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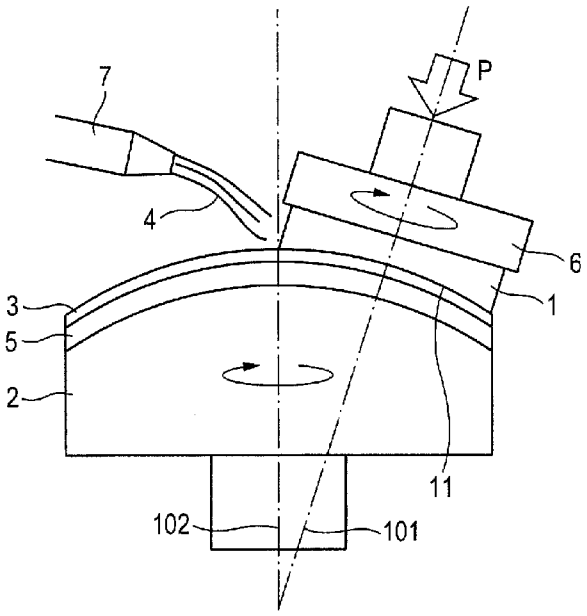
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[Continued on next page]

(54) Title: PROCESSING APPARATUS, PROCESSING METHOD, AND COMPONENT MANUFACTURING METHOD



(57) Abstract: A workpiece and a tool whose processing surface includes a catalyst substance containing a transition metal which supports hydrolysis of a surface to be processed of the workpiece are relatively moved in a state of being press-contacted by a processing pressure with a water molecule of a processing fluid being interposed. During the processing, processing control of managing a relative speed of relatively moving the processing surface and the surface to be processed or the processing pressure is performed by a control unit. A processing rate of the surface to be processed is estimated by an estimation expression indicated by a difference between a member formed of a product of a first constant, the processing pressure and the relative speed and a member formed of a product of a second constant and a cube of the relative speed. Then, the relative speed is managed based on the estimated processing rate.

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Description

Title of Invention: PROCESSING APPARATUS, PROCESSING METHOD, AND COMPONENT MANUFACTURING METHOD

Technical Field

[0001] The present invention relates to a processing apparatus, a processing method, and a component manufacturing method that process a workpiece using a tool whose processing surface includes a catalyst substance containing a transition metal which supports hydrolysis of a surface to be processed of the workpiece.

Background Art

[0002] Conventionally, as a method of polishing an optical element such as a spherical lens, a free abrasive polishing method of removing a surface of a workpiece by bringing a tool and the workpiece into contact and relatively moving them while supplying polishing slurry containing abrasive grains such as cerium oxide to a surface of the tool is generally used. By this operation for processing, the surface of the workpiece is smoothed, and a processed surface with low surface roughness is obtained.

[0003] In this kind of polishing, it is important to remove an affected layer which is generated on a surface of a workpiece by pre-processing such as grinding. A processing amount above a certain level is required in polishing in order to obtain a high-quality processed surface having no affected layer, and from a viewpoint of improving productivity, it is demanded to efficiently set a processing condition for obtaining the processing amount above a certain level.

[0004] Generally, it is known that the processing amount (processing depth) in free abrasive polishing is proportional to a processing pressure when the workpiece and the tool are brought into contact, a relative speed of the tool and the workpiece, and processing time. This proportional relation is widely known as Preston's empirical formula, and based on Preston's empirical formula, a method of predicting a processing amount of a workpiece has been proposed (PTL 1 below). In the polishing method disclosed in PTL 1, a processing pressure, a relative speed, processing time, and the number of times of processing are set based on Preston's empirical formula so that a processing amount distribution of a workpiece becomes a target value.

[0005] For polishing of glass used as an optical element material, conventionally a cerium oxide is mainly used as abrasive grains. However, cerium oxide is a rare earth element whose price has rapidly fluctuated in recent years, and there is a problem that it cannot be stably obtained.

[0006] With such a problem in the background, in recent years, as a method of processing a workpiece without using abrasive grains, a catalyst support type processing method has

been proposed (PTL 2 below). In the processing method in PTL 2, a workpiece is a solid oxide for example, and a catalyst substance which helps production of a decomposition product by hydrolysis is used as a processing surface (processing reference surface). Then, in the presence of water (pure water, for example), a surface to be processed of the workpiece and the processing surface are disposed in contact or very closely and both are relatively moved so as to slide, thereby promoting hydrolysis of the surface to be processed by catalytic reaction and removing the decomposition product from the workpiece.

[0007] In catalyst support type processing, when the catalyst substance included in the processing surface of a tool is brought into contact with or very close to the surface to be processed, binding force of a backbond between an oxygen element and another element forming an oxide weakens. Then, a water molecule is dissociated, the backbond between the oxygen element and another element of the oxide is cut and adsorbed, and thus a decomposition product is produced by hydrolysis and removed from the surface to be processed, thereby processing is proceeded.

[0008] According to the catalyst support type processing, a workpiece formed of a solid oxide, which is represented by optical glass, can be smoothed without using abrasive grains. Note that, in the catalyst support type processing, processing is possible when the actual surface to be processed is an oxide, and the workpiece is not always limited to the oxide. For example, by irradiating the surface to be processed with ultraviolet rays, or using a component that oxidizes the surface to be processed for a processing fluid, the surface to be processed is oxidized, and the workpiece of a different material from the oxide in a normal state can be also processed.

[0009] The relation among the processing amount, the processing pressure, and the relative speed of the surface to be processed and the processing (catalyst) surface in the catalyst support type processing is reported in NPL 1 below. According to NPL 1, it is indicated that, under the condition that the relative speed is lower than 100 mm/s, the processing amount is roughly proportional to the processing pressure and the relative speed similarly to free abrasive polishing.

Citation List

Patent Literature

[0010] PTL 1: Japanese Patent Application Laid-Open No. 2001-298008

PTL 2: International Publication No. WO 2013/084934

Non Patent Literature

[0011] NPL 1: Japanese Journal of Applied Physics 51(2012) 046501 "Improvement of Removal Rate in Abrasive-Free Planarization of 4H-SiC Substrates Using Catalytic Platinum and Hydrofluoric Acid"

Summary of Invention

Technical Problem

[0012] However, in the catalyst support type processing method, in the case that processing is carried out under the condition of being faster than the relative speed indicated in NPL 1, there is a possibility that a relation similar to Preston's empirical formula, which is applicable to the free abrasive polishing, is not established as it is. As described later, the relation between the processing amount actually measured under a certain fixed processing pressure and the relative speed of the surface to be processed and the processing (catalyst) surface deviates from Preston's empirical formula. Therefore, in the catalyst support type processing method, for example, the processing amount (processing rate) or the processing time cannot be appropriately predicted from the conditions of the processing pressure and the relative speed of the surface to be processed and the processing (catalyst) surface by using Preston's empirical formula.

[0013] A subject of the present invention is, in consideration of the above, to accurately predict a processing amount or processing rate of a workpiece under an arbitrary processing condition and efficiently manufacture a high-quality workpiece, in a catalyst support type processing method.

Solution to Problem

[0014] In order to solve the problem, in the present invention, in a processing apparatus, a processing method or a component manufacturing method for processing a surface to be processed of a workpiece by relatively moving a tool and the surface to be processed in a state that the tool and the workpiece are press-contacted by a processing pressure with a water molecule being interposed, the processing surface including a catalyst substance containing a transition metal which supports hydrolysis of the surface to be processed, a control unit configured to manage a relative speed of relatively moving the processing surface and the surface to be processed or the processing pressure is provided, and by the control unit, a processing rate of the surface to be processed obtained under the processing pressure is estimated by an estimation expression indicated by a difference between a member formed of a product of a first constant, the processing pressure and the relative speed and a member formed of a product of a second constant and a cube of the relative speed, and the relative speed or the processing pressure is managed based on the estimated processing rate.

[0015] According to the present invention, an effect of being capable of efficiently manufacturing a high-quality workpiece is demonstrated because the processing rate under an arbitrary processing condition can be accurately predicted by an estimating operation using the above estimation expression performed in the control unit and a processing condition for obtaining a predetermined processing amount can be ef-

ficiently set.

[0016] Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

Brief Description of Drawings

[0017] [fig.1]Fig. 1 is an illustrative drawing illustrating a processing form of a workpiece relating to one embodiment of the present invention.

[fig.2]Fig. 2 is a diagram illustrating a relation between a processing amount (processing rate) of a workpiece and a relative speed of a tool and the workpiece.

[fig.3]Fig. 3 is a diagram illustrating a relation between a processing amount (processing rate) of a workpiece and a relative speed of a tool and the workpiece relating to one embodiment of the present invention.

[fig.4]Fig. 4 is an illustrative drawing enlarging and illustrating a processing state of a workpiece relating to one embodiment of the present invention.

[fig.5]Fig. 5 is an illustrative drawing illustrating a processing form of a workpiece in an example 1 of the present invention.

[fig.6]Fig. 6 is a diagram illustrating a relation between a processing rate of a workpiece and a relative speed of a tool and the workpiece in the example 1 of the present invention.

[fig.7]Fig. 7 is a bar graph chart illustrating an estimated value of a processing amount of a workpiece and an actual processing amount in the example 1 of the present invention.

[fig.8]Fig. 8 is an illustrative drawing illustrating surface roughness of a workpiece processed in the example 1 of the present invention.

[fig.9]Fig. 9 is a diagram illustrating a relation between a processing rate of a workpiece and a relative speed between a tool and the workpiece for each of different processing pressures in an example 2 of the present invention.

[fig.10]Fig. 10 is a block diagram illustrating a configuration of a control unit configured to control processing or manufacturing of a workpiece relating to one embodiment of the present invention.

[fig.11]Fig. 11 is a flowchart illustrating a flow of a processing control procedure for controlling processing or manufacturing of a workpiece relating to one embodiment of the present invention.

[fig.12]Fig. 12 is a diagram illustrating a processing result in an example 3 of the present invention.

Description of Embodiments

[0018] Hereinafter, a mode for carrying out the present invention will be described with reference to examples illustrated in the attached drawings. Note that the example il-

lustrated below is only an example, and a configuration of details for example can be appropriately changed by a person skilled in the art in a range not deviating from the meaning of the present invention. Also, a numerical value taken up in the present embodiment is a reference numerical value and does not limit the present invention.

[0019] Fig. 1 illustrates a configuration for processing a surface 11 of a workpiece 1 that has a concave spherical surface, as an example of a processing form relating to the present invention. In Fig. 1, a tool 2 has a processing surface 3 (catalyst part) facing the surface 11 to be processed of the workpiece 1.

[0020] Then, a processing fluid 4 containing water is supplied between the surface 11 to be processed and the processing surface 3, and the workpiece 1 and the tool 2 are relatively moved along a shape of the processing surface 3 (catalyst part) in the state of interposing a water molecule of the processing fluid 4 between the surface 11 to be processed and the processing surface 3 (catalyst part).

[0021] The processing surface 3 of the tool 2 includes a catalyst substance containing a transition metal that supports hydrolysis of the surface 11 to be processed of the workpiece 1. The catalyst substance included in the processing surface 3 of the tool 2 is selected from at least one kind or more of transition metal elements, as the catalyst substance that cuts a backbond of an element and another element including in the workpiece 1 by dissociation of the water molecule and assists production of a decomposition product by hydrolysis. Examples of the transition metal element are Pt, Au, Ag, Cu, Ni, Cr, and Mo or the like. The catalyst substance may be a simple substance of these metal elements, or an alloy including the plurality of metal elements.

