

The invention relates to an apparatus for the manufacture of a contact lens having, especially, (an) aspherical front and/or rear face(s), by material-removing shaping, having a spindle which is rotatably mounted in a spindle carrier and to which there can be secured a lens button which is rotatable about the spindle axis with the spindle, a material-removing tool which can be displaced relative to the lens button, and an adjusting device by means of which an adjusting movement of the tool relative to the lens button can be adjusted during shaping.

Such an apparatus is known from DE 3 110 624 C2. In the case of the known apparatus, templates are used for adjusting or altering the pivot radius of the material-removing tool constructed as a turning tool with respect to the pivot axis during the shaping operation. The template has control faces which are sensed by a sensing device, and the sensing movement is transferred to the cutting turning tool in order to alter the pivot radius of the turning tool. In that manner it is possible to manufacture contact lenses having different front and/or rear face geometries. For example, aspherical rear face geometries or multifocal, especially bifocal, contact lenses can be produced from a lens button by a cutting shaping operation.

The use of such control templates requires a precise mechanical manufacture and adjustment of those parts. In many cases of use, that is possible only with relatively great expenditure of resources. In addition, it is necessary to have a set of control templates for different geometries. The change-over to different geometries requires relatively long set-up times, as a result of which the degree of automation in the manufacture of lenses is impaired.

Numerically controlled automatic turning devices are also used. Such CNC automatic turning devices are, however, relatively expensive. In addition, it is not possible to manufacture continuous contours using those automatic turning devices because the displacement of the tool or workpiece takes place step-wise with small steps which, in an optimum case, are nevertheless still 0.1 micron. As a result, an additional polishing step is necessary in the manufacture of contact lenses in order to obtain a smooth lens surface, which naturally involves the risk that contour errors will occur on the surface of the contact lens during the polishing step.

The problem of the invention is accordingly to provide an apparatus of the type mentioned in the introduction in the case of which a fine adjustment of the pivot radius of the material-removing tool with respect to its pivot axis with position changes in the nm range is achieved.

That problem is solved according to the invention in the case of the apparatus of the type mentioned in the introduction in that the adjusting device comprises a piezoelectric drive which produces an adjusting movement for the tool during shaping. With such a piezoelectric drive in the adjusting device, a relative movement can be achieved between the lens button and the tool, which may preferably be in the form of a turning diamond or in the form of a laser, by extremely small changes in position in the nm range, total adjusting paths of some 100 microns and, if necessary, up to the region of a millimetre being possible. In that manner it is possible in the case of a preferred arrangement, by the linear adjusting movement which the piezoelectric drive device exerts on the tool, in combination with the pivoting movement which the tool performs about its pivot axis during material-removing shaping, to produce practically

any contact lens geometry required, and even non-rotationally symmetrical lens geometries, on the front face and/or rear face.

In the case of another arrangement, the material-removing tool is adjustable relative to the lens button in the direction of and parallel to the spindle axis and also in a direction perpendicular thereto. In the case of that arrangement, the piezoelectric drive can also be guided on the slide guideway, with the material-removing tool, in a straight line in the direction of and parallel to the spindle axis and also perpendicular thereto. The direction of action of the piezoelectric drive is in this case preferably oriented in the direction of and parallel to the spindle axis.

The lens button may be a starting body that has not yet been pre-shaped or a body that has already been partially pre-shaped, such as, for example, an approximately dish-shaped button (EP 0 299 628 A1 or US-PS 4 761 436), in the case of which a relatively small degree of material removal is still necessary.

Owing to the practically unlimited resolution of the piezoelectric drive system, it is possible to obtain, on the front and/or rear face(s) and on the transitional region of the contact lens connecting the two faces, smooth faces which require no further processing steps, such as, for example, polishing to improve the surface quality. The surface quality can be further increased by using air-mounted or hydraulically mounted spindles.

The adjusting movement of the piezoelectric drive is preferably controlled in dependence on the pivot angle assumed by the tool about its pivot axis. For that purpose, the piezoelectric drive preferably also performs

the pivoting movement of the tool at the same time. In an advantageous manner, the piezoelectric drive can accordingly be mounted on a slide guideway which is rotatable about the pivot axis and on which the tool is also guided in a radial direction with respect to the pivot axis.

