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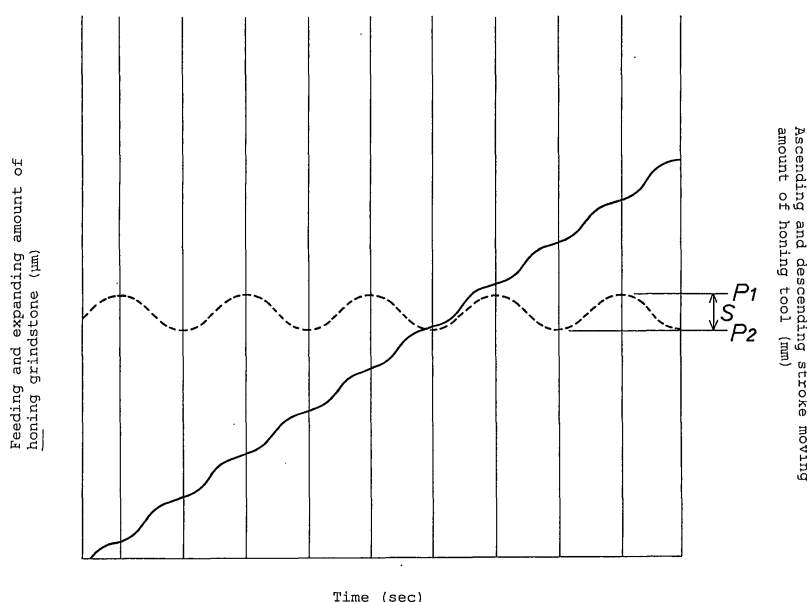
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(54) **Honing method and honing machine**

(57) A honing processing technology for making uniform the load applied to honing grindstones by cooperating the reciprocal motion of the honing grindstones with the feeding and expanding motion at high precision by a specified relation. Servo motors are used as drive sources respectively for spindle reciprocal drive part and grindstone depth cutting part, and these two servo motors are mutually cooperated, and the feeding and expanding mo-

tion of the honing grindstones is controlled to be synchronized and tuned with the ascending and descending (reciprocal) motion of the honing tool so that the processing load applied to the honing grindstones may be averaged. Hence, without modifying the basis existing mechanical elements, the load applied to the honing grindstones may be averaged, and the honing process may be stabilized in precision and enhanced in precision.

Fig. 6



Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a honing method and a honing machine, and more particularly to a honing technology of honing while feeding a honing grindstone by force at a specified depth of cut mechanically to the inner circumference of a workpiece.

Description of the Related Art

[0002] Honing process is known as one of the processing methods of finishing the inner circumference of a workpiece (or work) to a mirror-smooth surface. In this honing process, the honing grindstone and the work are set in a relatively floating state, and the honing grindstone is driven by rotary motions and reciprocal motions, and the honing grindstone is expanded by spring repulsive forces to finish the inner circumference of the work precisely.

[0003] In the conventional honing process, the honing grindstone was pressed against the work by a specific force (spring repulsive force), and the inner circumference of the work was cut off gradually, but recently, same as in the grinding process, various honing machines for honing by a high pressure or a forced depth of cut are developed, and are presently used in the mainstream.

[0004] Honing machines of this kind are roughly classified into a constant pressure processing method for feeding and expanding the honing grindstone at a specific pressure by hydraulic driving means or the like, and a forced depth setting (constant) processing method for feeding and expanding the honing grindstone at a specific depth of cut by mechanical driving means, and in the honing machines of any method, from the preceding process by drilling machine or boring machine, the process can immediately transferred to the honing process by omitting the grinding process of the like, that is, the conventional grinding process and the honing process can be combined, and an efficient precision finishing is realized.

[0005] In the honing process of forced depth setting (constant) processing method, as mentioned above, while the rotating honing grindstone is moved reciprocally in the axial direction of the work, by mechanical driving means, the honing grindstone is continuously fed and expanded at a specific depth of cut from the beginning of depth setting process until the end of machining processing by mechanical driving means, and in the conventional processing cycle, mutual control of reciprocal motion of honing grindstone (ascending and descending stroke motion) and feeding and expanding motion is theoretically effected on the reciprocal motion of the honing grindstone, and the feeding and expanding motion of the honing grindstone is designed to be executed in gradual

steps by feeding at a specific stroke in the descending stroke, and is stopped in the ascending stroke (see, for example, Japanese Patent Application Laid-Open No. 2003-170344).

[0006] However, in such theoretical control configuration, actually, as shown in Fig. 8, the reciprocal motion and the feeding and expanding motion of the honing grindstone are not exactly synchronized (non-synchronous), and the motions are independent mutually (in Fig. 8, the broken-line waveform indicates the position waveform in the ascending and descending stroke motion of the honing grindstone, and the solid-line waveform indicates the position waveform in the feeding and expanding motion of the honing grindstone).

[0007] That is, theoretically, the feeding and expanding motion is controlled so that one expanding command of the honing grindstone is entered in every stroke of the reciprocal motion of the honing grindstone (in the case of Fig. 8, an expanding command comes in the intermediate position of the descending stroke of the honing grindstone), but actually if the expanding command of the honing grindstone is entered, structurally, a motion delay (time lag) of the honing grindstone occurs, and it has not been specifically clarified at which position of one stroke the honing grindstone is expanded (fed in).

[0008] In such conventional grindstone depth cutting control, by the feeding and expanding motion of the honing grindstone (depth setting timing, depth setting speed, and depth of cut) in relation to the reciprocal motion of the honing grindstone, a sudden load may be applied to the honing grindstone when feeding and expanding the honing grindstone, or the load on the honing grindstone may not be stable but may fluctuate significantly, and abrasive grains of the honing grindstone may drop off excessively, and the state is not always ideal for the honing grindstone, and much improvement has been required from the viewpoint of stability of honing precision or enhancement of precision.

BRIEF SUMMARY OF THE INVENTION

[0009] It is hence a primary object of the invention to present a novel honing technology solving these conventional problems.

[0010] It is other object of the invention to present a honing technology capable of stabilizing the precision and enhancing the precision of honing process, in the honing process of forced depth setting (constant) processing method, by cooperating between the reciprocal motion and the feeding and expanding motion of the honing grindstone at high precision with a specified relation, and making uniform the load applied to the honing grindstone.

[0011] The honing method of the present invention is a method of honing the inner circumference of a work by moving a honing tool having a honing grindstone reciprocally in the axial direction of the inner circumference of the work, rotating about the axial line, and feeding and

expanding the honing grindstone at a specific depth of cut by mechanical driving means, in which a spindle reciprocal driving servo motor and a depth setting driving servo motor are used respectively as a spindle reciprocal driving source for moving a rotational spindle having the honing tool reciprocally in the axial direction of the inner circumference of the work, and a depth cutting driving source for feeding and expanding the honing tool, and the motions of the two servo motors are mutually cooperated, so that the feeding and expanding motion of the honing grindstone is controlled to be synchronized and tuned with the reciprocal motion of the honing tool in order that the processing load applied to the honing grindstone may be made uniform.

[0012] A preferred embodiment includes the following configurations.

(1) The position waveform in feeding and expanding motion of the honing grindstone is control to be synchronized and tuned with the position waveform in ascending and descending stroke motion of the honing tool.

(2) The control configuration for synchronizing and tuning the feeding and expanding motion with the reciprocal motion is controlled to form preliminarily a position waveform in ascending descending stroke motion of the honing tool and a position waveform in feeding and expanding motion of the honing grindstone, to synchronize and tune the position waveform in the feeding and expanding motion with the position waveform in the ascending and descending stroke motion, and to control the spindle reciprocal driving servo motor and the depth setting driving servo motor to operate respectively at the position waveform in the ascending and descending stroke motion and the position waveform in the feeding and expanding motion of the honing grindstone.

(3) The operation to synchronize and tune the position waveform in the feeding and expanding motion with the position waveform in the ascending and descending stroke motion is executed by mutually matching the start point and end point in time in these both position waveforms, and mutually matching the position change rates in these both position waveforms.