[0022] Note that, in the present description, the workpiece 1 having a concave spherical surface, which is an optical element such as a lens or a mirror, is given as an example. A concave and convex relation of the workpiece 1 and the tool 2 may be the opposite, and it is easy to apply the configuration in Fig. 1 (or Fig. 5) to processing of the workpiece 1 having a convex spherical surface.

[0023] Although a kind of the workpiece in the present invention is not limited in particular, from a viewpoint that a processing rate at a practical production level can be obtained, it is desirable that the workpiece is optical glass. For example, in a finishing step of the optical glass used in a camera lens or the like, a thickness of an affected layer remaining before processing is generally about 1 to 4μm. In practical production, since the affected layer is generally removed in time of about 20 min or shorter, the processing rate of 200 nm/min or higher is demanded. Therefore, it is desirable that the workpiece in the present invention is the optical glass for which the processing rate of 200 nm/min or higher can be obtained.

[0024] The present description illustrates a configuration of relatively moving the workpiece 1 and the tool 2 by rotationally driving the workpiece 1 and the tool 2 in the same

rotating direction around a workpiece rotary axis 101 and a tool rotary axis 102 respectively. However, the workpiece 1 and the tool 2 can be relatively moved also by rotationally driving one of the workpiece 1 and the tool 2. Also, in the case of rotationally driving both of the workpiece 1 and the tool 2, processing can be performed in a configuration of giving rotational driving directions that are directions opposite to each other. In any case, as long as it is a drive system capable of generating a relative speed of the workpiece 1 and the tool 2 used in an estimation expression (expression (6)) described later, a form of relative movement of the workpiece 1 and the tool 2 is arbitrary, and does not limit the present invention.

[0025] Note that, as illustrated by an arrow 103, either one or both of the workpiece 1 and the tool 2 may be swung along a contact surface of the workpiece 1 and the tool 2. Such a swing movement is made using a swing mechanism so called a fixing pin or the like. Below, description is given on the assumption that the workpiece 1 and the tool 2 are not relatively swung like the arrow 103 (or this swing condition is neglected) in order to provide an explanation easier to understand.

[0026] In the present example, on the basis of a processing pressure (P) of press-contacting the workpiece 1 and the tool 2 and the relative speed of relatively moving (sliding) the workpiece 1 and the tool 2, a processing rate (a processing amount (processing depth) per minute, for example) is predicted (estimated) based on the estimation expression (expression (6) described later). This estimation expression (expression (6) described later) is an estimation expression of the processing rate, which is indicated expressed by a difference between a member formed of a product of a first constant, the processing pressure, and the relative speed and a member formed of a product of a second constant and a cube of the relative speed.

[0027] The estimation expression (expression (6)) of the processing rate will be described in detail below.

[0028] In conventional free abrasive polishing that uses abrasive grains, as indicated in the following expression (1), it is known that the processing amount is proportional to the processing pressure, the relative speed, and the processing time.

[0029] [Math.1]

$$M = KPVT \qquad (1)$$

wherein M is the processing rate (the processing amount per minute), K is a constant determined by a polishing state, P is the processing pressure, V is the relative speed, and T is the processing time. The expression (1) is well-known and called Preston's empirical formula.

[0030] As described above, it is indicated that a relation equal to the expression (1) is established also in the catalyst support type processing under the condition that the

relative speed is low. However, it has been unknown whether or not the relation equal to the expression (1) is established also under the condition that the relative speed is higher.

[0031] Fig. 2 illustrates a relation between the processing rate (the processing amount per minute) and the relative speed in the case of processing the workpiece 1 formed of optical glass by the processing form illustrated in Fig. 1. Note that, in the present description, in the case that the relative movement of the workpiece 1 and the tool 2 is a circular movement as in Fig. 1 (or Fig. 5 described later), it is assumed that a speed at an outermost periphery of the workpiece 1 is used for the relative speed. However, any relative speed of the workpiece 1 and the tool 2 may be used as long as its definition including a measurement part or the like should be consistent in constant calculation of the estimation expressions described later (expressions (6) and (7) described later) and an estimating operation using the estimation expressions. That is, it is not always needed to use a peripheral speed at the outermost periphery of the workpiece 1 for the relative speed of the workpiece 1 and the tool 2, and for example, the relative speed of an arbitrary part may be used.

[0032] In the example in Fig. 2, the processing pressure is 40 kP_a, and the relative speed is changed under four conditions in a range from 188 mm/s to 1510 mm/s. Fig. 2 illustrates ratios of the processing rate (the processing amount per minute) under the respective conditions when the processing rate (the processing amount per minute) at the relative speed of 188 mm/s is defined as 1.

[0033] As in the figure, when the relative speed becomes 754 mm/s or higher, an experimental value of the processing rate largely deviates from Preston's empirical formula (a straight line 201). That is, in a catalyst support type processing method, in the case that the relative speed between the workpiece 1 and the processing surface 3 (catalyst part) of the tool 2 is high, the processing rate or the processing amount cannot be accurately predicted by Preston's empirical formula that is applicable in conventional polishing.

[0034] In consideration of the above, inventors have derived the estimation expression that predicts the processing rate (the processing depth per unit time) based on the following assumption.

[0035] First, when the processing amount at a unit contact point of the workpiece 1 and the processing surface 3 is defined as "processing amount per contact", the processing amount M can be represented as "processing amount per contact" × "the number of times of contacts per unit time" × "processing time T". Here, assuming that "the number of times of contacts per unit time" is proportional to a product of "a contact area S of a catalyst and the workpiece" and "the relative speed V of the catalyst and the glass", the processing rate R can be represented by the following expression (2).

[0036] [Math.2]

$$R = K_a S V \qquad (2)$$

wherein K_a is a proportionality constant. Further, since it is conceivable that the contact area S of the processing surface (catalyst part) and the surface 11 to be processed is proportional to an average contact pressure P_c of the processing surface of the tool 2 and the workpiece 1, the contact area S can be represented as the following expression (3).

[0037] [Math.3]

$$S = K_b P_c \qquad (3)$$

[0038] Next, a pressure applied to the workpiece 1 is taken into consideration. Fig. 4 conceptually illustrates a local contact state in the case of bringing the workpiece 1 into contact with the processing surface 3 (catalyst part) of the tool 2 by the processing pressure P and moving them at the relative speed V. In the figure, in the state that the processing fluid 4 containing water exists between the tool 2 and the workpiece 1, the processing surface 3 (catalyst part) of the tool 2 and the workpiece 1 are relatively moved (slid).

[0039] Since the processing surface 3 (catalyst part) of the tool 2 and a surface of the workpiece 1 are not smooth surfaces and some recesses and projections exist, as illustrated in Fig. 4, it is conceivable that the workpiece 1 receives fluid pressure P_f in a direction vertical to a direction of the relative movement. Therefore, the relation of the average contact pressure P_c, the processing pressure P, and the fluid pressure P_f can be represented by the following expression (4).

[0040] [Math.4]

$$P_c = P - P_f \qquad (4)$$

[0041] Since resistance force that an object receives in fluid is proportional to a square of a speed, the fluid pressure P_f can be represented by the following expression (5).

[0042] [Math.5]

$$P_f = K_c V^2 \qquad (5)$$

[0043] When the expressions (3)-(5) are substituted in the above expression (2) and organized, it is $R=K_a \cdot K_b \cdot V \cdot P - K_a \cdot K_b \cdot K_c \cdot V^3$. Here, when it is gathered and organized as $K1=K_a \cdot K_b$ and $K2=K_a \cdot K_b \cdot K_c$, the relation of the relative speed V, the processing pressure P, and the processing rate R (a removal rate: the processing depth per unit time) is expressed by the estimation expression of the following expression (6).

[0044] [Math.6]

$$R = K_1 P V - K_2 V^3 \qquad (6)$$

wherein a first constant K_1 and a second constant K_2 are $K_1=K_a \cdot K_b$ and $K_2=K_a \cdot K_b \cdot K_c$. The first constant K_1 and the second constant K_2 are constants determined by parameters other than the relative speed V and the processing pressure P respectively.

[0045] Here, it is conceivable that the parameter "other than" the relative speed V and the processing pressure P is a processing condition such as a material, hardness or the like of the workpiece 1 and the processing surface (catalyst part), and it can be practically calculated by sample processing described later.

[0046] A result of comparing an estimated value (301) and an experimental value (302) in the case of substituting fixed values for the first constant K_1 and the second constant K_2 of the estimation expression (expression (6)) is illustrated in Fig. 3. As in the figure, the estimated value (301) obtained by the estimation expression (the expression (6)) and a measured value (302) obtained by an experiment indicate excellent approximation.

[0047] Therefore, it is conceivable that the estimation expression (expression (6)) is very appropriate as an equation for predicting the processing rate R (the removal rate; the processing depth per unit time) in the catalyst support type processing method (at least within a relative speed range illustrated in Fig. 3).

[0048] When putting the estimation expression (the expression (6)) to practical use, it is needed to perform sample processing for example and calculate the first constant K_1 and the second constant K_2 in the expression. As the processing condition of the sample processing, it is desirable to change at least one of the processing pressure and the relative speed for three or more conditions, perform the sample processing for the number of times, and use the obtained experimental values. Also, for example, it is desirable to execute the sample processing as much as possible under three or more conditions and obtain the first and second constants so that an error of the processing amount obtained by the estimation expression and the actual processing amount becomes 25% or lower.

[0049] Using the estimation expression, the relative speed can be controlled so that the processing rate R does not exceed the maximum value in an arbitrary processing pressure. When the expression (6) is differentiated by V, dR/dV is expressed by the following expression (7).

[0050] [Math.7]

$$\frac{d}{dV}R = K_1 P - 3K_2 V^2 \qquad (7)$$

At the time when dR/dV is 0, the processing rate R becomes the highest. When the

relative speed at that time is defined as V_{max}, the relative speed V_{max} is expressed by the following expression (8) from expression (7).

[0051] [Math.8]

$$V_{max} = \sqrt{\frac{K_1 P}{3K_2}} \qquad (8)$$

[0052] By substituting the values of the obtained constants K_1 and K_2 and the processing pressure P in the above expression (8), V_{max} under an arbitrary condition can be calculated. The expressions (6)-(8) (Fig. 3, Fig. 6) indicate that there is an upper limit (V_{max}) for the relative speed V capable of obtaining the highest (optimum) processing rate. That is, even when the value of the highest relative speed V_{max} or higher is given as the relative speed V of the tool and the workpiece, the processing rate is not improved and declines instead.

[0053] Therefore, by using the estimation expressions (expressions (6)-(8)), the processing pressure P and the relative speed V are controlled and the required processing time is set so as to obtain a desired (or optimum) processing rate. Thus, the processing rate under an arbitrary processing condition can be accurately predicted, the processing condition for obtaining the predetermined processing amount can be efficiently set, and a high-quality workpiece can be efficiently produced.

[0054] Two examples (an example 1 and an example 2) of processing a concave spherical lens as the workpiece 1 by the catalyst support type processing method relating to the present invention are illustrated below.

Example 1

[0055] In the present example 1, an example of processing a concave spherical lens whose outer diameter (2r: diameter) is 17.8 mm and target curvature radius RW is 63.267 mm as the workpiece 1 by the catalyst support type processing method relating to the present invention is described.

[0056] Fig. 5 illustrates the processing form of the present example. For a material of the workpiece 1, optical glass (lanthanide glass (for example, S-LAM55 manufactured by OHARA INC.)) containing O^{2-} as an anion component and containing at least cation components listed below in terms of cation% (mol%) was used.