For example, the piezoelectric drive may be in the form of a piezotranslator which performs its adjusting movement in a longitudinal axis. One end of the piezotranslator is supported against a slide which is guided on the slide guideway and on which a tool holder for the tool, which is, especially, in the form of a turning tool, is also mounted, and the other end of the piezotranslator is supported against the tool holder. The tool holder is preferably biased against the piezoelectric drive. It is also possible to place the tool directly on the piezoelectric drive (piezotranslator) which is supported against the tool holder. The piezoelectric drive may also comprise a plurality of piezotranslators which are arranged one behind the other in a radial direction with respect to the pivot axis and which can be actuated as desired in order to produce the adjusting movement.

In order to achieve the desired contact lens geometry on the front and/or rear face(s), the operating voltage of the piezoelectric drive can be adjusted in dependence on the pivot angle of the tool about the pivot axis. That adjustment can be monitored by a regulating device. For that purpose, a sensor for the actual adjusting movement of the piezoelectric drive can be connected to a computer unit. In addition, the computer unit can receive and/or store desired values of the adjusting movement of the piezoelectric drive which are predetermined by the desired lens geometry for respective pivot angles of the tool. The operating voltage for the piezoelectric drive

is then adjusted in dependence on the comparison of the desired value and the actual value.

For the coarse adjustment of the pivot radius of the tool about its pivot axis, the slide on which the tool is mounted may be linearly displaceable on the slide guideway. The coarse adjustment can also be regulated by the computer.

The piezoelectric drive may also be in the form of a piezotranslator device acting directly on the tool. For that purpose the piezotranslator may preferably assume the function of the tool holder.

It is also possible for the piezoelectric drive to be composed of two piezotranslator devices, that is to say, a first piezotranslator device which, as already explained above, acts on the tool holder, and a second piezotranslator device which acts directly on the tool, for example forms the tool holder. The piezotranslator device acting on the tool holder can be used in connection with the coarse adjustment, and the piezotranslator device in the form of a tool holder can be used in connection with the fine adjustment of the tool.

It is also possible to control the tool adjustment additionally by a template by means of which, for example, in the case of the manufacture of multifocal lenses, basic geometries are adjusted, while the fine adjustment is effected by means of the piezoelectric drive. A set of templates having only a small number of individual templates is required for the purpose. The arrangement of the templates and the control by means of the templates can be effected in the manner described in German Patent Specification 3 110 624.

An increase in accuracy and, especially, compensation for wear on the tool during the production of the desired lens geometry can be achieved also by controlling the adjustment of the tool in dependence on the output signal of a surface measuring device which detects the actual geometry produced by the tool on the lens preferably by contact-less sensing.

It is possible to manufacture in a reproducible manner contact lenses of any geometry, that is to say, even those having non-rotationally symmetrical geometries, a high degree of automation being achieved. It is merely necessary to feed the desired contact lens geometry into a memory device of the electronic control system of the adjusting device. Contact lenses having aspherical front and/or rear face(s) can be manufactured, and especially the rear faces of the lenses can be adapted accurately to the particular cornea surfaces of the contact lens wearer. It is also readily possible to manufacture multifocal, especially bifocal, contact lenses for the care of presbyopic patients.

The invention is explained in more detail using an embodiment with reference to the attached Figure.

The Figure is a diagrammatic view of a turning machine having an electronic control system for a piezoelectric drive for the fine adjustment of the pivot radius of the turning tool, the electronic control and regulating device being shown in the form of a block diagram.