(4) The position waveform in ascending and descending stroke motion of the honing tool is a sinusoidal waveform.

(5) The position waveform in ascending and descending stroke motion of the honing tool is a triangular waveform. Herein, the triangular waveform refers to a position waveform in ascending and descending stroke motion at which the stroke speed of the honing tool is uniform (the same meaning applies throughout the present specification).

(6) The feeding and expanding amount of the honing grindstone is an expansion by a specific amount per stroke in the ascending and descending stroke of

the honing tool.

[0013] The honing machine of the present invention is a honing machine for moving a honing tool having a honing grindstone reciprocally in the axial direction of the inner circumference of a work, rotating about the axial line, and honing the inner circumference of the work, including a rotational spindle supported to be movable reciprocally in the axial direction of the inner circumference of the work, and to be rotatable about the axial line, spindle rotating means for rotating and driving the rotational spindle about the axial line, spindle reciprocating means for moving the rotational spindle reciprocally in the axial direction of the inner circumference, a honing tool mounted on the leading end of the rotational spindle, being provided with an expandable and contractable honing grindstone having a wheel surface along the inner circumference, grindstone depth cutting means for feeding and expanding the honing grindstone of the honing tool with a specified depth of cut, and control means for controlling automatically by mutually cooperating with the spindle rotating means, spindle depth setting means, and grindstone depth cutting means, in which drive source of the spindle reciprocating means and the grindstone depth cutting means are realized respectively by a spindle reciprocal driving servo motor and a depth setting servo motor, the control means mutually cooperates the motions of these two servo motors, so that the feeding and expanding motion of the honing grindstone is controlled to be synchronized and tuned with the reciprocal motion of the honing tool in order that the processing load applied to the honing grindstone may be made uniform.

[0014] A preferred embodiment includes the following configurations.

(1) The control means is designed to control position waveform in feeding and expanding motion of the honing grindstone so as to be synchronized and tuned with the position waveform in ascending and descending stroke motion of the honing tool.

(2) The control configuration in the control device for synchronizing and tuning the feeding and expanding motion with the reciprocal motion is controlled to form preliminarily a position waveform in ascending descending stroke motion of the honing tool and a position waveform in feeding and expanding motion of the honing grindstone, to synchronize and tune the position waveform in the feeding and expanding motion with the position waveform in the ascending and descending stroke motion, and to control the spindle reciprocal driving servo motor and the depth setting driving servo motor to operate respectively at the position waveform in the ascending and descending stroke motion and the position waveform in the feeding and expanding motion of the honing grindstone.

(3) The operation in the control means to synchronize and tune the position waveform in the feeding and expanding motion with the position waveform in

the ascending and descending stroke motion is executed by mutually matching the start point and end point in time in these both position waveforms, and mutually matching the position change rates in these both position waveforms.

(4) The position waveform in ascending and descending stroke motion of the honing tool is a sinusoidal waveform.

(5) The position waveform in ascending and descending stroke motion of the honing tool is a triangular waveform.

(6) The feeding and expanding amount of the honing grindstone is an expansion by a specific amount per stroke in the ascending and descending stroke of the honing tool.

[0015] According to the present invention, a spindle reciprocal driving servo motor and a depth setting driving servo motor are used respectively as a spindle reciprocal driving source for moving a rotational spindle having a honing tool reciprocally in the axial direction of the inner circumference of a work, and a depth cutting driving source for feeding and expanding a honing grindstone of the honing tool, and the motions of the two servo motors are mutually cooperated, so that the feeding and expanding motion of the honing grindstone is controlled to be synchronized and tuned with the reciprocal motion of the honing tool in order that the processing load applied to the honing grindstone may be made uniform, and therefore the following effects are obtained, and in the forced depth setting (constant) processing method, without modifying the basic existing mechanical elements (not required to add sensor or other additional mechanism), the reciprocal motion of the honing grindstone and the feeding and expanding motion can be cooperated at high precision in a specified relation, and the load applied to the honing grindstone can be made uniform, and the honing technology capable of stabilizing the precision and enhancing the precision of honing process can be presented.

(1) Extension of life of honing grindstone

[0016] According to the present invention, the motions of the spindle reciprocal driving servo motor and the depth setting driving servo motor are mutually cooperated, and the feeding and expanding motion of the honing grindstone is synchronized and tuned with the reciprocal motion of the honing tool so that the processing load applied on the honing grindstone may be averaged, and therefore excessive load is not applied to the honing grindstone when feeding and expanding the honing grindstone, and a tender feeding and expanding motion is realized for the honing grindstone.

[0017] Specifically, when the feeding and expanding amount of the honing grindstone is fixed at one stroke of the ascending and descending stroke of the honing tool, and it can be expanded by a fixed depth of cut, and since

the feeding and expanding of the honing grindstone can be executed depending on the stroke speed of the honing tool, and dropping of abrasive grains of the honing grindstone can be suppressed, and the life of the honing grindstone may be substantially extended, and a honing grindstone of a long life is realized.

(2) Stability of precision

[0018] As mentioned above, excessive load is not applied to the honing grindstone when feeding and expanding the honing grindstone, and the load applied to the honing grindstone is uniform without variations, and the precision of honing process is stabilized, and the precision is enhanced.

(3) Control of hole shape

[0019] The feeding and expanding motion of the honing grindstone is controlled to be synchronized and tuned with the reciprocal motion of the honing tool, and the feeding and expanding motion of the honing grindstone can be executed at a desired position depending on the reciprocal stroke position of the honing tool, and the processing hole shape of the work can be controlled as desired.

(4) Correction of hole shape

[0020] Since the processing hole shape of the work can be controlled, the processing hole shape of the work can be corrected appropriately.

[0021] These and other purposes and features of the present invention will be fully appreciated and understood by reading the following detailed description taken in conjunction with the drawings and novel facts indicated in the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWING

[0022]

Fig. 1 is a front view showing a partial section of an outline configuration of a honing machine in preferred embodiment 1 of the present invention.

Fig. 2 is a front sectional view showing a magnified view of grindstone depth cutting part of the honing machine.

Fig. 3 is a block diagram of configuration of device control part of the honing machine.

Fig. 4 is a block diagram of configuration of a servo control part in the device control part.

Fig. 5 is a diagram for explaining the definition of synchronizing and tuning of position waveform in feeding and expanding motion of a honing grindstone in control of the device control part and position waveform in ascending and descending stroke of a honing tool.

Fig. 6 is a diagram showing the relation between ascending and descending stroke motion of honing tool and feeding and expanding motion of honing grindstone in the honing machine.

Fig. 7 is a diagram showing the relation between ascending and descending stroke motion of honing tool and feeding and expanding motion of honing grindstone in a honing machine in preferred embodiment 3 of the present invention.

Fig. 8 is a diagram showing the relation between ascending and descending stroke motion of honing tool and feeding and expanding motion of honing grindstone in a conventional honing machine.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0023] Preferred embodiments of the present invention are specifically described below while referring to the accompanying drawings.

[0024] Fig. 1 to Fig. 7 show preferred embodiments of the present invention, in which same constituent members or elements are identified with same reference numerals throughout the drawings.

Preferred embodiment 1

[0025] A honing machine of the present invention is shown in Fig. 1, and specifically this honing machine is a vertical type machine for machining an inner circumference W_a of a cylindrical processing hole of a work W , and mainly includes a rotational spindle 2 having a honing tool 1 at the leading end, a spindle rotational driving part (spindle rotating means) 3, a spindle reciprocal driving part (spindle reciprocating means) 4, a grindstone depth cutting part (grindstone depth cutting means) 5, and a device control part (control means) 6.

[0026] The honing tool (or honing head) 1 is detachably fitted to the leading end of the rotational spindle 2, that is, at a lower end 2a.