- 13% or more and 28% or less as Si^{4+}
- 23% or more and 48% or less as B^{3+}
- 16% or more and 22% or less as Ba^{2+}
- 2% or more and 11% or less as Ti^{4+}
- 2% or more and 11% or less as Zn^{2+}
- 1% or more and 7% or less as Zr^{4+}
- 5% or more and 11% or less as La^{3+}

・0% or more and 2% or less as Sb^{3+}

[0057] Note that, while the material of the workpiece 1 belongs to a solid oxide, in the case that the workpiece 1 is not an oxide such as a substrate of a semiconductor (such as gallium nitride), processing can be performed in a configuration similar to Fig. 5 by using a unit that oxidizes the surface 11 to be processed together. In that case, for example, the surface 11 to be processed is oxidized by adding a unit for irradiating the surface 11 to be processed with ultraviolet rays or changing a composition of the processing fluid 4.

[0058] An upper surface of the tool 2 was covered with an elastic body 5, and a thin film of Pt was coated by a thickness of about 100 nm as a catalyst part forming the processing surface 3 on a surface of the elastic body 5. For the elastic body 5, foamed polyurethane (NFP05 manufactured by KOKONOE ELECTRIC CO., LTD., for example) was used. Purified water was used for the processing fluid 4, and was supplied at a flow rate of 1000 ml per minute to the surface of the processing surface 3 of the tool 2 by a supply unit 7 (detailed illustrations of a pump and the like are omitted in the figure).

[0059] The workpiece 1 is supported by a holder 6, and in the state of tilting the tool rotary axis 102 to the workpiece rotary axis 101 by 8.1 degrees, the workpiece 1 and the tool 2 are brought into contact by a predetermined processing pressure. The processing pressure (P) is generated using energizing force of a spring or the like (not shown in the figure) that energizes the tool rotary axis 102 in an axial direction. Preferably, the processing pressure of the workpiece 1 and the tool 2 is configured to be adjustable.

[0060] The workpiece 1 and the tool 2 are rotated by drive force of motors (220 and 221 in Fig. 10) that rotationally drive the workpiece rotary axis 101 and the tool rotary axis 102. In the present example, the rotating directions of these motors are the same as illustrated in the figure, and the relative movement (sliding) is performed in a direction of the contact surface of the workpiece 1 and the processing surface 3.

[0061] The relative speed (V) of the workpiece 1 and the tool 2 can be controlled by adjusting the speed of the motors (220 and 221 in Fig. 10) that drive the workpiece 1 and the tool 2.

[0062] Here, it is assumed that the tool 2 has a diameter which is double the workpiece 1 (diameter 2r=17.8 mm) or larger as in Fig. 5 (Fig. 1), and a posture that the outer periphery of the workpiece 1 coincides with a rotation center of the tool 2 as in the figure is considered. In such a polishing posture, in the case that the rotating directions and the rotation numbers of the tool 2 and the workpiece 1 are the same, both of the relative speeds on an effective radius (length 4r) of the processing surface 3 of the tool 2 and the diameter (length 2r) of the workpiece 1 are the same, and become equal to the peripheral speed of the outermost periphery of the workpiece 1. In the present

example (similarly in the example 2), it is assumed that the speed on the effective radius of the processing surface 3 of the tool 2 (the diameter of the workpiece 1) is used for the relative speed (V).

[0063] First, in the above configuration, in order to calculate the first constant K_1 and the second constant K_2 in the estimation expression (expression (6)), the processing amount (processing depth) per minute of the processing time was measured in the configuration of Fig. 5. The processing pressure was 40 kPa, and the rotation speed of the workpiece and the tool was turned to four conditions of 200 rpm, 400 rpm, 800 rpm, and 1600 rpm. In these conditions, the relative speed (V) between the workpiece 1 (diameter 2r=17.8 mm) and the processing surface 3 of the tool 2 becomes roughly 188 mm/s, 377 mm/s, 754 mm/s and 1510 mm/s, respectively.

[0064] The processing amount (processing depth) per minute, namely, the processing rate, under the respective conditions above can be measured using a scanning type white interferometer or the like, and the measured values under the above conditions were 374 nm, 718 nm, 1015 nm and 1026 nm, respectively. Four plots (602) in Fig. 6 indicate these processing rates.

[0065] Next, using the obtained processing amount, the constants in the above estimation expression (expression (6)) are calculated. The first constant K_1 and the second constant K_2 in the above estimation expression (the expression (6)) were calculated by repeatedly performing calculation such that errors of the estimated value to the experimental values under the respective conditions became 25% or less. As a result, in the case that the first constant K_1 and the second constant K_2 were $K_1=3.93\times10^{-2}$ and $K_2=4.58\times10^{-7}$, the errors of the estimated value to the respective experimental values were turned to 25% or less. The expression (9) below is the expression in which the obtained values are substituted for the constants K_1 and K_2 of the expression (6).

[0066] [Math.9]

$$R = (3.93 \times 10^{-2})PV - (4.58 \times 10^{-7})V^3 \qquad (9)$$

The characteristic of the processing rate of the expression (7) is indicated as a characteristic curve (601) in Fig. 6.

[0067] Subsequently, using the above expression (9) (which is an example of the estimation expression (6)), the processing rate R was obtained with the processing pressure P of 30 kPa and the relative speed V of 1510 mm/s. Furthermore, the required processing time was calculated in the case that the processing amount (processing depth) of 2000 nm or more was needed.

[0068] Here, for the workpiece 1, the one for which grinding by a diamond grindstone was performed as pre-processing and whose affected layer was left by the thickness of about 2000 nm was used. In the catalyst support type processing of the present

example, it is assumed that the processing depth sufficient to remove the affected layer is achieved.

[0069] On the other hand, it is recognized that, in order to obtain the processing amount of 2000 nm or more at the processing rate estimated by the above estimation expression (9), the processing time of 9.8 minutes or longer is required. Then, the processing time was set at 10 minutes and processing was carried out.

[0070] Fig. 7 illustrates the processing amount actually obtained and the processing amount by the estimation expression. As in Fig. 7, the estimated value was 2050 nm (left side), and the actually obtained processing amount was 2845 nm (right side). The error of the estimated value to the actual processing amount was 28%, and it was confirmed that the processing amount was considerably accurately predicted by the expression (6).

[0071] Fig. 8 illustrates a result of measuring the surface of the workpiece after processing with a scanning type white interferometer. As illustrated in Fig. 8, surface roughness was turned from 70 nmRMS before processing to around 0.9 nmRMS over a center part, a middle belt part and an outer peripheral part after processing, and it is recognized that the high-quality workpiece whose affected layer was almost perfectly removed was obtained.

[0072] As is clear from the example using the estimation expression (9), it is recognized that the processing rate in the catalyst support type processing can be estimated with excellent accuracy in a practical view, by using the estimation expression (expression (6)) described above.

[0073] As described above, the processing rate can be accurately estimated by the estimation expression (expression (6)), that is, the estimation expression indicated by the difference between the member formed of the product of the first constant, the processing pressure P and the relative speed V and the member formed of the product of the second constant and the cube of the relative speed V. Therefore, when the estimation expression (expression (6)) is used, since the processing amount under the arbitrary processing condition can be accurately predicted and the processing condition for obtaining the predetermined processing amount can be efficiently set, the high-quality workpiece can be efficiently manufactured.

Example 2

[0074] The present example 2 describes an example of using the same estimation expression (expression (9)) as the one with which the first constant K_1 and the second constant K_2 were obtained in the example 1. The processing pressure P and the relative speed V are set for wider conditions, and the experimental value and the estimated value of the processing rate R are compared. In the present example 2, processing was carried out under the total of 12 conditions that are three conditions of 30 kPa, 80 kPa and 120 kPa

for the processing pressure and four conditions of 200 rpm, 400 rpm, 800 rpm and 1600 rpm for the rotation speed.

[0075] A result of comparing the processing amount per minute and the processing amount by the estimation expression is illustrated in Fig. 9. In the figure, the experimental values (plots by symbols of a circle, a triangle, a square and the like) of the processing rate under the respective conditions and curves of processing rate characteristics 901, 902, 903 and 904 estimated by the estimation expression (expression (9)) coincide well. From the result, it is recognized that, when the estimation expression (expression (9) or (6)) is used, the processing rate can be accurately estimated under the wide processing conditions. Therefore, using the estimated value of the processing rate obtained by using the estimation expression (expression (9) or (6)), for example, the processing condition for obtaining the predetermined processing amount can be efficiently set.

[0076] As described above, also by the present example 2, it is recognized that the processing amount under the arbitrary processing condition can be accurately predicted when the estimation expression (expression (6)) is used. Therefore, using the estimated value of the processing rate obtained by using the estimation expression (expression (9) or (6)), for example, the processing condition for obtaining the predetermined processing amount can be efficiently set. That is, according to the present example 2, since the processing rate under the arbitrary processing condition can be accurately predicted and the processing condition for obtaining the predetermined processing amount can be efficiently set, the high-quality workpiece (an optical element such as a lens or a mirror, for example) can be efficiently manufactured.

Example 3

[0077] An example 3 describes an example of carrying out processing using, as the workpiece, optical glass (fluorophosphate glass S-TIH11 manufactured by OHARA INC.) containing O^{2-} as an anion component and containing at least cation components listed below in terms of cation% (mol%).

- 27% or more and 37% or less as Si^{4+}
- 0% or more and 3% or less as Ca^{2+}
- 3% or more and 8% or less as Ba^{2+}
- 20% or more and 28% or less as Ti^{4+}
- 0% or more and 1% or less as Sb^{3+}
- 2% or more and 12% or less as K^{+}
- 0.5% or more and 5% or less as Nb^{5+}
- 17% or more and 36% or less as Na^{+}

[0078] The shape of the workpiece 1 is a planar shape whose outer diameter D_W is 34.0

[mm]. The outer diameter of the tool 2 is 68.0 [mm] which is double the outer diameter of the workpiece. The elastic body 5 was provided on the upper surface of the tool 2, and the thin film of Pt was coated by the thickness of about 100 nm as the catalyst part 3 on the surface of the elastic body 5. For the elastic body 5, the foamed polyurethane NFP05 manufactured by KOKONOE ELECTRIC CO., LTD. was used. Purified water was used for the processing fluid 4, and was supplied at the flow rate of 1000 ml per minute to the surface of the catalyst part 3 by a supply unit. The workpiece 1 was supported by the holder 6, and the workpiece 1 and the tool 2 were brought into contact by pressurization. By rotating the workpiece 1 and the tool 2 by the drive force of the motors respectively, the relative movement was performed in the direction of the contact surface of the workpiece 1 and the catalyst part 3.

[0079] In order to obtain the constants in the estimation expression indicated in the expression (6), the processing pressure was set to 40 kPa, the rotation speed of the workpiece and the tool was set to three conditions of 100 rpm, 400 rpm and 800 rpm, and the processing amount per minute of the processing time was acquired. The relative speeds of the workpiece and the catalyst part were 178 mm/s, 712 mm/s and 1424 mm/s, respectively. The processing amounts per minute under the respective conditions were 138 nm, 453 nm and 466 nm. Next, using the acquired processing amounts, the constants in the estimation expression indicated in the expression (6) were obtained. As a result, in the case of $K_1=1.80\times10^{-2}$ and $K_2=2.00\times10^{-7}$, the errors of the estimated value to the respective experimental values became 25% or less. The following expression (10) indicates the expression for which the values are substituted for the constants K_1 and K_2 of the expression (6).

[0080] [Math.10]

$$R = (1.80 \times 10^{-2})PV - (2.00 \times 10^{-7})V^3 \qquad (10)$$

In this case, the relative speed V_{max} at which the maximum value of the processing rate R can be obtained is as in the following expression (11).