The lathe shown is arranged on a machine bed 7 and has a spindle carrier 15 in which a spindle 5 is rotatably mounted. The spindle 5 can be mounted in an air or hydraulic bearing known per se and can be caused to rotate about its spindle axis by a drive (not shown in

more detail). The spindle 5 has a spindle tip 16, for example in the form of a calotte-like member which is secured to the spindle and to which a lens button 2 can be secured by means of a suitable securing means, for example putty. The lathe also has a column-like turning support 17 which is pivotable about a pivot axis 3. A slide guideway 6 is secured to the turning support 17. It is, however, also possible for the slide guideway 6 to be mounted on the turning support 17 so as to be rotatable about the pivot axis 3 and for the turning support 17 to be mounted in a stationary manner on the machine bed 7. A tool slide 8 is guided on the slide guideway 6 to be movable in a linear manner and in a radial direction with respect to the pivot axis. A tool holder 19 for a turning tool 1, especially a turning diamond, is mounted on the tool slide 8. For the coarse adjustment of the pivot radius of the turning tool 1 about the pivot axis 3, the tool slide 8 can be moved along the slide guideway 6, for example, by means of a motor drive (not shown in detail) or also by means of a manual crank drive. The coarse adjustment can be effected by the control of a computer unit 10.

For the fine adjustment of the pivot radius of the material-removing tool, which is preferably in the form of a turning tool 1, about the pivot axis 3 during lens manufacture, in the case of the illustrated embodiment of a lathe an adjusting device 14 has a piezoelectric drive which comprises two piezotranslator devices 4 and 21 in the embodiment illustrated. Such piezoelectric drives are known, for example, from PI, Physik Instrumente, Piezo Guide, Part 1, Piezostelltechnik in Theorie und Praxis. The piezoelectric drive used preferably comprises piezotranslators which perform adjusting movements in their longitudinal axis in dependence on an applied operating voltage. Rapid expansions with short response

times are an outstanding feature of such piezoelectric drives. Such piezoelectric drives are preferably made from PZT (lead-zirconium-titanate) ceramics. When operating voltage is applied, an almost instantaneous alteration in the length of the piezotranslator is achieved as a result of the discontinuously increased electrical field strength.

Those properties of the piezoelectric drive are exploited in the case of the invention especially for the fine adjustment of the pivot radius of the pivot tool about the pivot axis 3.

In an advantageous manner, several piezotranslators can be arranged one behind the other to form a chain. The individual piezotranslators can then be actuated as desired in dependence on the desired length alteration or adjusting movement. The expansion behaviour of the individual piezotranslators can then be combined for the adjusting movement to be achieved by suitable actuation. As a result, not only fine adjustment but also coarse adjustment can be achieved.

The control device for controlling an operating voltage for the piezoelectric drive, which voltage, in the case of the embodiment, is supplied by a voltage amplifier 12, comprises the computer unit 10. The computer unit 10 receives data for the desired contact lens geometry from a memory device 13 which may also be in the form of a geometry input device. The computer unit 10 converts those contact lens geometries for the front and/or rear face(s) of the contact lens to be manufactured into radius values of the turning tool 1, relative to the pivot axis 3, which are associated with respective pivot angles of the turning tool 1 about the pivot axis. The actual pivot radius of the turning tool 1 can be sensed

by means of a sensor 11. The output signal of the sensor 11 is likewise conveyed to the computer unit 10. The pivot angle adopted by the turning tool about the pivot axis 3, starting from a zero position, is also conveyed to the computer unit 10. An angle sensor 20 is provided for the purpose.

In the cutting machining operation, the turning tool 1 is placed on the lens button 2. For the purpose of coarse adjustment, the tool slide 8 is displaceable in linear manner on the slide guideway 6, optionally controlled by the computer unit 10, by manual operation or by an electromotor drive (not shown in detail). For the fine adjustment of the pivot radius of the turning tool 1 during the production of the final desired lens geometry, the computer unit 10 actuates the voltage amplifier 12 in appropriate manner so that the latter delivers an operating voltage for the piezoelectric drive comprising the two piezotranslator devices 4 and 21, as a result of which an adjusting movement is brought about. That adjusting movement of the piezoelectric drive is determined by the stored values of the pivot radii of the turning tool 1 which depend on the pivot angles of the tool on the basis of the contact lens geometry fed in. In addition, the adjusting movement impressed on the tool 1 can be detected by the sensor 11 and compared with a desired value setting so that, on the basis of that comparison of the desired value with the actual value, the piezoelectric drive is supplied in regulated manner with operating voltage. In that manner, any hysteresis properties of the piezoelectric drive and also tolerances are compensated for during the transfer of movement from the piezoelectric drive to the tool holder 19.