[0027] The inside of this honing tool 1 includes, as shown in Fig. 2, a plurality of honing grindstones 10, 10, ... disposed so as to be free to expand and contract in the radial direction, a cone rod 11 for expanding and contracting these honing grindstones 10, 10, ..., and a reset spring (not shown) for resetting the honing grindstones 10, 10,

[0028] Each honing grindstone 10 has a wheel surface 10a along the inner circumference W_a of the work W . The cone rod 11 is disposed movably in vertical direction in the honing tool 1, and its wedge 11a at the leading end is a wheel expanding part for pressing a wheel base 10b of each honing grindstone 10, and its base rod 11b in the upper part is coupled to a wheel expanding rod 35 described below. Although not shown in the drawing, the honing grindstones 10, 10, ... are elastically forced in an always contracting direction by the reset spring.

[0029] The honing grindstones 10, 10, ... are expand-

ed and opened by the rising motion of the cone rod 11, and is contracted and closed by the reset spring along with the rising motion of the cone rod 11.

[0030] The rotational spindle 2 has the honing tool 1 at its lower end, and is also coupled to the spindle rotational driving part 3 including a spindle drive shaft 15, power transmission parts 25a to 25c, a drive motor 16, and others, and to the spindle reciprocal driving part 4 including a slide main body 18, a feed screw mechanism 19, a drive motor 20, and others.

[0031] In other words, the rotational spindle 2 is rotatably supported on the slide main body 18, and this slide main body 18 is elevated and guided by a guide rail 22, and is driven by and coupled to the feed screw mechanism 19 and the drive motor 20 as the elevating drive source, and thereby the spindle reciprocal driving part 4 is composed.

[0032] The guide rail 22 is extended straightly in the vertical direction on a machine body 21, and a sliding part 18a of the slide main body 18 is slidably guided and supported on this guide rail 22. In the sliding part 18a of the slide main body 18, a nut body 19a of the feed screw mechanism 19 is integrally coupled and fixed, and this nut body 19a is extended in vertical direction perpendicularly on the machine body 21, and is screwed to be movable back and forth in vertical direction to a feed screw 19b supported rotatably. The upper end of the feed screw 19b is driven by and coupled to a motor shaft 20a of the drive motor 20 by way of a coupling 23. This drive motor 20 is a servo motor integrally incorporating a position detection sensor 73 such as rotary encoder, and the rotation amount of the drive motor 20 detected by this position detection sensor 73.

[0033] By rotation and driving of the motor shaft 20a of the drive motor 20, the feed screw 19b of the ball screw mechanism 19 is rotated, and the slide main body 18 which is integral with the nut body 21b is moved in the vertical direction, and through this slide body 18, the rotational spindle 2, that is, the honing tool 1 is elevated and lowered. The ascending and descending motion of the honing tool 1 is detected by the position detection sensor 73 built in the drive motor 20, and the result of detection is sent to a spindle reciprocal control part 71 of the device control part 6 as described below.

[0034] The upper end part 2b of the rotational spindle 2 is driven by and coupled to the spindle rotational drive part 3. That is, the upper end part 2b of the rotational spindle 2 is spline-fitted to the spindle drive shaft 15 provided rotatably on a head part 21a of the machine body 21, and is coupled to this spindle drive shaft 15 so as to be movable relatively in the vertical direction (axial direction) and rotatable integrally.

[0035] Specifically, the upper end part 2b of the rotational spindle 2 is supported slidably in vertical direction on the head part 21a of the machine body 21 by a rotary spline device 24, and is connected coaxially, integrally and rotatably on the spindle drive shaft 15.

[0036] The spindle drive shaft 15 is provided with a

transmission pulley 25a, and this transmission pulley 25a is coupled to a transmission pulley 25c mounted on a motor shaft 16a of the drive motor 16 by way of a transmission belt 25b. This drive motor 16 is, for example, a servo motor integrally incorporating a position detection sensor 63 such as rotary encoder, and the rotation amount of the drive motor 16 is detected by the position detection sensor 63, and thereby the rotary motion of the honing tool 1 is detected.

[0037] By rotation and driving of the drive motor 16, the rotational spindle 2, that is, the honing tool 1 is rotated and driven by way of the spindle drive shaft 15. The rotary motion of the honing tool 1 is detected by the position detection sensor 63 built in the drive motor 16, and the detection result is sent to a spindle rotation drive part 61 of the device control part 6 described below.

[0038] The grindstone depth cutting part 5 is to feed the honing grindstones 10, 10, ... by a specified depth of cut, and mainly includes, as shown in Fig. 1 and Fig. 3, a grindstone depth cutting drive part (depth setting driving means) 30, and a grindstone depth cutting control part (depth setting control means) 62.

[0039] The wheel dept setting drive part 30 mechanically feeds the honing grindstones 10, 10, ... by a specified depth of cut, and it specifically includes the cone rod 11 (Fig. 2) of the honing tool 1, the wheel expanding rod 35 (Fig. 2), a depth setting drive mechanism 36, and a drive motor 37.

[0040] The wheel expanding rod 35, although not shown specifically, is disposed movably in the axial direction (vertical direction) in a shaft hole provided in the lower half of the rotational spindle 2, and its lower end part 35a is coupled to a base rod 11b of the cone rod 11 (see Fig. 2), and its upper end part (not shown) is coupled to the depth setting drive mechanism 36.

[0041] The depth setting drive mechanism 36 moves the wheel expanding rod 36 in the vertical direction (axial direction), and mainly includes, same as in the prior art, a follower 40 coupled to the wheel expanding rod 35, and a drive screw shaft member 41 for moving the follower 40 vertically.

[0042] The follower 40 is disposed on the rotational spindle 2 so as to be slidable relatively in the vertical direction, and is coupled to the wheel expanding rod 35 disposed in the rotational spindle 2 integrally in the vertical direction.

[0043] The follower 40 is engaged with the drive screw shaft member 41 so as to be free to screw back and forth in the vertical direction by way of a female thread member (not shown) fixed integrally therewith. This drive screw shaft member 41 is supported on the slide main body 18 rotatably and parallel to the rotational spindle 2.

[0044] The drive screw shaft member 41 is engaged with a depth setting drive shaft 42 provided rotatably in the head part 21a of the machine body 21. Specifically, the depth setting drive shaft 42 is supported parallel to the drive screw shaft member 41, and its upper end part 42a is spline-fitted to a rotary gear shaft 43a of the gear

mechanism 43 provided rotatably in the head part 21a of the machine body 21, and is coupled to this rotary gear shaft 43a so as to be movable relatively in the vertical direction and rotatable integrally.

[0045] Specifically, the upper end part 42a of the depth setting drive shaft 42 is supported on the head part 21a of the machine body 21 slidably in the vertical direction by means of a rotary spline device 44, and is connected to the rotary gear shaft 43a coaxially and rotatably integrally. This rotary gear shaft 43a is engaged with a gear 43b, and this gear 43b is integrally mounted and fixed on the motor shaft 37a of the drive motor 37. On the other hand, the depth setting drive shaft 42 is driven by and coupled to the upper end part 41a of the drive screw shaft member 41 by way of the gear mechanism 44.

[0046] The drive motor 37 is, for example, a servo motor integrally incorporating a position detection sensor 64 such as rotary encoder, and the rotation amount of the drive motor 37 is detected by the position detection sensor 64, and thereby the feeding and expanding motion of the honing grindstones 10, 10,... of the honing tool 1 is detected.

[0047] By rotation and driving of the motor shaft 37a of the drive motor 37, the depth setting drive shaft 42 is put in rotation, and the drive screw shaft member 41 is put in rotation, and the follower 40 engaged therewith so as to be free to screw back and forth is relatively moved downward or upward on the rotational spindle 2. That is, in the descending motion of the follower 40, the integrally formed wheel expanding rod 35 pushes down the cone rod 11, and the honing grindstones 10, 10, ... are expanded. On other hand, in the ascending motion of the follower 40, along with the ascending motion of the wheel expanding rod 35, the honing grindstones 10, 10, ... are contracted and closed by a reset spring (not shown) in the honing tool 1. The feeding and expanding motion of the honing grindstones 10, 10, ... is detected by the position detection sensor 64 built in the drive motor 20, and the detection result is sent to a grindstone depth cutting control part 62 of the device control part 6 described below.