[0081] [Math.11]

$$V_{max} = \sqrt{\frac{(1.80\times10^{-2})P}{3(2.00\times10^{-7})}} \qquad (11)$$

[0082] From the expression (11) above, the relative speed V_{max} of the tool and the workpiece at which the processing rate becomes the highest under the condition that the processing pressure P is 40 kPa is obtained as 1095 mm/s. It is conceivable that the processing rate suitable for practical production can be obtained when the relative speed is within the range of about 700 mm/s lower and 700 mm/s higher than the relative speed at which the processing rate becomes the highest. Therefore, the rotation

speed of the workpiece and the tool was turned to 600 rpm, the relative speed was turned to 1068 mm/s, and the processing rate was confirmed. As a result, while the estimated value was 525 nm/min, the actual processing rate was 530 nm/min.

[0083] Fig. 12 illustrates the relation of the relative speed and the processing rate in the present example. In the figure, a processing rate curve corresponding to the above estimation expression (expression (11)) is 801, and the experimental values used for obtaining the constant members of the estimation expression (expression (11)) are 803. In Fig. 12, the processing rate obtained in actual processing is 802, the error of the estimated value (801) to the actual processing rate 802 is about 1%, and it was confirmed that the processing amount was accurately predicted by the expression. As described above, according to the present example, it was verified that the relative speed at which the efficient processing rate can be obtained can be set based on the expression (6) even in a region where the processing rate is high. Also, it was confirmed that the processing rate that is high enough to be practically used in production of optical lens can be obtained.

Example 4

[0084] In the practical production of optical elements, generally the processing rate of 200 nm/min or higher is often obtained. Therefore, from the estimation expressions (6)-(8) and the estimation expressions (9)-(11), the range of the relative speed V in which the processing rate R becomes 200 nm/min or more was calculated. The calculation result is indicated in the table 1 below. Note that a lower limit value (V_{min}) of the relative speed is rounded up, and an upper limit value (V_{max}) of the relative speed is rounded down.

[0085] [Table 1]

Table1 Unit mm/s

Glass kind		20kPa	30kPa	40kPa	50kPa	60kPa	70kPa	80kPa	90kPa	100kPa	110kPa	120kPa
S-LAM55	min	300	200	200	200	100	100	100	100	100	100	100
	max	1100	1500	1700	2000	2200	2400	2500	2700	2900	3000	3100
S-TIH11	min	0	400	300	300	200	200	200	200	200	200	100
	max	0	1400	1700	1900	2200	2400	2600	2700	2900	3000	3200

[0086] From the table 1, it is recognized that, in the case that the workpiece is optical glass, it is preferable to perform processing with the relative speed being 400 mm/s or higher and 1400 mm/s or lower when the processing pressure is 30 KPa or higher and lower than 40 KPa, and with the relative speed being 300 mm/s or higher and 1700 mm/s or lower when the processing pressure is 40 KPa or higher and lower than 50 KPa.

[0087] Further, it is recognized that it is preferable to perform processing with the relative speed being 300 mm/s or higher and 1900 mm/s or lower when the processing pressure

is 50 KPa or higher and lower than 60 KPa, and with the relative speed being 200 mm/s or higher and 2200 mm/s or lower when the processing pressure is 60 KPa or higher and lower than 70 KPa.

[0088] Further, it is recognized that it is preferable to perform processing with the relative speed being 200 mm/s or higher and 2400 mm/s or lower when the processing pressure is 70 KPa or higher and lower than 80 KPa, and with the relative speed being 200 mm/s or higher and 2600 mm/s or lower when the processing pressure is 80 KPa or higher and lower than 90 KPa.

[0089] Further, it is recognized that it is preferable to perform processing with the relative speed being 200 mm/s or higher and 2700 mm/s or lower when the processing pressure is 90 KPa or higher and lower than 100 KPa, and with the relative speed being 200 mm/s or higher and 2900 mm/s or lower when the processing pressure is 100 KPa or higher and lower than 110 KPa.

[0090] Further, it is recognized that it is preferable to perform processing with the relative speed being 200 mm/s or higher and 3000 mm/s or lower when the processing pressure is 110 KPa or higher and lower than 120 KPa, and with the relative speed being 100 mm/s or higher and 3100 mm/s or lower when the processing pressure is 120 KPa or higher and lower than 130 KPa.

[0091] As described above, by appropriately selecting the processing pressure from the range of 30 KPa or higher and lower than 130 KPa and the relative speed from the range of 100 mm/s or higher and 3100 mm/s or lower in processing optical glass, components of the optical element such as lens or mirror can be efficiently manufactured. As described above, by utilizing the above estimation expressions (6)-(11), the processing condition for obtaining a desired processing amount can be efficiently set, and the high-quality workpiece can be efficiently produced.

Example 5

[0092] The following table 2 and table 3 respectively illustrate results of calculating, based on the above estimation expressions (6)-(11), the ranges of the relative speed of the tool and the workpiece to be used in regions where the processing rate is 800 nm/min and 1000 nm/min or higher at which the optical element can be further efficiently processed.

[0093] [Table 2]

Table 2 Unit mm/s

Glass kind		20kPa	30kPa	40kPa	50kPa	60kPa	70kPa	80kPa	90kPa	100kPa	110kPa	120kPa
S-LAM55	min			600	500	400	300	300	300	300	200	200
	max			1500	1800	2000	2200	2400	2600	2800	2900	3100
S-TIH11	min					900	700	600	600	500	500	400
	max					1700	2000	2300	2500	2700	2900	3000

[0094] [Table 3]

Table 3 Unit mm/s

Glass kind		20kPa	30kPa	40kPa	50kPa	60kPa	70kPa	80kPa	90kPa	100kPa	110kPa	120kPa
S-LAM55	min			800	600	500	400	400	300	300	300	300
	max			1300	1700	2000	2200	2400	2600	2700	2900	3000
S-TIH11	min						1000	800	700	600	600	500
	max						1900	2200	2400	2600	2800	3000

[0095] As is clear from the tables 2 and 3, in order to more efficiently proceed processing in these processing rate regions, the processing pressure is selected from the range of 60 KPa or higher and lower than 130 KPa, and the relative speed is selected from the range of 200 mm/s or higher and 3000 mm/s or lower. Thus, it is recognized that the processing rate of 800 nm/min or higher can be obtained. As a further preferable processing condition, when the processing pressure is selected from the range of 70 KPa or higher and lower than 130 KPa, and the relative speed is selected from the range of 300 mm/s or higher and 3000 mm/s or lower, it is recognized that the processing rate of 1000 nm/min or higher can be achieved. As described above, even in the region of the processing rate higher than that in the example 4, by utilizing the above estimation expressions (6)-(11), the processing condition for obtaining the desired processing amount can be efficiently set, and the high-quality workpiece can be efficiently produced.

Example 6

[0096] A configuration example of a control unit 200 for controlling processing apparatus hardware in Fig. 1, and an example of a control procedure will be described below.

[0097] Fig. 10 illustrates the configuration example of the control unit 200 of the processing apparatus. The control unit in Fig. 10 comprises a CPU 201 including a general purpose microprocessor or the like, a ROM 202, a RAM 203, an input unit 211, an output unit 212, the motors 220 and 221 as a processing drive system, and a processing pressure control unit 222 or the like.

[0098] The ROM 202 is a computer-readable recording medium, and can be used for storing a processing control program described later and control data for example. Note that, in order to update the processing control program and the control data stored in the ROM 202 later, a storage area for that may include a rewritable storage device such as an E(E)PROM. Also, an area of the rewritable storage device in the ROM 202 may include a detachable flash memory. Such a detachable computer-readable recording medium can be used to install or update the processing control program configuring a part of the present invention in the ROM 202 (E(E)PROM area), for example. In this case, various kinds of the detachable computer-readable recording medium store the

control program configuring the present invention, and the recording medium itself configures the present invention.

[0099] The RAM 203 includes a DRAM element or the like, and is used as a work area for the CPU 201 to execute various kinds of control and processing. Functions relating to the processing control in the present example are realized when the CPU 201 executes the processing control program stored in the ROM 202 using the RAM 203 as the work area.

[0100] The input unit 211 is an input unit for inputting the processing condition (control condition), and includes an interface device to input the processing condition described in a predetermined data format from another control terminal (a computer or a server device for example) or the like. The interface device includes for example various kinds of serial buses, parallel buses and network interfaces or the like. The input unit 211 may include a user interface device to which an operator inputs a desired processing condition. In that case, the user interface device can include a pointing device or the like such as a keyboard, a display, a mouse and a track pad (ball).

[0101] The CPU 201 controls the processing drive system of the processing apparatus in Fig. 5 through the output unit 212. The processing drive system of the processing apparatus in the present example includes at least the motor 220 that rotationally drives the workpiece 1 through the holder 6 in Fig. 5, the motor 221 that rotationally drives the tool 2, and the processing pressure control unit 222.

[0102] Note that the swing movement of the holder 6 can be generated by using a mechanism (not shown in the figure) such as a cam or a link and converting the rotational movement of the motor 220 or 221 to the swing movement. However, in the case that a drive source (not shown in the figure) such as an independent motor is used for the holder 6 that swings the workpiece 1, the drive source of the holder 6 can be also configured to be controlled by the CPU 201.

[0103] The processing apparatus in Fig. 5 is configured to control the processing pressure (P) that press-contacts the workpiece 1 to the tool 2 through the holder 6 preferably. In that case, a processing pressure generating mechanism (not shown in the figure) can be configured to apply press-contacting force (processing pressure) in a direction of the tool 2 to the holder 6 holding the workpiece 1 by a solenoid (not shown in the figure) or the like. Also, the processing pressure itself may be generated by a spring (not shown in the figure), and a solenoid (not shown in the figure) that changes a compression amount of the spring may be provided as a processing pressure varying unit.

[0104] For example, one of the solenoids described above can be used as the processing pressure control unit 222, and the processing pressure that press-contacts the workpiece 1 to the tool 2 through the holder 6 can be controlled by changing drive force of the solenoid.

[0105] The CPU 201 can control the relative speed of the workpiece 1 and the tool 2 by controlling the number of rotation (rotation speed) of the motors 220 and 221 through the output unit 212. The CPU 201 can also control the processing pressure (P) that press-contacts the workpiece 1 and the tool 2 through the processing pressure control unit 222 through the output unit 212. The output unit 212 can include an interface circuit and a driver circuit or the like that convert a command (digital data of one to several bytes) of the CPU 201 to information (a voltage or a current or the like) capable of driving the motors 220 and 221 and the processing pressure control unit 222.

[0106] A timer circuit 213 includes a timer device such as an RTC (real time clock). The CPU 201 can determine a length of the processing time (period) for example using the timer circuit 213.

[0107] The CPU 201 performs the processing control of controlling the processing operation of the workpiece 1 by controlling the individual units according to the processing condition described later, which is input from the input unit 211. In the present example, the relative speed of the workpiece 1 and the tool 2 controllable through the motors 220 and 221, the processing pressure controllable through the processing pressure control unit 222, the desired processing amount (processing depth) of the workpiece 1, and the processing time and the like can be input from the input unit 211.

[0108] According to the processing condition input through the input unit 211, the CPU 201 stops the rotational drive of the motors 220 and 221 and finishes catalyst support processing when the processing period (processing time) is ended according to the timing of the timer circuit 213. Furthermore, at the time, the CPU 201 may perform control of separating the workpiece 1 from the tool 2 through a mechanism (not shown in the figure) of the processing apparatus, and stopping the catalytic reaction by stopping supply of the processing fluid 4.