In the case of the embodiment shown, the piezoelectric drive comprises the piezotranslator device 21 acting

directly on the tool 1 and the piezotranslator device 4 acting on the tool holder 19. The piezotranslator device 21, which may comprise one piezotranslator or several piezotranslators connected one behind the other, is used as the tool holder. It is thus ensured that the adjusting movement is transferred directly onto the tool 1. The piezotranslator device 21 is accordingly suitable for fine adjustment.

The second piezotranslator device 4 is supported at one end against the tool slide 8 and at the other end against the tool holder 19. The piezotranslator device 4 may likewise comprise one piezotranslator or several piezotranslators connected one behind the other. The piezotranslator device 4 can also be used in connection with the coarse adjustment of the tool 1, the fine or extremely fine adjustment, as already explained, then being ensured by the piezotranslator device 21.

Adjusting movements of the piezotranslator device 4 are effected against the biasing force of a spring 18, which ensures that, when the direction of the adjusting movement of the piezotranslator device 4 is changed, the tool also performs that change of direction at the same time.

Instead of using both piezotranslator devices 4 and 21, it is also possible to use only one of the two piezotranslator devices for fine adjustment - either the piezotranslator device 4, which acts on the tool holder 19, or the piezotranslator device 21, which acts directly on the tool 1.

While the lens button 2 rotates about the spindle axis 9, the turning tool 1 performs, in the plane of the spindle axis 9, the already addressed pivoting movement about the

pivot axis 3 and thus produces the desired geometry on the lens to be manufactured.

In addition, a sensing device may also be provided for sensing a template. This arrangement is not shown in the Figure. It may be constructed in the manner known from DE-PS 3 110 624. By means of the template it is possible to obtain a basic geometry, for example in the case of the manufacture of multifocal lenses.

In order to achieve a high degree of accuracy of the contact lens geometry to be produced, the geometry produced by the tool 1 on the lens can be sensed without making contact. A surface measuring device 22 which senses without making contact is suitable for the purpose. That device may be, for example, a known type of surface measuring device that senses with the aid of a laser beam. A laser beam is focused on the surface to be measured, and the light scattered back from the surface is analysed by means of a detector. If the focus deviates from the surface, the detector emits a signal for the lens system to follow, the tracking path being evaluated in order to determine the surface profile.

The output signal of the surface measuring device 22 is fed to the central computer unit 10 which then, additionally in dependence on the actual geometry of the lens ascertained, causes the piezoelectric drive to be actuated in suitable manner. Any wear on the tool can be advantageously detected thereby and compensated for during the manufacture of the lens.

In order to produce a non-rotationally symmetrical lens geometry, it is advantageous to sense the angle of rotation of the spindle 5 about the spindle axis 9 with the aid of a sensor device 23. The sensor device 23 sends

a corresponding rotational angle signal to the computer unit 10. The computer unit 10 then sends a corresponding control signal to the piezoelectric drive 4 or 21. As a result, in dependence on the particular angle of rotation, the adjusting movement of the piezoelectric drive 4 or 21 is then transmitted to the tool 1.

In the case of the adjusting device 14 shown in the Figure, the tool slide 8 can be guided on the slide guideway 6 in a straight line in the direction of the spindle axis 9 and parallel thereto and also perpendicular to that direction. That is to say, the tool 1 and the associated piezoelectric drive 4, 21 are thereby likewise guided on the slide guideway 6 in those mutually perpendicular directions with respect to the lens button 2. It is not necessary in the case of this arrangement for the slide guideway 6 to be mounted on the support 17 to be rotatable about the pivot axis 3. Rather, the slide guideway 6 may be mounted in stationary manner on the support 17.