[0048] The device control part 6 automatically controls by mutually cooperating the motions of the control parts 3, 4, 5 of the honing machine, and is specifically composed mainly of microcomputers such as CPU, ROM, RAM and I/O port.

[0049] The device control part 6 stores processing programs for executing honing process and other data, and is mainly composed of, as shown in Fig. 3, a main control part 70, a spindle rotation control part 61 for controlling the drive motor 16 as drive source of the spindle rotation drive part 3, a spindle reciprocal control part 71 for controlling the drive motor (servo motor for spindle reciprocal drive) 20 as drive source of spindle reciprocal drive part 4, and a grindstone depth cutting control part 62 for controlling the drive motor (servo motor for grindstone depth cutting) 37 as drive source of the grindstone depth cutting part 5.

[0050] The main control part 70 stores various infor-

mation necessary for driving of the drive sources 16, 20, 37 of the drive parts 3, 4, 5, for example, the rotating speed and ascending and descending speed of the honing tool 1, or the reference positions (stroke positions) P_1 , P_2 and stroke width S (see Fig. 2) of the honing grindstones 10, 10, ..., or the depth setting speed and depth setting timing, entered and set properly and selectively as NC (numerical control) data or through the keyboard of the operation panel or the like, and the control parts 61, 62, 71 are controlled according to such data.

[0051] The spindle rotation control part 61, the spindle reciprocal control part 71, and the grindstone depth cutting control part 62 are specifically servo amplifiers composed of an arithmetic part 80 and a motor control part 81 as shown in Fig. 4, and individually detection signals from the position detection sensors 63, 73, 64 such as rotary encoders for detecting the number of revolutions of the motor shafts 16a 20a, 37a of the drive motors 16, 20, 37 are fed back and supplied into the arithmetic part 80, and this arithmetic part 80 compares and calculates the entered detection values (number of revolutions) with the command value (number of revolutions) from the main control part 70, and supplies an electric power in proportion to the error of the detection value and the command value to the drive motors 16, 19, 37 so as to match between the detection values and the command values on the basis of the result of calculation.

[0052] In particular, the spindle reciprocal control part 71 and the grindstone depth cutting control part 62 are operated according to the command from the main control part 70, and the motions of the drive motors 20 and 37 are mutually cooperated, so that the feeding and expanding motions of the honing grindstones 10, 10,... are synchronized and tuned with the reciprocal motion of the honing tool 1 in order that the processing load applied to the honing grindstones 10, 10, ... is made uniform.

[0053] That is, according to the command from the main control part 70, the grindstone depth cutting control part 62 controls the grindstone depth cutting servo motor 37 of the grindstone depth cutting drive part (depth cutting means) 30 so that the processing load applied to the honing grindstones 10, 10, ... may be made uniform.

[0054] More specifically, the position waveform in the feeding and expanding motion of the honing grindstones 10, 10,... is controlled to be synchronized and tuned with the position waveform in the ascending and descending stroke motion of the honing tool 1, and the feeding and expanding speed of the honing grindstones 10, 10, ... is controlled to be proportional to the ascending and descending stroke speed of the honing tool 1.

[0055] In this manner, by synchronizing and tuning the both position waveforms, while the positioning of the honing tool 1 and the honing grindstones 10, 10, ... is controlled at high precision, the feeding and expanding speed of the honing grindstones 10, 10, ... can be tuned with the ascending and descending stroke speed of the honing tool 1.

[0056] Herein, synchronizing and tuning of the position

waveform in the feeding and expanding motion of the honing grindstones 10, 10,... with the position waveform in the ascending and descending stroke motion of the honing tool 1 may be defined as follows.

[0057] Referring to Fig. 5, the position change amount (the change amount of the honing tool 1 in the axial direction) from the upper end position P_1 to the lower end position P_2 (see Fig. 2), or from the lower end position P_2 to the upper end position P_1 in the position waveform in the ascending and descending stroke motion of the honing tool 1, that is, the stroke width S per stroke (see Fig. 2), and the stroke time t (see (a) in Fig. 5), and the position change amount per stroke time t in the position waveform in the feeding and expanding motion of the honing grindstones 10, 10, ..., that is, the grindstone depth cutting amount D (the change amount of the honing tool 1 in the radial direction) (see (b) in Fig. 5) are determined by the processing condition depending on the material and the design conditions of the work W to be processed.

[0058] At this time, in the both position waveforms, it is defined to be "tuned" when the position change rate is the same in the position change amounts S and D at stroke time t , and it is defined to be "synchronized" when the start point t_1 and the end point t_2 in time are mutually same per stroke in the both position waveforms. At this time, if the signs of + and - are reverse in the position change amounts S and D , it is defined to be "tuned" if the position change rates are the same.

[0059] In the illustrated preferred embodiment, as shown in Fig. 6, the position waveform in the ascending and descending stroke motion of the honing tool 1 is a sinusoidal waveform (the broken line waveform in Fig. 6), and the position waveform in the feeding and expanding motion of the honing grindstones 10, 10, ... is a same sinusoidal waveform (the solid line waveform in Fig. 6), and the expanding timing and the expanding speed in the honing grindstones 10, 10, ... are synchronized and tuned with the ascending and descending stroke motion of the honing tool 1. That is, as shown in Fig. 6, the feeding and expanding amount of the honing grindstones 10, 10, ... is a specific expanding amount per stroke of the ascending and descending (reciprocal) motion of the honing tool 1, and when the ascending and descending stroke speed of the honing tool 1 is zero, the feeding and expanding speed of the honing grindstones 10, 10, ... is also zero, and when the ascending and descending stroke speed of the honing tool 1 is maximum, the feeding and expanding speed of the honing grindstones 10, 10, ... is also maximum.

[0060] In a specific control configuration for synchronizing and tuning the feeding and expanding motion of the honing grindstones 10, 10,... with the reciprocal motion of the honing tool 1, the position waveform in the ascending and descending stroke motion of the honing tool 1 and the position waveform in the feeding and expanding motion of the honing grindstones 10, 10,... are generated preliminarily, and the position waveform in the

feeding and expanding motion is synchronized and tuned with the position waveform in the ascending and descending stroke motion, and the servo motor 20 for spindle reciprocal drive of the spindle reciprocal drive part 4 and the servo motor 37 for grindstone depth cutting of the grindstone depth cutting drive part 30 are controlled respectively by the position waveform in the ascending and descending stroke motion and the position waveform in the feeding and expanding motion of the honing grindstones.

[0061] In other words, the position waveform in the ascending and descending stroke motion of the honing tool 1 (the motion position waveform of the ascending and descending stroke axis (in the shown example, the feed screw mechanism 19)) and the position waveform in the feeding and expanding motion of the honing grindstones 10, 10, ... (the motion position waveform of the wheel expanding rod 35) are generated preliminarily, and are controlled so that the feed screw mechanism 19 (the servo motor 20 for spindle reciprocal drive) and the wheel expanding rod 35 (the servo motor 37 for grindstone depth cutting) may be operated by these position waveforms respectively. In this case, the stroke width S is set in condition in relation to the ascending and descending stroke, and a command is issued to the stroke width S not to operate by the position waveform (sinusoidal wave in the illustrated preferred embodiment) in the ascending and descending stroke motion. On the other hand, in the feeding and expanding motion, the extending amount per stroke of the honing tool 1 is fixed and set in condition (to prevent fluctuations of the processing cycle time), and a command is issued to the expanding amount not to operate by the position waveform (sinusoidal wave in the illustrated preferred embodiment) in the feeding and expanding motion. In these motion position waveforms, the position waveform in the feeding and expanding motion is synchronized and tuned with the position waveform in the ascending and descending stroke motion.

[0062] In this case, in synchronizing and tuning of the position waveform in the feeding and expanding motion with the position waveform in the ascending and descending stroke motion, the start point and the end point in time in these motion position waveforms are matched with each other, and the position change rates in the both position waveforms are mutually matched.