[0109] (Control form 1)

In a simple form of the processing control using the control unit 200 in Fig. 10, an operator specifies all of the relative speed of the workpiece 1 and the tool 2, the processing pressure, and the processing time by manual operation through the input unit 211.

[0110] In this form, processing operation is ended at the point of time when the processing period (processing time) is ended according to the timing of the timer circuit 213. In this system, since all the processing conditions are determined by manual operation, there is no room for operating the processing rate estimation by the above estimation expression (expression (6)). The operator determines the processing conditions based on experiences and repeats processing, for example while estimating the processing time slightly shorter and measuring the size and the shape of the surface 11 to be processed using an interferometer or the like.

[0111] (Control form 2)

On the other hand, by using the estimation expression (expression (6)), the processing rate can be accurately estimated as illustrated in the above examples. Accordingly, a desired processing depth of the surface 11 to be processed is input to a right side of the estimation expression (expression (6)) together with the corresponding relative speed of the workpiece 1 and the tool 2 and the processing pressure. Then, using these input conditions, the CPU 201 estimates the processing rate using the estimation expression (expression (6)). Note that, of course, the first and second constants in the estimation expression (expression (6)) are determined beforehand by actual measurements using different relative speeds or processing pressures as described above.

[0112] Further, the CPU 201 obtains the required processing time by dividing the input processing depth by the estimated processing rate. The processing time is set to the timer circuit 213. Then, the motors 220 and 221 and the processing pressure control unit 222 are controlled so as to be the input relative speed and processing pressure, and the processing is ended when the timer circuit 213 times the set processing time.

[0113] In this way, by using the estimation expression (expression (6)), the required processing time necessary to process the desired processing depth can be determined accurately, together with the relative speed of the workpiece 1 and the tool 2 and the processing pressure.

[0114] (Control form 3)

Further, it is also possible to input the desired processing depth of the surface 11 to be processed in the input unit 211, specify one of the relative speed and the processing pressure, and manage the other processing pressure or relative speed using the estimation expression (expression (6)). In this case, for example, the desired processing time (or processing rate) is further specified from the input unit 211, and the CPU 201 controls the other processing pressure or relative speed using the estimation expression (expression (6)) so as to achieve the desired processing depth and the desired processing time (processing rate).

[0115] By such control, the processing pressure or the relative speed can be controlled and the surface 11 to be processed can be processed by the desired processing depth within the desired processing time. For example, this control corresponds to the control of selecting one of different curves of relative speed-processing rate in Fig. 9 and achieving the desired processing depth and the desired processing time.

[0116] (Control form 4)

Further, in the system of specifying the processing depth and the processing pressure in the input unit 211 and controlling the relative speed in the CPU 201, the following control can be performed in consideration of characteristics of the estimation ex-

pression (expression (6)).

[0117] When paying attention to the estimation expression (expression (6)) and the corresponding curves of relative speed-processing rate in Fig. 5 and Fig. 9, it is clear that a processing characteristic of the catalyst support processing is not one-dimensional (linear) as indicated by Preston's empirical formula. That is, the curve of relative speed-processing rate corresponding to the estimation expression (expression (6)) has a maximum value, and a region where the processing rate oppositely declines at the relative speed over a certain level under a certain processing pressure is recognized.

[0118] Thus, when the processing pressure is determined and the first and second constants in the estimation expression (expression (6)) are calculated, the CPU 201 can calculate the maximum value (optimum value: V_{max} in expressions (8) and (11)) of the relative speed, at which the highest processing rate can be obtained under a specific processing pressure. Then, the CPU 201 can manage the relative speed so as to use the maximum value (optimum value) of the relative speed, at which the highest processing rate can be obtained under the processing pressure. Therefore, the relative speed can be managed so as to automatically select the maximum value (optimum value) of the relative speed of the workpiece 1 and the tool 2 just by inputting the desired processing pressure and processing depth from the input unit 211, and the workpiece 1 can be processed under the processing conditions with the best processing efficiency.

[0119] (Control procedure)

Fig. 11 illustrates an example of the processing control procedure performed by the control unit in Fig. 10. The procedure in Fig. 11 may be stored in the ROM 202 as a control program of the CPU 201. The control program describing the processing control procedure of the present example may be supplied to a control system in Fig. 10 by a computer-readable optical disk or various kinds of flash memories (both not shown in the figure). In that case, a predetermined area of the ROM 202 including the E(E)PROM or the like may be configured by various kinds of detachable flash memories and the control program may be installed or updated to the control system in Fig. 10 by utilizing the area. The control program describing the processing control procedure of the present example may be supplied to the control system in Fig. 10 to be installed and updated through a network interface (not shown in the figure) or the like.

[0120] The procedure of Fig. 11 is based on steps S10-S13 and S15 which correspond to the processing control in the control forms 1-3. Also, step S14 corresponds to a main part of the control of automatically selecting the optimum value of the relative speed of the workpiece 1 and the tool 2 described in the control form 4, and by adding step S14, the processing control in the control form 4 can be performed.

[0121] In step S11 of Fig. 11, among processing control conditions of the processing

pressure, the relative speed of the workpiece 1 and the tool 2, the desired processing depth (or the desired processing time) and the like, the ones necessary in the control forms 1-4 are input by the input unit 211.

[0122] A plurality of sets of the first and second constants of the estimation expression (expression (6)) can be calculated beforehand for example according to the material of the workpiece 1 or the like. The plurality of sets of the first and second constants of the estimation expression (expression (6)) can be made into a database in association with the material of the workpiece 1 or the like and stored in the RAM 203 or the ROM 202. In that case, in step S11, the estimation expression (expression (6)) having appropriate first and second constants can be selected so as to be used in the processing control by specifying the material of the workpiece 1 or the like from the input unit 211 for example.

[0123] The above respective processing control conditions are, in the case of manual input by the operator, input by a manual operation using the input unit 211 including the user interface device. Also, in the case that the network interface or the like is included in the input unit 211, the processing control conditions described in the predetermined data format can be inputted from another control terminal (a computer or a server device for example) using the interface.

[0124] In step S12 in Fig. 11, the CPU 201 sets the motors 220 and 221 and the processing pressure control unit 222 according to the processing control conditions input in step S11. For example, in the case that the relative speed of the workpiece 1 and the tool 2 is specified from the input unit 211, the rotation number of the motors 220 and 221 is determined so as to obtain the relative speed. Also, a pressure control condition of the processing pressure control unit 222 is determined so as to obtain the processing pressure specified from the input unit 211. Also, in the case that the processing time is specified from the input unit 211 as in the control form 1, the timing time of the timer circuit 213 is set.

[0125] In the case of the control forms 2-4, setting processing in step S12 is as follows.

[0126] Further, as in the control form 2, in the case that the relative speed of the workpiece 1 and the tool 2, the processing pressure, and the desired processing depth of the surface 11 to be processed are input in step S10, the CPU 201 performs an operation of estimating the processing rate using the estimation expression (expression (6)). In this example, processing of estimating the processing rate using the estimation expression (expression (6)) is included in a processing rate estimation step. The CPU 201 can calculate the processing time using the processing rate estimated using the estimation expression (expression (6)) and the specified processing depth, and sets the processing time to the timer circuit 213.

[0127] As in the control form 3, in order to achieve the desired processing depth and the

desired processing time (or the processing rate) from the input unit 211, the other processing pressure or relative speed can be controlled as well. In this case, the processing time (or the processing rate) and either one of the relative speed and the processing pressure are specified from the input unit 211 in step S10. Then, the CPU 201 estimates the processing rate using the estimation expression (expression (6)) (estimation step). Further, the CPU 201 calculates the other processing pressure or relative speed so as to achieve the specified processing depth or the desired processing time using the estimated value of the processing rate, and sets the processing pressure control unit 222 or the motors 220 and 221.

[0128] In the case of the control form 4 corresponding to optimum control, it is not always needed to specify the processing time (or the processing rate) in step S10. In this case, at least the processing pressure and the desired processing depth may be determined, and the CPU 201 can calculate the relative speed, in particular, the maximum value (optimum value) thereof, using the estimation expression (expression (6)) in step S12.

[0129] For example, the CPU 201 differentiates a function expressed by the estimation expression (expression (6)) to which the input processing pressure and first and second variables (both are determined by the material of the workpiece or the like) are applied. Then, by obtaining the inflection point from the differential function or the like, the highest (optimum) relative speed at which the processing rate estimated by the expression becomes the highest can be calculated. Then, the CPU 201 selects the rotation number of the motors 220 and 221 so as to obtain the highest (optimum) relative speed. Also, using the desired processing depth and the highest processing rate obtained by the above-described operation, the CPU 201 can calculate the processing time, and set the processing time to the timer circuit 213.

[0130] After the setting above, while monitoring a processing end condition in step S15, a processing control loop of driving each unit such as the motors 220 and 221 and the processing pressure control unit 222 in step S13 based on the conditions set in step S12 is executed. The processing corresponds to a management step of managing the relative speed of relatively moving the processing surface 3 and the surface 11 to be processed and the processing pressure or the like based on the processing rate estimated in the processing rate estimation step.

[0131] The highest or optimum speed control indicated in step S14 explicitly illustrates the control of keeping the relative speed at the maximum (optimum) value (V_{max} in the expressions (8) and (11)) as in the control form 4. Step S14 is performed while executing step S13 in the case of performing the control corresponding to the control form 4. For example, in the case that the relative speed is already determined in step S12 and the relative speed is controlled by open loop control as described above, there is no need to perform the control especially at a position of step S14 in the figure.

[0132] However, in the case that an encoder that detects an actual rotation number of the motors 220 and 221 is provided or the like, at the position of step S14, closed loop control can be performed so that the relative speed of the workpiece 1 and the tool 2 does not exceed the maximum (optimum) value. As described above, in the processing rate characteristic of the estimation expression (expression (6)), when the relative speed of the workpiece 1 and the tool 2 exceeds a speed value at which the highest processing rate can be obtained, the processing rate (efficiency) declines instead. By performing the closed loop control described above, the decline of the processing rate (efficiency) of the workpiece 1 due to relative speed excess can be prevented. The closed loop control by which the relative speed of the workpiece 1 and the tool 2 does not exceed the maximum (optimum) value in this way may be used together in the case that the relative speed is already determined in step S12 for example.

[0133] Note that, in the configuration capable of detecting the rotation number of the motors 220 and 221 using the encoder or the like, the CPU 201 can detect fluctuation of the relative speed of the workpiece 1 and the tool 2 constantly. Then, when these respective relative speeds and the estimation expression (expression (6)) are used, fluctuation of (the estimated value of) the processing rate can be detected constantly, and further, for example, the estimated value of the processing amount can be obtained by an integration operation or the like. As described above, the rotation number of the motors 220 and 221 is detected using the encoder or the like, and the estimated value of the (actual) processing amount can be computed constantly from the relative speed. For example, using the estimated value of the (actual) processing amount and the processing depth input from the input unit 211, processing of correcting the processing time set to the timer circuit 213 may be performed.

[0134] End condition detection in step S15 can be executed by timeout detection of the timer circuit 213 in the case that the processing time is set to the timer circuit 213 as described above. Such timer control can be executed for example by utilizing a control mechanism of the CPU 201 such as timer interruption processing (exception handling).

[0135] As described above, the control unit 200 can execute the processing control of driving each unit such as the motors 220 and 221 and the processing pressure control unit 222, in order to achieve the processing depth input from the input unit 211.

[0136] In that case, the processing control can be performed in each control mode indicated as the control forms 1-4 described above. In particular, in the control form 4, the relative speed of the workpiece 1 and the tool 2 at which the processing rate (efficiency) of the workpiece 1 becomes the highest can be automatically selected. Therefore, in the control of the control form 4, the optimum processing efficiency can be obtained just by specifying the processing depth (and the processing pressure) for example, without specifying the processing time or the relative speed from the input

unit 211.