Patent Claims

1. An apparatus for the manufacture of a contact lens having, especially, (an) aspherical front and/or rear face(s), by material-removing shaping, having a spindle (5) which is rotatably mounted in a spindle carrier (15) and in which there can be secured a lens button (2) which is rotatable about the spindle axis with the spindle (5), a material-removing tool (1) which can be displaced relative to the lens button (2), and an adjusting device (14) by means of which an adjusting movement of the tool (1) relative to the lens button (2) can be adjusted during shaping, wherein the adjusting device (14) comprises a piezoelectric drive (4, 21) which produces an adjusting movement for the tool (1) during shaping.
2. An apparatus according to claim 1, wherein the material-removing tool (1) is pivotable about a pivot axis (3) perpendicular to the spindle axis (9) and the adjusting movement of the piezoelectric drive (4, 21) for the pivot radius adjustment of the tool (1) depends on the pivot angle of the tool (1) about the pivot axis (3).
3. An apparatus according to claim 1, wherein the material-removing tool (1) is adjustable by the adjusting device (14) in the direction of and parallel to the spindle axis (9) and also in a direction perpendicular thereto, and the piezoelectric drive (4, 21) provides an adjusting movement for the material-removing tool (1) at least in the direction of and parallel to the spindle axis (9).
4. An apparatus according to any one of claims 1 to 3, wherein the piezoelectric drive (4, 21) is mounted on a



slide guideway (6) on which the tool (1) is guided.

5. An apparatus according to claim 4, wherein the piezoelectric drive (4, 21) is mounted on the slide guideway (6) which is rotatable about the pivot axis (3) and on which the tool (1) is guided in a radial direction with respect to the pivot axis (3).

6. An apparatus according to claim 3 and claim 4, wherein the piezoelectric drive (4, 21) is guided on the slide guideway (6), with the material-removing tool (1), in a straight line in the direction of and parallel to the spindle axis (9) and also perpendicular thereto.

7. An apparatus according to any one of claims 1 to 6, wherein the piezoelectric drive (4, 21) comprises a piezotranslator device (4), one end of which is supported against a slide (8) which is guided on the slide guideway (6) and on which a tool holder (19) for the tool (1) is mounted, and the other end of which is supported against the tool holder (19).

8. An apparatus according to any one of claims 1 to 7, wherein the tool holder (19) is biased against the piezotranslator device (4).

9. An apparatus according to any one of claims 1 to 8, wherein the piezotranslator device (4) comprises a plurality of piezotranslators arranged one behind the other in a radial direction with respect to the pivot axis (3).

10. An apparatus according to any one of claims 1 to 9, wherein the piezoelectric drive (4, 21) comprises a piezotranslator device (21) acting directly on the tool (1).



11. An apparatus according to claim 10, wherein the piezotranslator device (21) is in the form of a tool holder.

12. An apparatus according to any one of claims 1 to 11, wherein the piezotranslator device (21) acting directly on the tool (1) is used for the fine adjustment of the tool (1), and the piezotranslator device (4) acting on the tool holder (19 or 21) is used for the coarse adjustment of the tool (1).

13. An apparatus according to any one of claims 1 to 12, wherein the tool adjustment is additionally controlled by a template.

14. An apparatus according to either claim 1 or claim 2, wherein, in order to achieve the desired geometry on the front and/or rear face(s) of the lens, the operating voltage of the piezoelectric drive (4, 21) is adjusted in dependence on the pivot angle of the tool (1) about the pivot axis (3).

15. An apparatus according to any one of claims 1 to 14, wherein a sensor (11) for the actual adjusting movement of the piezoelectric drive (4, 21) is connected to a computer unit (10), the computer unit (10) also receives and/or stores desired values of the adjusting movement which are predetermined by the desired lens geometry for respective pivot angles of the tool (1), and the operating voltage for the piezoelectric drive (4, 21) is adjusted in dependence on the comparison of the desired value and the actual value.

16. An apparatus according to any one of claims 1 to 12, wherein, in addition, the slide (8) is displaceable in



linear manner on the slide guideway (6) for a coarse adjustment of the tool (1).

17. An apparatus according to any one of claims 1 to 12, wherein the tool (1) is in the form of a cutting turning tool.

18. An apparatus according to any one of claims 1 to 12, wherein the tool (1) is in the form of a laser.

19. An apparatus according to any one of claims 1 to 18, wherein the adjustment of the tool (1) is also controlled in dependence on the output signal of a surface measuring device (22) which detects the actual geometry produced by the tool (1) on the lens.

20. An apparatus according to any one of claims 1 to 19, wherein the adjusting movement of the piezoelectric drive (4, 21) is controlled in dependence on the angle of rotation of the spindle (5) about the spindle axis (9).