[0063] Thus, the position waveform in the ascending and descending stroke motion of the honing tool 1 and the position waveform in the feeding and expanding motion of the honing grindstones 10, 10,... are generated preliminarily, and these position waveforms are synchronized and tuned, and the stroke motion of the honing tool 1 and the feeding and expanding motion of the honing grindstones 10, 10,... are controlled simultaneously to follow these position waveforms, and the both motions can be completely synchronized and tuned, and time lag between the both motions can be prevented effectively.

[0064] By feeding and expanding the honing grindstones 10, 10, ... by the same sinusoidal waveform and

the same timing as the speed change of the ascending and descending stroke of the honing tool 1 (that is, by synchronizing and tuning), the pressure of the contact surface of the honing grindstones 10, 10, ... and the inner circumference Wa of the processing hole of the work W, that is, the load applied to the honing grindstones 10, 10, ... per stroke is dispersed and averages.

[0065] For example, in the conventional processing cycle shown in Fig. 8, regarding the ascending and descending stroke motion of the honing tool 1, this ascending and descending stroke motion is monitored, and depending on the speed changes, the honing grindstones 10, 10, ... are fed and expanded in gradual stages (one feeding and expanding motion carried out per stroke of the ascending and descending stroke motion of the honing tool 1), but it is not exactly synchronized and tuned with the ascending and descending (reciprocal) motion of the honing tool 1, and a time lag occurs, and for example, when the ascending and descending stroke speed of the honing tool 1 is zero, the feeding and expanding speed of the honing grindstones 10, 10, ... is maximum, and at this time, it has been experimentally known that the pressure of the contact surface of the honing grindstones 10, 10, ... and the inner circumference Wa of the processing hole of the work W increases momentarily.

[0066] In this preferred embodiment, since the servo motors 20, 37 are provided as drive sources for spindle reciprocal drive part 4 and grindstone depth cutting part 5, the time per stroke in the ascending and descending stroke of the honing tool 1 is divided into multiple sections (2048 sections in the illustrated preferred embodiment), and the ascending and descending stroke position of the honing tool 1, and the feeding and expanding position of the honing tools 10, 10, ... are mutually positioned at each time point of the multiple divided sections, and the honing grindstones 10, 10, ... are expanded smoothly, and expansion gentle for the honing grindstones 10, 10, ... is realized. That is, for example, as compared with the conventional processing cycle shown in Fig. 8, in this conventional processing cycle, one feeding and expanding motion is carried out per stroke of the ascending and descending stroke motion of the honing tool 1, whereas in this preferred embodiment, one stroke of ascending and descending stroke motion of the honing tool 1 is divided into 2048 sections, and the feeding and expanding motion is divided, and the pressure applied to the wheels when feeding the honing grindstones 10, 10, ... is effectively dispersed.

[0067] For example, in the illustrated preferred embodiment, the stroke width S is 50 mm, and the stroke speed is 15 m/min, and one reciprocal time of ascending and descending stroke is 0.4 sec, and this 0.4 sec is divided into 2048 sections and controlled.

[0068] Therefore, in the honing machine having such configuration, the motions of the spindle rotational drive part 3, spindle reciprocal drive part 4, and grindstone depth cutting part 5 are mutually cooperated and control-

led automatically by the device control part 6, and the honing tool 1 is operated in a uniform honing process (honing processing method) at a specific depth of cut over the entire honing region (that is, the stroke width S in Fig. 2), on the inner circumference Wa of the work W supported on the work holding jig 8.

[0069] That is, the honing tool 1 is rotated about the axial line of the inner circumference Wa of the work W by the spindle rotational drive part 3, and is moved reciprocally about the axial line of the inner circumference Wa of the work W by the spindle reciprocal drive part 4, and the honing grindstones 10, 10, ... are fed and expanded by a specific depth of cut by the grindstone depth cutting part 5, and thereby the inner circumference Wa of the work W is processed by honing.

[0070] At this time, the feeding and expanding motion of the honing grindstones 10, 10, ... is mutually cooperated with the motions of the drive motors 20 and 37, and is controlled to be synchronized and tuned with the ascending and descending (reciprocal) motion of the honing tool 1, so that the processing load applied to the honing grindstones 10, 10, ... may be averaged (see Fig. 5).

[0071] Thus, according to the honing processing method of the present preferred embodiment, the servo motor for spindle reciprocal drive and the servo motor for depth cutting drive are used respectively as the drive motor 20 for spindle reciprocal drive part 4 and the drive motor 37 for wheel depth cutting part (wheel depth cutting means) 5, and the motions of these two servo motors are mutually cooperated, and the feeding and expanding motion of the honing grindstones 10, 10, ... is controlled by synchronizing and tuning with the ascending and descending (reciprocal) motion of the honing tool 1, so that the processing load applied to the honing grindstones 10, 10, ... may be averaged, and therefore the following effects are obtained, and in this kind of forced depth setting (constant) honing process, without modifying the basic existing mechanical elements, the feeding and expanding motion can be cooperated with the reciprocal motion of the honing grindstones 10, 10, ... at high precision with a specified relation, and the processing load applied to the honing grindstones 10, 10, ... can be made uniform substantially, and a honing technology capable of stabilizing the precision of honing process and enhancing the precision may be presented.

(a) Extension of life of honing grindstones 10, 10, ...

[0072] According to the honing method of the present preferred embodiment, as mentioned above, the servo motor 20 for spindle reciprocal drive and the servo motor 37 for depth setting drive are mutually cooperated, and the feeding and expanding motion of the honing grindstones 10, 10, ... is controlled by synchronizing and tuning with the ascending and descending (reciprocal) motion of the honing tool 1, so that the processing load applied to the honing grindstones 10, 10, ... may be averaged, and therefore sudden load is not applied to the

honing grindstones 10, 10, ... when feeding and expanding the honing grindstones 10, 10, ..., and a tender feeding and expanding motion for the honing grindstones is realized.

[0073] Specifically, when the feeding and expanding amount of the honing grindstones 10, 10, ... is fixed at one stroke of the ascending and descending stroke of the honing tool 1, and it can be expanded by a fixed depth of cut, and since the feeding and expanding of the honing grindstones 10, 10, ... can be executed depending on the stroke speed of the honing tool 1, and therefore sudden load is not applied to the honing grindstones 10, 10, ... , and dropping of abrasive grains of the honing grindstones 10, 10, ... can be suppressed, and the life of the honing grindstones 10, 10, ... may be substantially extended, and honing grindstones 10, 10, ... of a long life are realized.

[0074] In other words, the fast stroke speed of the honing tool 1 means that the distance is long for dividing the work W by the honing grindstones 10, 10, ... per unit time, and dropping of abrasive grains of the honing grindstones 10, 10, ... is significant per unit time. In this preferred embodiment, the depth setting speed is increased in a position where dropping of abrasive grains of the honing grindstones 10, 10, ... is significant, and the depth setting speed is decreased in a position where dropping of abrasive grains of the honing grindstones 10, 10, ... is less significant, and therefore the pressure load applied to the honing grindstones 10, 10, ... is effectively dispersed and averaged.

(b) Stability of precision

[0075] As mentioned above, sudden load is not applied to the honing grindstones 10, 10, ... when feeding and expanding the honing grindstones 10, 10, ..., and the load applied to the honing grindstones 10, 10, ... is uniform without variations, and the precision of honing process is stabilized, and the precision is enhanced.

(c) Control of hole shape

[0076] The feeding and expanding motion of the honing grindstones 10, 10, ... is controlled to be synchronized and tuned with the ascending and descending (reciprocal) motion of the honing tool 1, and the feeding and expanding motion of the honing grindstones 10, 10, ... can be executed at a desired position depending on the ascending and descending (reciprocal) stroke position of the honing tool 1, and the processing hole shape of the work W can be controlled as desired.