[0137] By executing the processing apparatus or the processing method of the present invention described above, a manufacturing method for manufacturing various components such as an optical element or a semiconductor substrate formed of a solid oxide or a semiconductor or the like can be achieved.

[0138] In the present invention, a program that achieves one or more functions of the examples described above can be supplied to a system or an apparatus through a network or a storage medium. In that case, the control of the present invention can be achieved also by processing that one or more processors in a computer of the system or the apparatus read and execute the program. Also, the control of the present invention can be achieved also by a circuit (ASIC, for example) that achieves one or more functions.

[0139] Even in the case of combining the relative swing of the workpiece 1 and the tool 2 by the fixing pin or the like illustrated in Fig. 1, the present invention can be executed. For example, when conditions including the rotating direction and a swing condition or the like and a measuring (calculating) system of the relative speed are consistent between the time of measuring the first and second constants K_1 and K_2 of the estimation expression (expression (6)) and the time of the estimating operation by the same expression, the present invention can be executed. For example, in the case of combining the relative swing with the relative movement by the rotational movement of the workpiece 1 and the tool 2, it is conceivable to use an absolute value of a composite speed vector or to use a speed component in a tangential direction of a circular movement of a specific rotating part as the relative speed. Also, in the case that the rotational driving directions of the tool and the workpiece are rotations opposite to each other in Fig. 1 and Fig. 5 or the like, the relative speed becomes different depending on a measuring part. Even in such a case, when conditions of the rotating direction or the like and the measuring (calculating) system including even the measuring part of the relative speed are consistent between the time of measuring the first and second constants K_1 and K_2 of the estimation expression (expression (6)) and the time of the estimating operation by the same expression, the present invention can be executed.

Other Embodiments

[0140] Embodiment(s) of the present invention can also be realized by a computer of a system or apparatus that reads out and executes computer executable instructions (e.g., one or more programs) recorded on a storage medium (which may also be referred to more fully as a 'non-transitory computer-readable storage medium') to perform the functions of one or more of the above-described embodiment(s) and/or that includes one or more circuits (e.g., application specific integrated circuit (ASIC)) for performing the functions of one or more of the above-described embodiment(s), and by

a method performed by the computer of the system or apparatus by, for example, reading out and executing the computer executable instructions from the storage medium to perform the functions of one or more of the above-described embodiment(s) and/or controlling the one or more circuits to perform the functions of one or more of the above-described embodiment(s). The computer may comprise one or more processors (e.g., central processing unit (CPU), micro processing unit (MPU)) and may include a network of separate computers or separate processors to read out and execute the computer executable instructions. The computer executable instructions may be provided to the computer, for example, from a network or the storage medium. The storage medium may include, for example, one or more of a hard disk, a random-access memory (RAM), a read only memory (ROM), a storage of distributed computing systems, an optical disk (such as a compact disc (CD), digital versatile disc (DVD), or Blu-ray Disc (BD)™), a flash memory device, a memory card, and the like.

[0141] While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

[0142] This application claims the benefit of Japanese Patent Application No. 2015-029373, filed February 18, 2015, which is hereby incorporated by reference herein in its entirety.

Claims

[Claim 1] A processing apparatus for processing a surface to be processed of a workpiece by relatively moving a tool and the surface to be processed, the processing apparatus comprising:
a control unit configured to manage a relative speed of relatively moving the tool and the surface to be processed or the processing pressure,
wherein the control unit estimates a processing rate of the surface to be processed obtained under the processing pressure by an estimation expression indicated by a difference between a member formed of a product of a first constant, the processing pressure and the relative speed and a member formed of a product of a second constant and a cube of the relative speed, and manages the relative speed or the processing pressure based on the estimated processing rate.

[Claim 2] The processing apparatus according to claim 1, wherein the first constant and the second constant in the estimation expression are calculated using the processing rates obtained respectively at a plurality of different relative speeds by relatively moving the tool and the surface to be processed at the plurality of different relative speeds beforehand under a specific processing pressure.

[Claim 3] The processing apparatus according to claim 1 or 2, wherein the control unit is configured to determine processing time to process the workpiece using the tool, based on the processing rate estimated using the estimation expression.

[Claim 4] The processing apparatus according to any one of claims 1 to 3, wherein the control unit is configured to control the relative speed so that the processing rate obtained under a specific processing pressure does not exceed a maximum value.

[Claim 5] A processing method for processing a surface to be processed of a workpiece by relatively moving the workpiece and a tool whose processing surface includes a catalyst substance containing a transition metal which supports hydrolysis of the surface to be processed in a state of being press-contacted by a processing pressure with a water molecule being interposed, and performing processing control of managing a relative speed of relatively moving the processing surface and the surface to be processed or the processing pressure by a control unit during the processing, the processing method comprising:

an estimation step in which the control unit estimates a processing rate of the surface to be processed obtained under the processing pressure by an estimation expression indicated by a difference between a member formed of a product of a first constant, the processing pressure and the relative speed and a member formed of a product of a second constant and a cube of the relative speed; and

a management step in which the control unit manages the relative speed or the processing pressure based on the processing rate estimated in the estimation step.

[Claim 6] The processing method according to claim 5, wherein the first constant and the second constant in the estimation expression are calculated using the processing rates obtained respectively at a plurality of different relative speeds by relatively moving the processing surface and the surface to be processed at the plurality of different relative speeds beforehand under a specific processing pressure.

[Claim 7] The processing method according to claim 5 or 6, wherein the control unit is configured to determine processing time to process the workpiece using the tool, based on the processing rate estimated using the estimation expression.

[Claim 8] The processing method according to any one of claims 5 to 7, wherein the control unit is configured to control the relative speed so that the processing rate obtained under a specific processing pressure does not exceed a maximum value.

[Claim 9] A processing control program, wherein the control unit is made to execute the processing control according to any one of claims 5 to 8.

[Claim 10] A computer-readable recording medium, wherein the processing control program according to claim 9 is stored.

[Claim 11] A component manufacturing method for processing a surface to be processed of a workpiece by relatively moving the workpiece and a tool whose processing surface includes a catalyst substance containing a transition metal which supports hydrolysis of the surface to be processed in a state of being press-contacted by a processing pressure with a water molecule being interposed, and performing processing control of managing a relative speed of relatively moving the processing surface and the surface to be processed or the processing pressure by a control unit during the processing, the component manufacturing method comprising:

an estimation step in which the control unit estimates a processing rate

of the surface to be processed obtained under the processing pressure by an estimation expression indicated by a difference between a member formed of a product of a first constant, the processing pressure and the relative speed and a member formed of a product of a second constant and a cube of the relative speed; and

a management step in which the control unit manages the relative speed or the processing pressure based on the processing rate estimated in the estimation step.

[Claim 12] A component manufacturing method for processing optical glass by bringing a catalyst part of a tool and the optical glass into contact and relatively moving the catalyst part and the optical glass, the tool having the catalyst part containing a transition metal on a surface facing the optical glass, the component manufacturing method comprising:

in a state of interposing a water molecule, bringing the catalyst part and the optical glass into contact by a pressure selected from a range of 30 KPa or higher and below 130 KPa;

relatively moving the catalyst part and the optical glass at a speed selected from a range of 100 mm/s or higher and 3100 mm/s or lower; and

performing the processing at a processing rate equal to or higher than 200 nm/min.

[Claim 13] The component manufacturing method according to claim 12, wherein, when the pressure is selected to be 30 KPa or higher and below 40 KPa, the speed is selected to be 400 mm/s or higher and 1400 mm/s or lower.

[Claim 14] The component manufacturing method according to claim 12 or 13, wherein, when the pressure is selected to be 40 KPa or higher and below 50 KPa, the speed is selected to be 300 mm/s or higher and 1700 mm/s or lower.

[Claim 15] The component manufacturing method according to any one of claims 12 to 14, wherein, when the pressure is selected to be 50 KPa or higher and below 60 KPa, the speed is selected to be 300 mm/s or higher and 1900 mm/s or lower.

[Claim 16] The component manufacturing method according to any one of claims 12 to 15, wherein, when the pressure is selected to be 60 KPa or higher and below 70 KPa, the speed is selected to be 200 mm/s or higher and 2200 mm/s or lower.

[Claim 17] The component manufacturing method according to any one of claims 12 to 16, wherein, when the pressure is selected to be 70 KPa or higher

and below 80 KPa, the speed is selected to be 200 mm/s or higher and 2400 mm/s or lower.

[Claim 18] The component manufacturing method according to any one of claims 12 to 17, wherein, when the pressure is selected to be 80 KPa or higher and below 90 KPa, the speed is selected to be 200 mm/s or higher and 2600 mm/s or lower.

[Claim 19] The component manufacturing method according to any one of claims 12 to 18, wherein, when the pressure is selected to be 90 KPa or higher and below 100 KPa, the speed is selected to be 200 mm/s or higher and 2700 mm/s or lower.

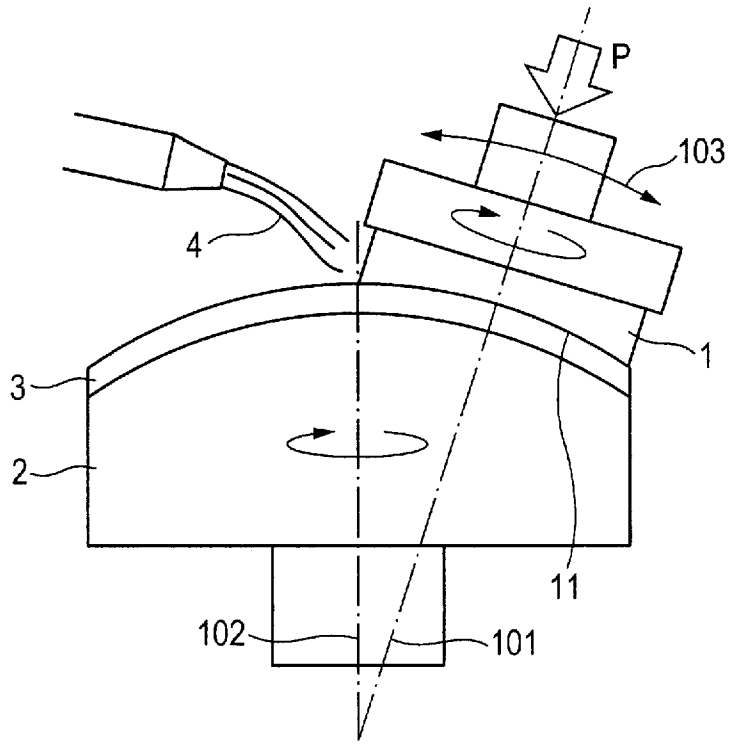
[Claim 20] The component manufacturing method according to any one of claims 12 to 19, wherein, when the pressure is selected to be 100 KPa or higher and below 110 KPa, the speed is selected to be 200 mm/s or higher and 2900 mm/s or lower.

[Claim 21] The component manufacturing method according to any one of claims 12 to 20, wherein, when the pressure is selected to be 110 KPa or higher and below 120 KPa, the speed is selected to be 200 mm/s or higher and 3000 mm/s or lower.

