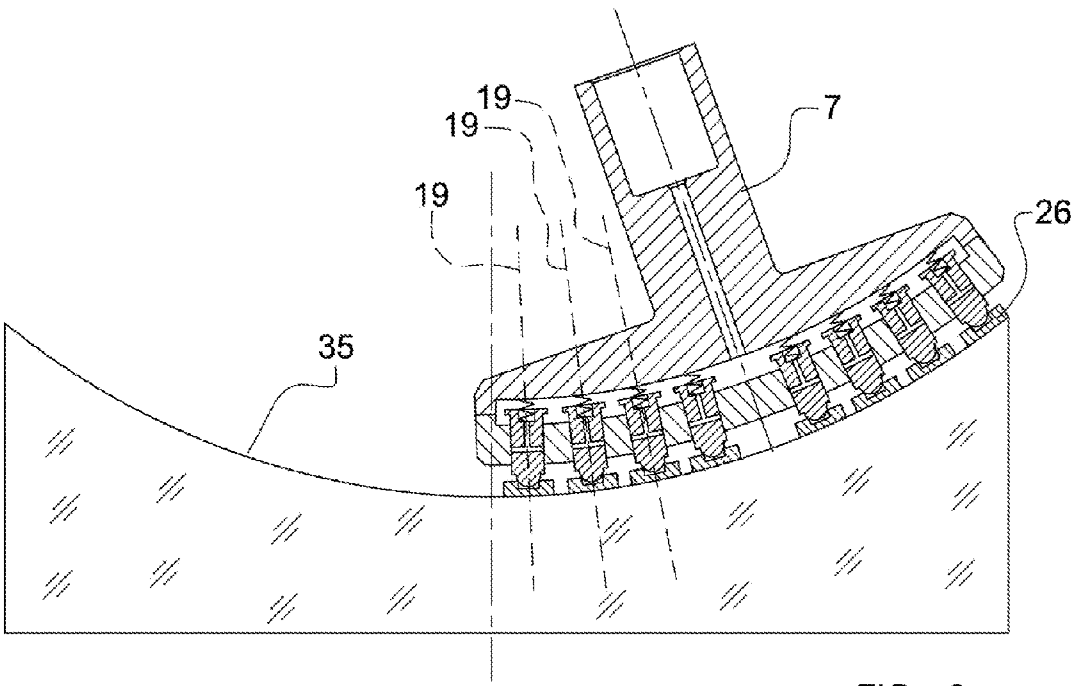

FIG 8

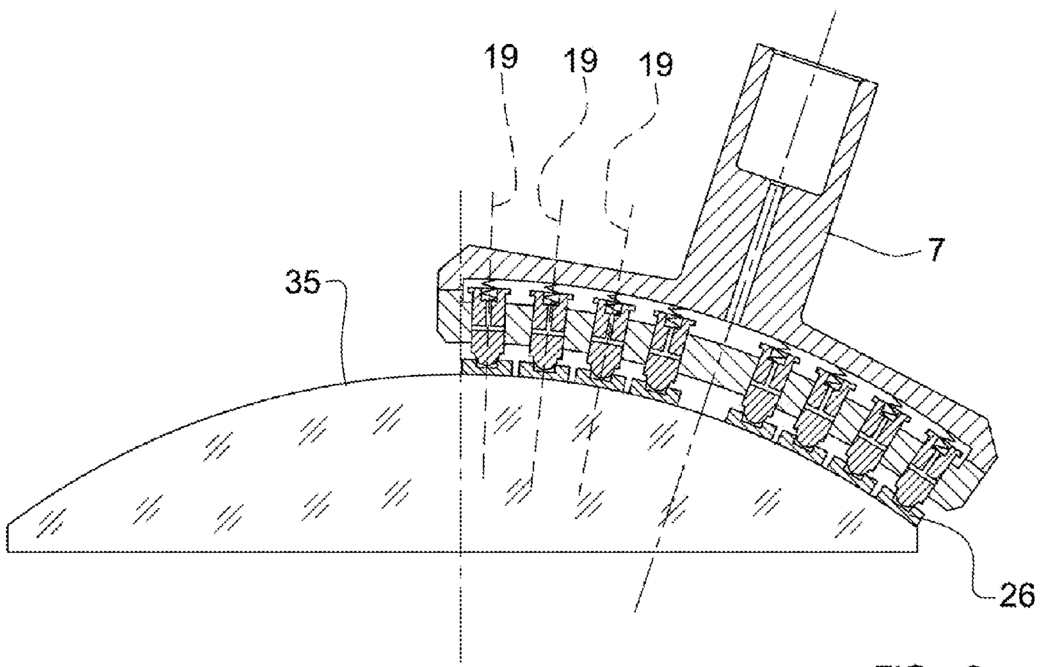

FIG 9

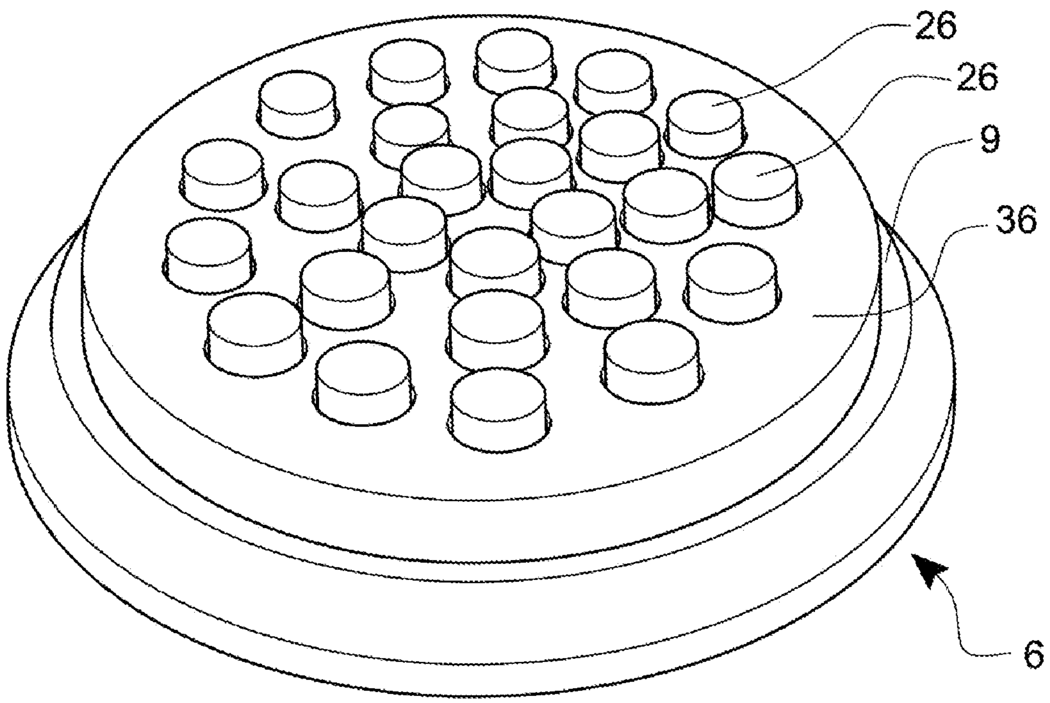

FIG 10