Preferred embodiment 2

[0077] This preferred embodiment is shown in Fig. 7, and is similar to preferred embodiment 1, except that the position waveforms in the feeding and expanding motion of the honing grindstones 10, 10, ... are modified.

[0078] That is, in this preferred embodiment, the position waveform in the ascending and descending stroke motion of the honing tool 1 is a triangular waveform (broken line waveform in Fig. 7), and the position waveform in the feeding and expanding motion of the honing grindstones 10, 10, ... is a linear waveform to be synchronized and tuned with this triangular waveform (solid line waveform in Fig. 7).

[0079] More specifically, the ascending and descending stroke speed of the honing tool 1 is a specified uniform stroke in the ascending stroke and the descending stroke, whereas the feeding and expanding amount of the honing grindstones 10, 10, ... is set at a specific depth of cut per stroke of the ascending and descending (reciprocal) motion of the honing tool 1, and the feeding and expanding speed is controlled to a specified uniform speed.

[0080] The other configuration and action are same as in preferred embodiment 1.

[0081] The foregoing preferred embodiments 1 and 2 show preferred embodiments of the present invention, but the present invention is not limited to these preferred embodiments, but may be changed and modified in design within the scope thereof. For example, the following modifications may be possible.

[0082] The position waveform in the ascending and descending stroke motion of the honing tool 1 and the position waveform in the feeding and expanding motion of the honing grindstones 10, 10, ... are not limited to those shown in the illustrated preferred embodiments (Fig. 5 and Fig. 6), as far as being synchronized and tuned with the reciprocal motion of the honing tool 1, and, for example, the position waveform in the ascending and descending stroke motion of the honing tool 1 may be modulation waveform.

[0083] The specific embodiments mentioned in the detailed description of the invention are illustrative and not restrictive, and since the scope of the present invention is defined by the appended claims rather than by the description preceding them, and all changes that fall within metes and bounds of the claims, or equivalence of such metes and bounds thereof are therefore intended to be embraced by the claims.

Claims

1. A honing method of honing the inner circumference of a work by moving a honing tool having a honing grindstone reciprocally in the axial direction of the inner circumference of the work, rotating about the axial line, and feeding and expanding the honing grindstone at a specific depth of cut by mechanical driving means, wherein a spindle reciprocal driving servo motor and a depth setting driving servo motor are used respectively as a spindle reciprocal driving source for moving a rotational spindle having the honing tool recip-

rocally in the axial direction of the inner circumference of the work, and a depth cutting driving source for feeding and expanding the honing grindstone, and

the motions of the two servo motors are mutually cooperated, so that the feeding and expanding motion of the honing grindstone is controlled to be synchronized and tuned with the reciprocal motion of the honing tool in order that the processing load applied to the honing grindstone may be made uniform.

2. The honing method according to claim 1, wherein the position waveform in feeding and expanding motion of the honing grindstone is controlled to be synchronized and tuned with the position waveform in ascending and descending stroke motion of the honing tool.
3. The honing method according to claim 2, wherein the control configuration for synchronizing and tuning the feeding and expanding motion with the reciprocal motion is controlled to form preliminarily a position waveform in ascending descending stroke motion of the honing tool and a position waveform in feeding and expanding motion of the honing grindstone, to synchronize and tune the position waveform in the feeding and expanding motion with the position waveform in the ascending and descending stroke motion, and to control the spindle reciprocal driving servo motor and the depth setting driving servo motor to operate respectively at the position waveform in the ascending and descending stroke motion and the position waveform in the feeding and expanding motion of the honing grindstone.
4. The honing method according to claim 3, wherein the operation to synchronize and tune the position waveform in the feeding and expanding motion with the position waveform in the ascending and descending stroke motion is executed by mutually matching the start point and end point in time in these both position waveforms, and mutually matching the position change rates in these both position waveforms.
5. The honing method according to claim 2, wherein the position waveform in ascending and descending stroke motion of the honing tool is a sinusoidal waveform.
6. The honing method according to claim 2, wherein the position waveform in ascending and descending stroke motion of the honing tool is a triangular waveform.
7. The honing method according to claim 2, wherein the feeding and expanding amount of the honing grindstone is an expansion by a specific

amount per stroke in the ascending and descending stroke of the honing tool.

8. A honing machine for moving a honing tool having a honing grindstone reciprocally in the axial direction of the inner circumference of a work, rotating about the axial line, and honing the inner circumference of the work by the honing grindstone, comprising:

a rotational spindle supported to be movable reciprocally in the axial direction of the inner circumference of the work, and to be rotatable about the axial line,
 spindle rotating means for rotating and driving the rotational spindle about the axial line,
 spindle reciprocating means for moving the rotational spindle reciprocally in the axial direction of the inner circumference,
 a honing tool mounted on the leading end of the rotational spindle, being provided with an expandable and contractable honing grindstone having a wheel surface along the inner circumference,
 grindstone depth cutting means for feeding and expanding the honing grindstone of the honing tool with a specified depth of cut, and
 control means for controlling automatically by mutually cooperating with the spindle rotating means, spindle reciprocating means, and grindstone depth cutting means,

wherein drive sources of the spindle reciprocating means and the grindstone depth cutting means are realized respectively by a spindle reciprocal driving servo motor and a depth setting servo motor, and the control means mutually cooperates the motions of these two servo motors, so that the feeding and expanding motion of the honing grindstone is controlled to be synchronized and tuned with the reciprocal motion of the honing tool in order that the processing load applied to the honing grindstone may be made uniform.

9. The honing machine according to claim 8, wherein the control means is designed to control position waveform in feeding and expanding motion of the honing grindstone so as to be synchronized and tuned with the position waveform in ascending and descending stroke motion of the honing tool.

10. The honing machine according to claim 9, wherein the control configuration in the control means for synchronizing and tuning the feeding and expanding motion with the reciprocal motion is controlled to form preliminarily a position waveform in ascending descending stroke motion of the honing tool and a position waveform in feeding and expanding motion of the honing grindstone, to synchronize

and tune the position waveform in the feeding and expanding motion with the position waveform in the ascending and descending stroke motion, and to control the spindle reciprocal driving servo motor and the depth setting driving servo motor to operate respectively at the position waveform in the ascending and descending stroke motion and the position waveform in the feeding and expanding motion of the honing grindstone.

11. The honing machine according to claim 10, wherein the operation in the control means to synchronize and tune the position waveform in the feeding and expanding motion with the position waveform in the ascending and descending stroke motion is executed by mutually matching the start point and end point in time in these both position waveforms, and mutually matching the position change rates in these both position waveforms.

12. The honing machine according to claim 9, wherein the position waveform in ascending and descending stroke motion of the honing tool is a sinusoidal waveform.

13. The honing machine according to claim 9, wherein the position waveform in ascending and descending stroke motion of the honing tool is a triangular waveform.

14. The honing machine according to claim 9, wherein feeding and expanding amount of the honing grindstone is an expansion by a specific amount per stroke in the ascending and descending stroke of the honing tool.