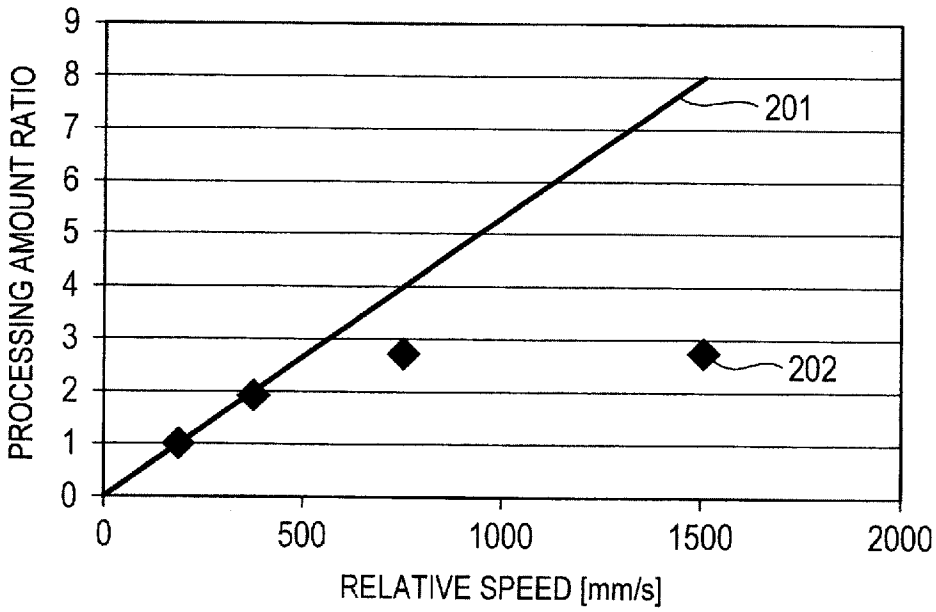
[Claim 22] The component manufacturing method according to any one of claims 12 to 21, wherein, when the pressure is selected to be 120 KPa or higher and below 130 KPa, the speed is selected to be 100 mm/s or higher and 3100 mm/s or lower.

[Claim 23] An optical element manufactured by the component manufacturing method according to any one of claims 11 to 22.

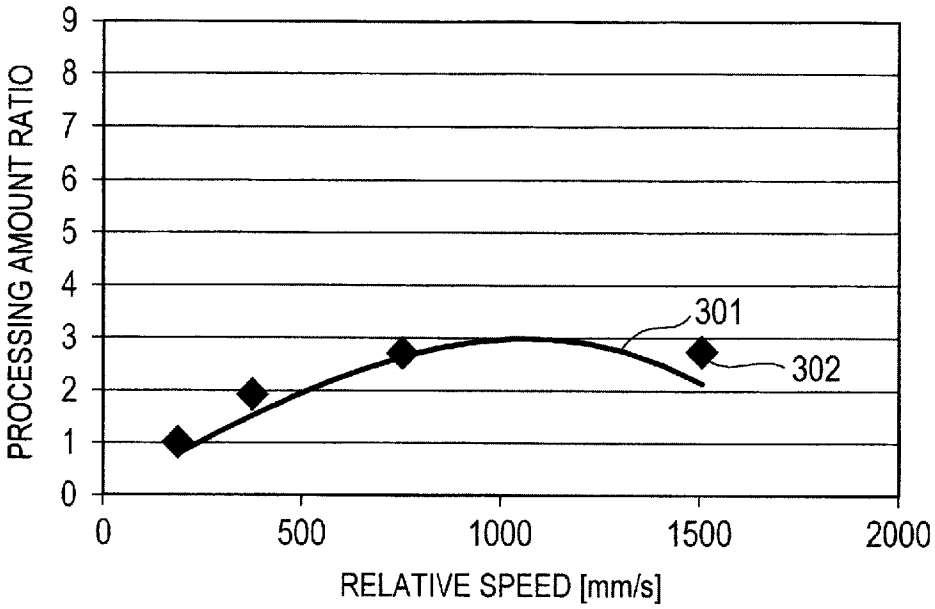
[Fig. 1]


P
103
4
1
3
2
11
102
101

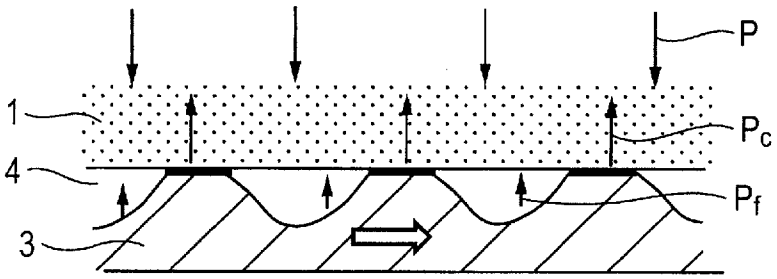
[Fig. 2]


PROCESSING AMOUNT RATIO
RELATIVE SPEED [mm/s]
0
1
2
3
4
5
6
7
8
9
0
500
1000
1500
2000
201
202

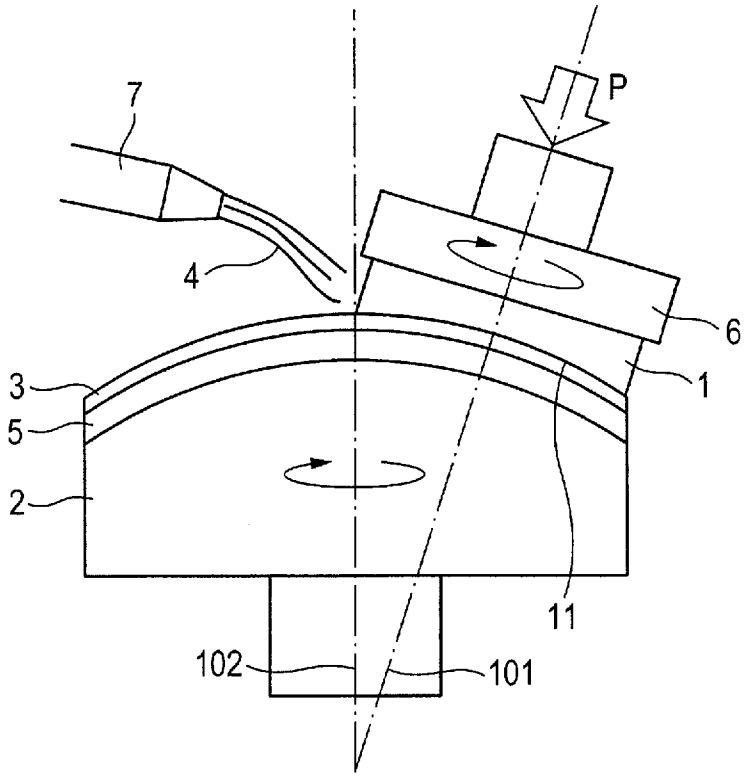
[Fig. 3]



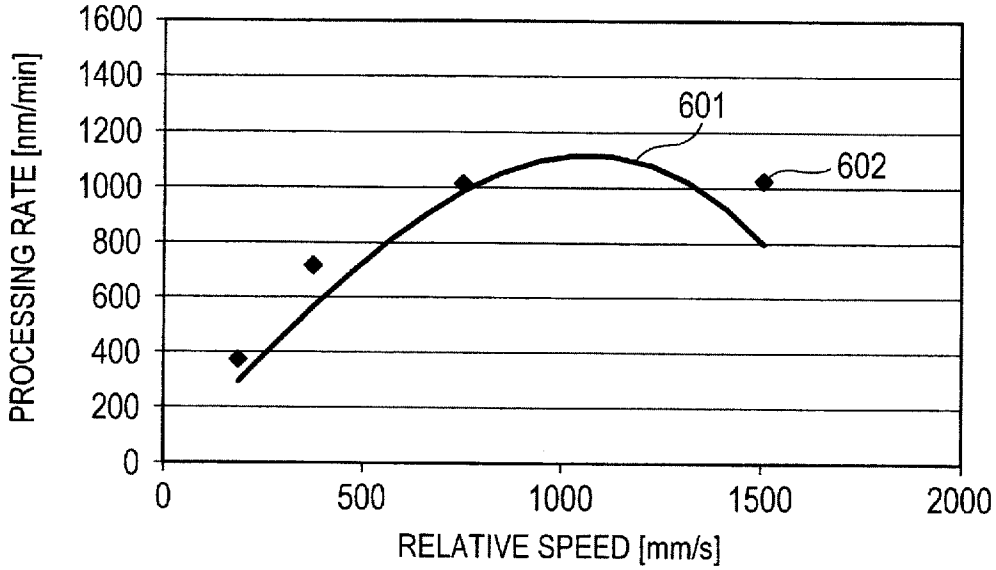
[Fig. 4]



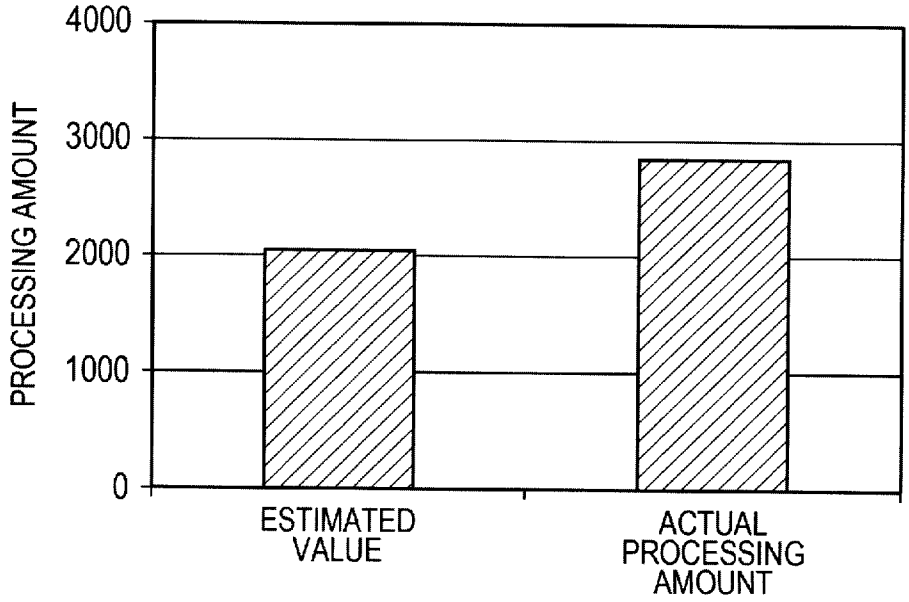
[Fig. 5]



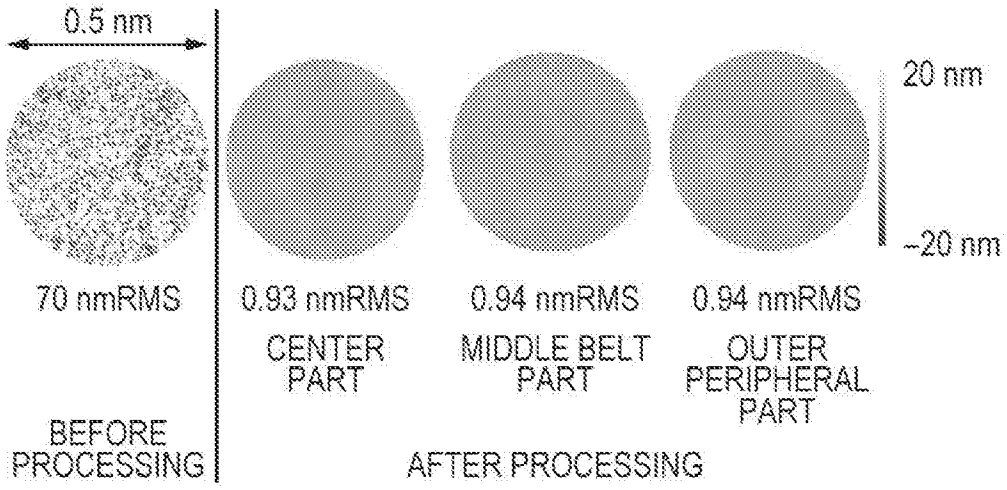
[Fig. 6]



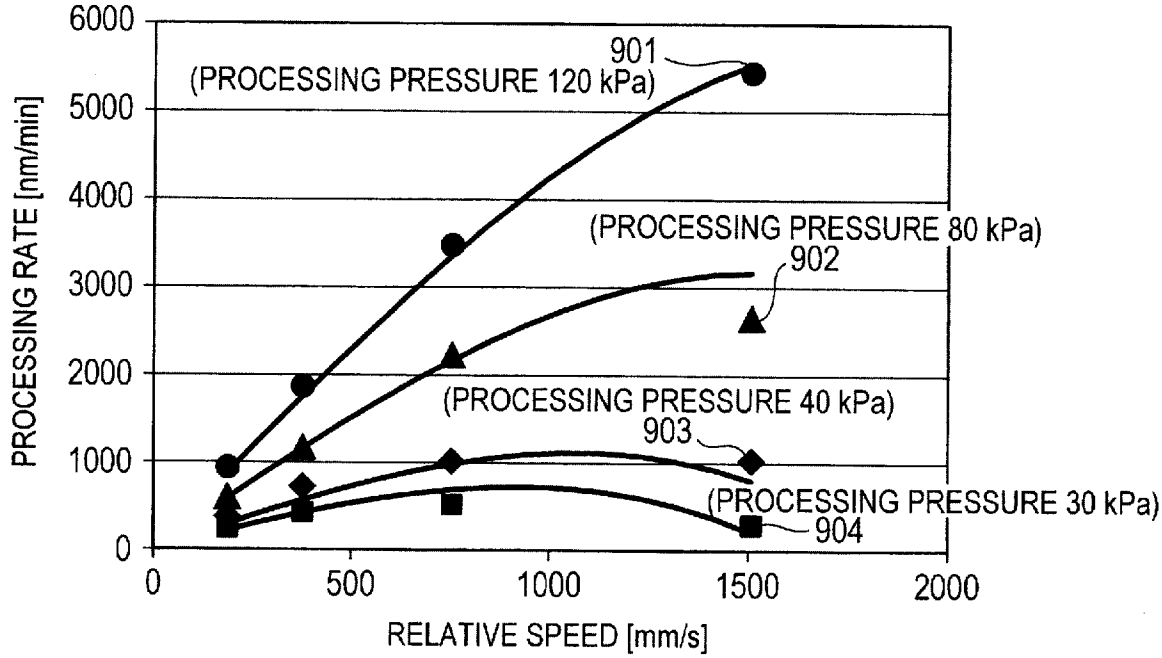
[Fig. 7]



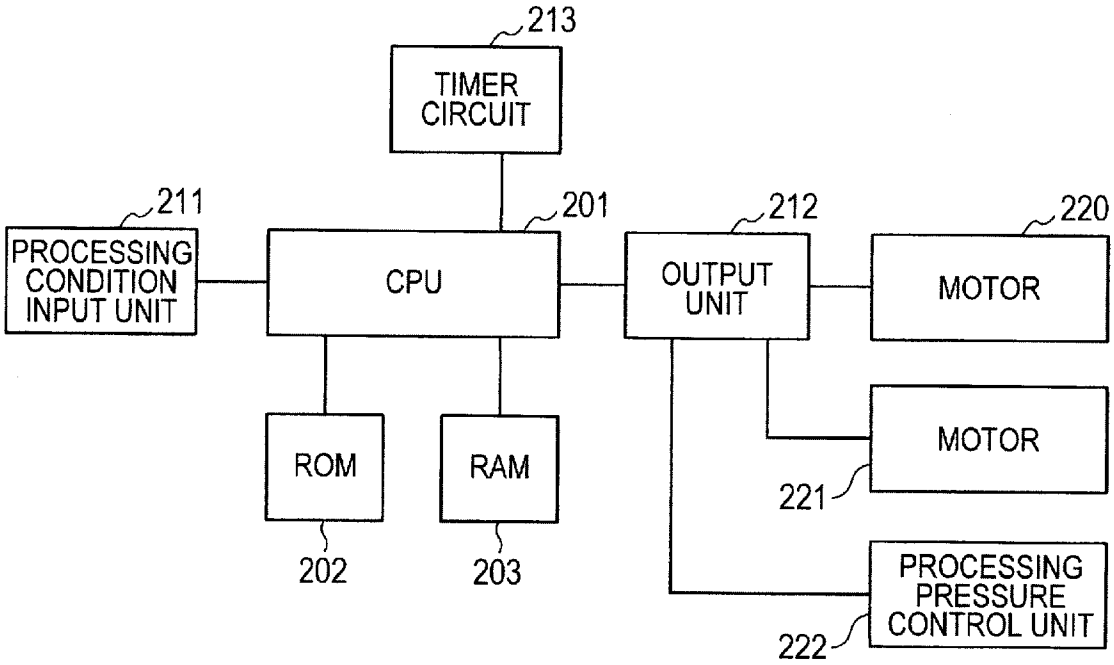
[Fig. 8]



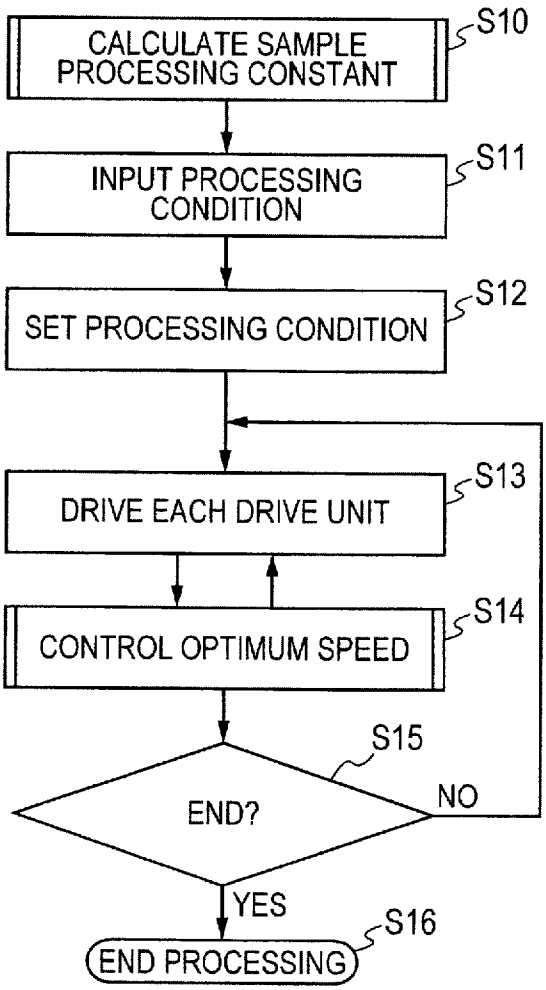
[Fig. 9]


6000
5000
4000
3000
2000
1000
0
PROCESSING RATE [nm/min]
0
500
1000
1500
2000
RELATIVE SPEED [mm/s]
901
(PROCESSING PRESSURE 120 kPa)
(PROCESSING PRESSURE 80 kPa)
902
(PROCESSING PRESSURE 40 kPa)
903
(PROCESSING PRESSURE 30 kPa)
904

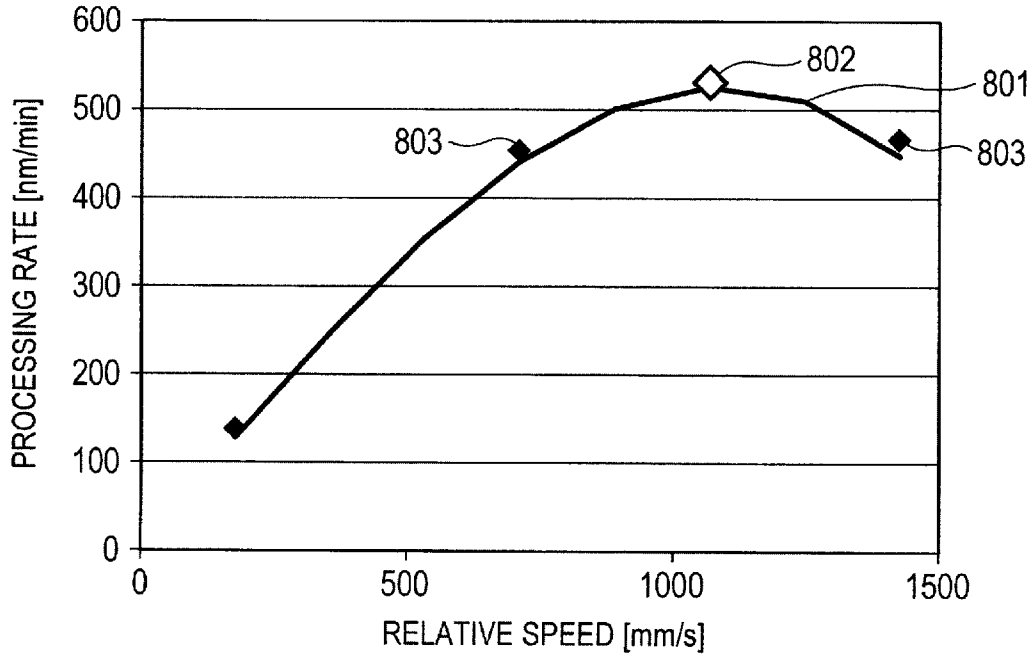
[Fig. 10]


213
TIMER CIRCUIT
211
PROCESSING CONDITION INPUT UNIT
201
CPU
212
OUTPUT UNIT
220
MOTOR
ROM
RAM
MOTOR
221
202
203
PROCESSING PRESSURE CONTROL UNIT
222

[Fig. 11]


CALCULATE SAMPLE PROCESSING CONSTANT
S10
INPUT PROCESSING CONDITION
S11
SET PROCESSING CONDITION
S12
DRIVE EACH DRIVE UNIT
S13
CONTROL OPTIMUM SPEED
S14
END?
S15
NO
YES
END PROCESSING
S16

[Fig. 12]


600
500
400
300
200
100
0
PROCESSING RATE [nm/min]
0
500
1000
1500
RELATIVE SPEED [mm/s]
802
801
803
803

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/000716

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. B23K20/02(2006.01)i, C03C19/00(2006.01)i, B01J31/28(2006.01)n

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. B23K20/00-20/26, C03C19/00, B01J31/28

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2016
Registered utility model specifications of Japan 1996-2016
Published registered utility model applications of Japan 1994-2016

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2789420 A1 (OSAKA UNIVERSITY) 2014.10.15,	12-23
A	paragraphs 0033-0036, 0040-0041, 0047, 0051, fig.1	1-11
A	JP 2002-270558 A (NIKON CORPORATION) 2002.09.20, paragraphs 0007-0015, 0087-0089, fig.1	1-11
A	WO 2006/022452 A2 (EBARA CORPORATION) 2006.03.02, column 29, lines 7-33, fig.12	1-11

☐ Further documents are listed in the continuation of Box C.

☑ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22.04.2016	17.05.2016

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	OKUZUMI, Takashi 3P 4016 Telephone No. +81-3-3581-1101 Ext. 3363

EP 2789420 A1	2014.10.15	WO 2013/084934 A1 TW 201338032 A KR 10-2014-0098129 A CN 104023889 A US 2014/0326612 A1
JP 2002-270558 A	2002.09.20	No Family
WO 2006/022452 A2	2006.03.02	JP 2006-62047 A US 2007/0205112 A1