Fig. 1

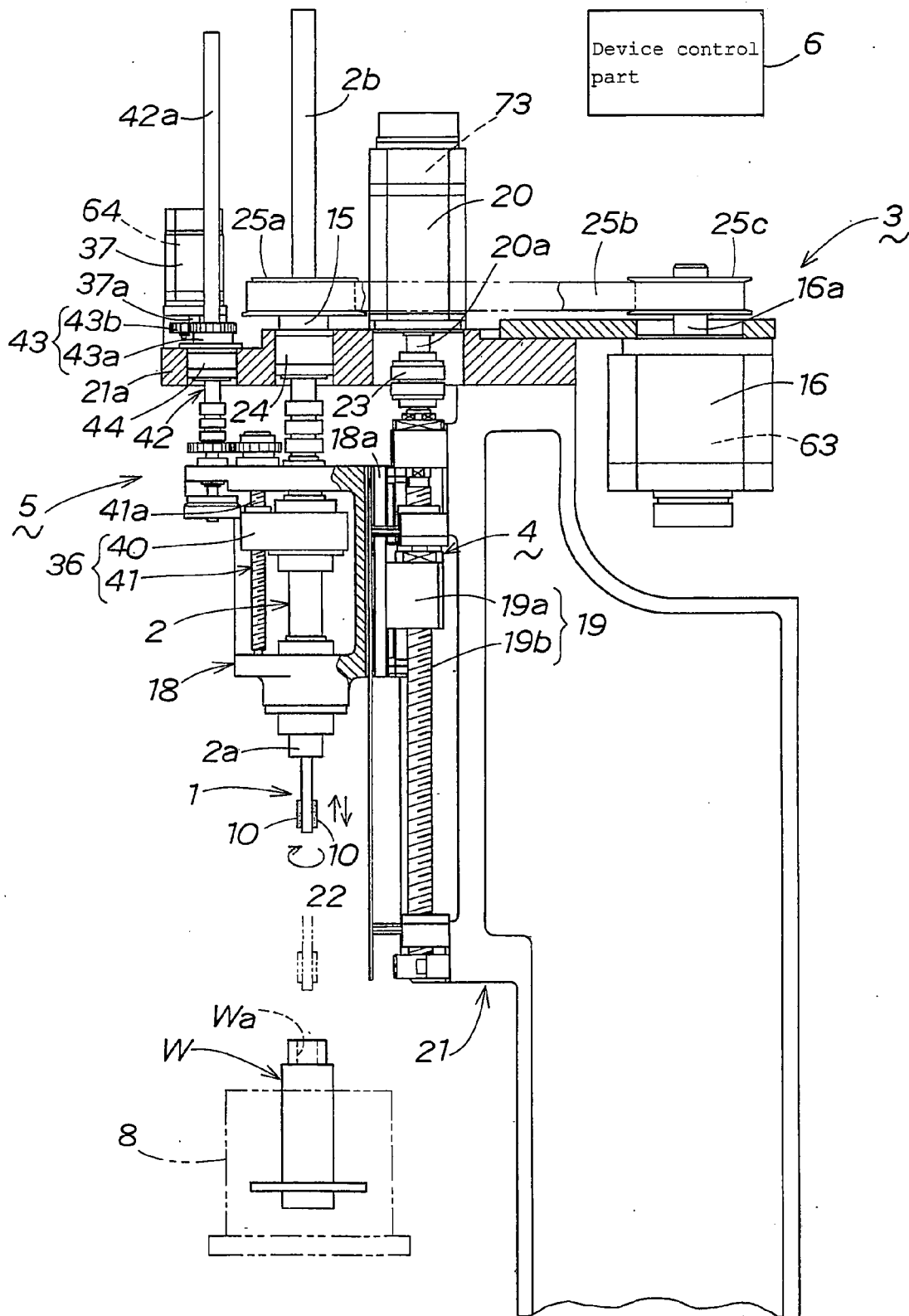


Fig. 2

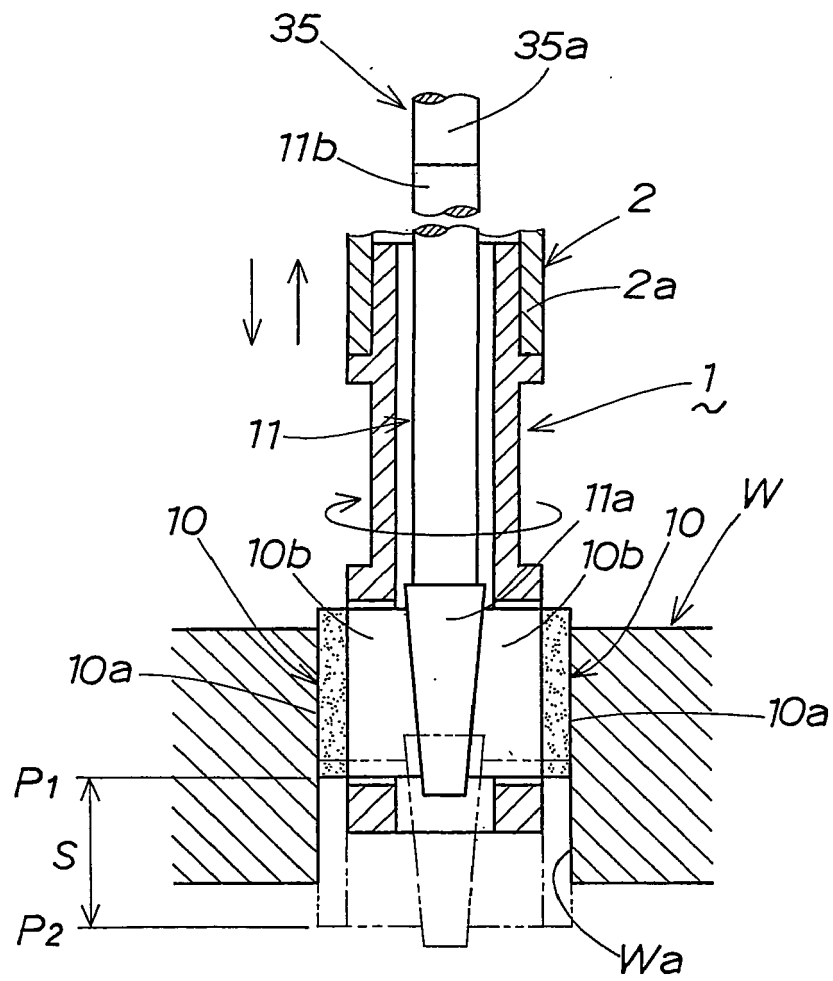


Fig. 3

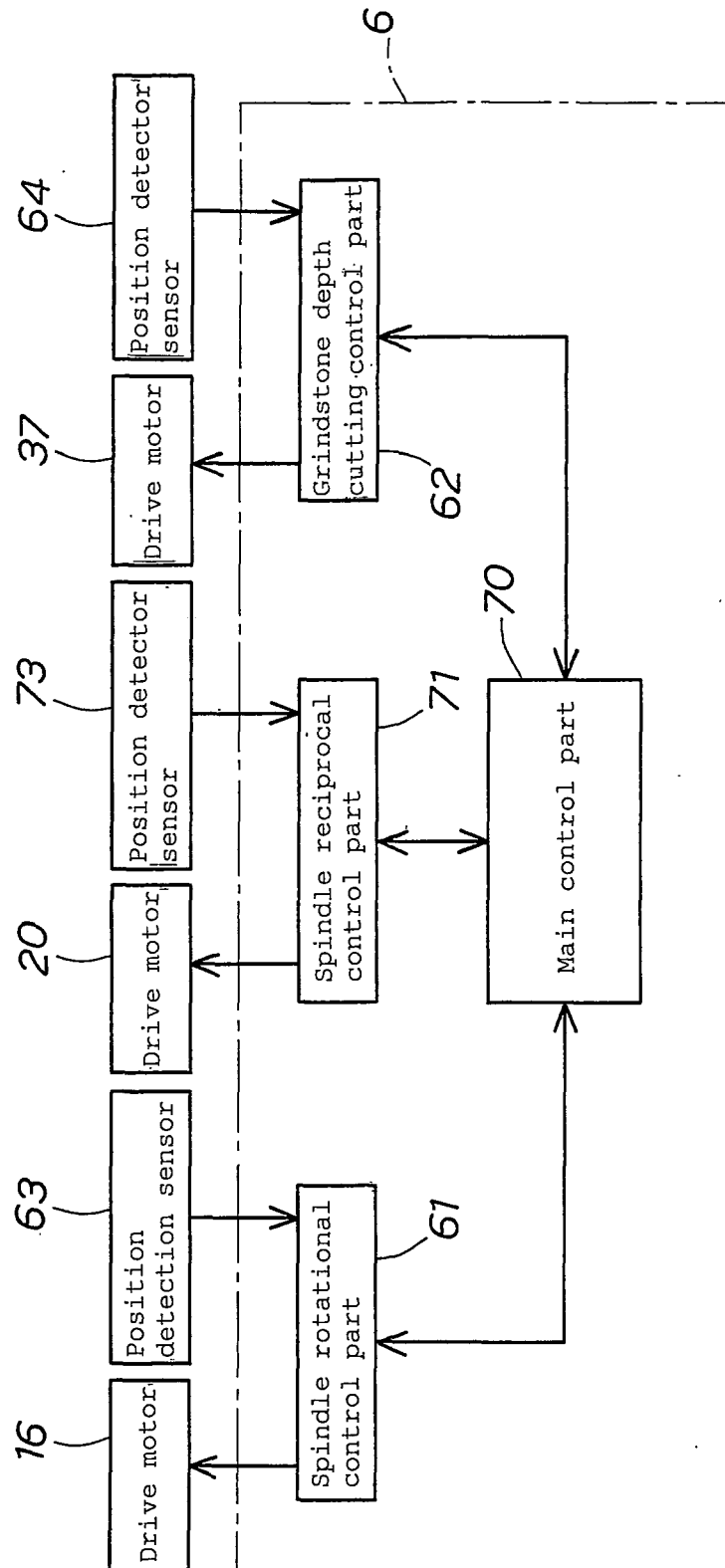
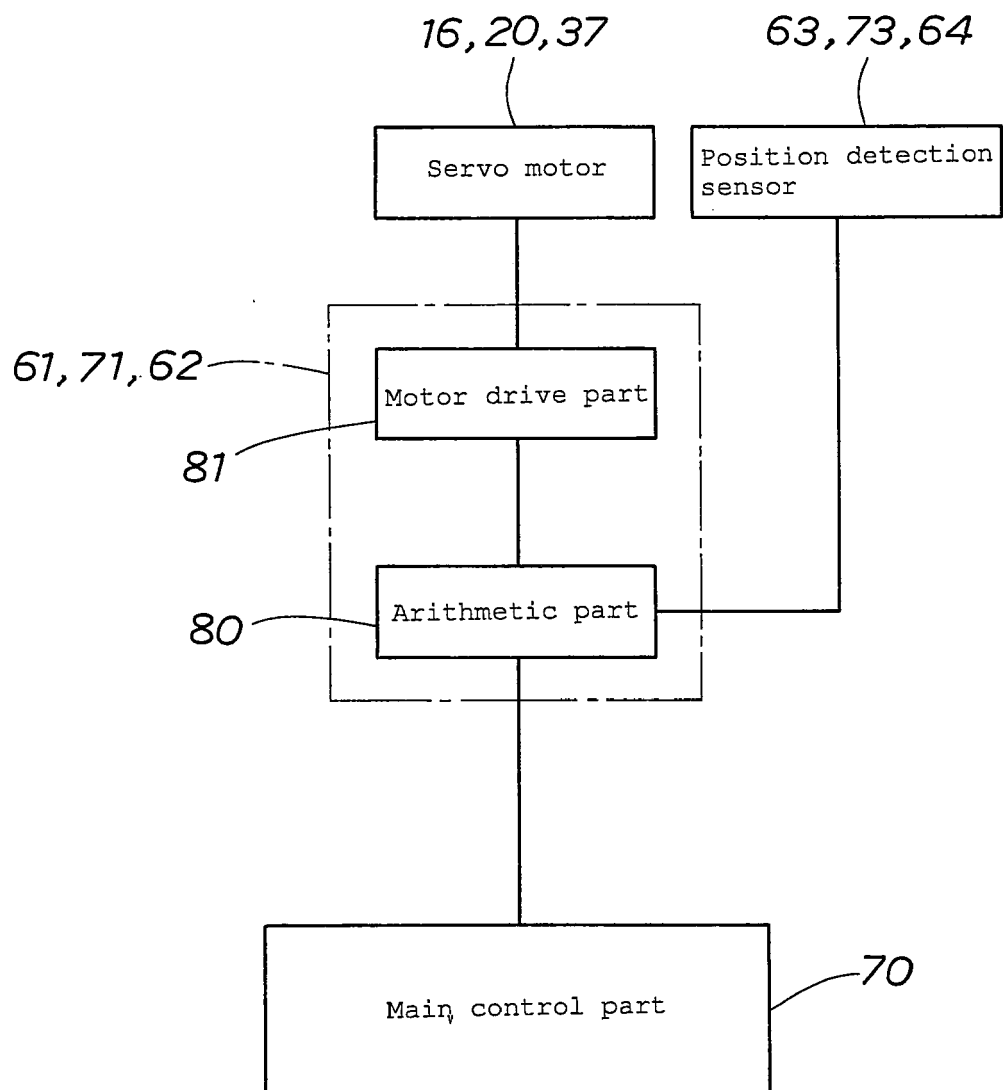


Fig. 4



(b)

Feeding and expanding amount of honing grindstone (mm)

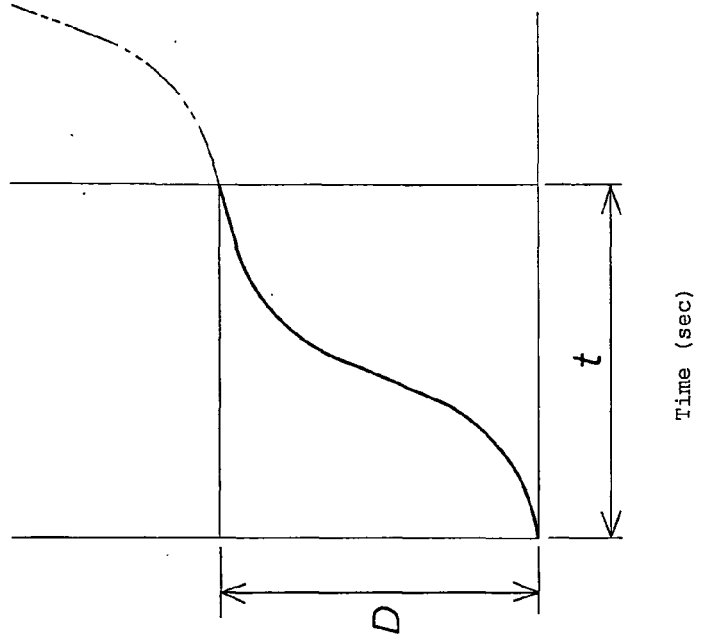


Fig. 5

(a)

Ascending and descending stroke moving amount of honing tool (mm)

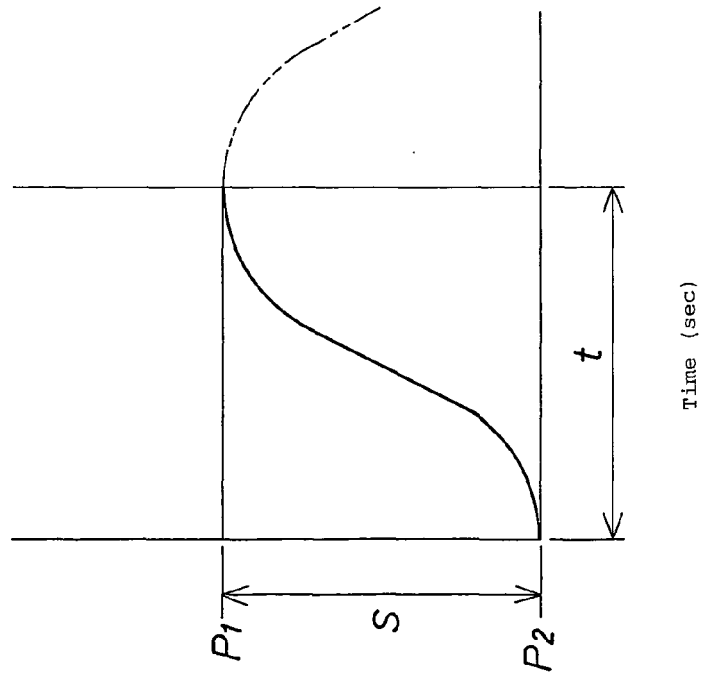


Fig. 6

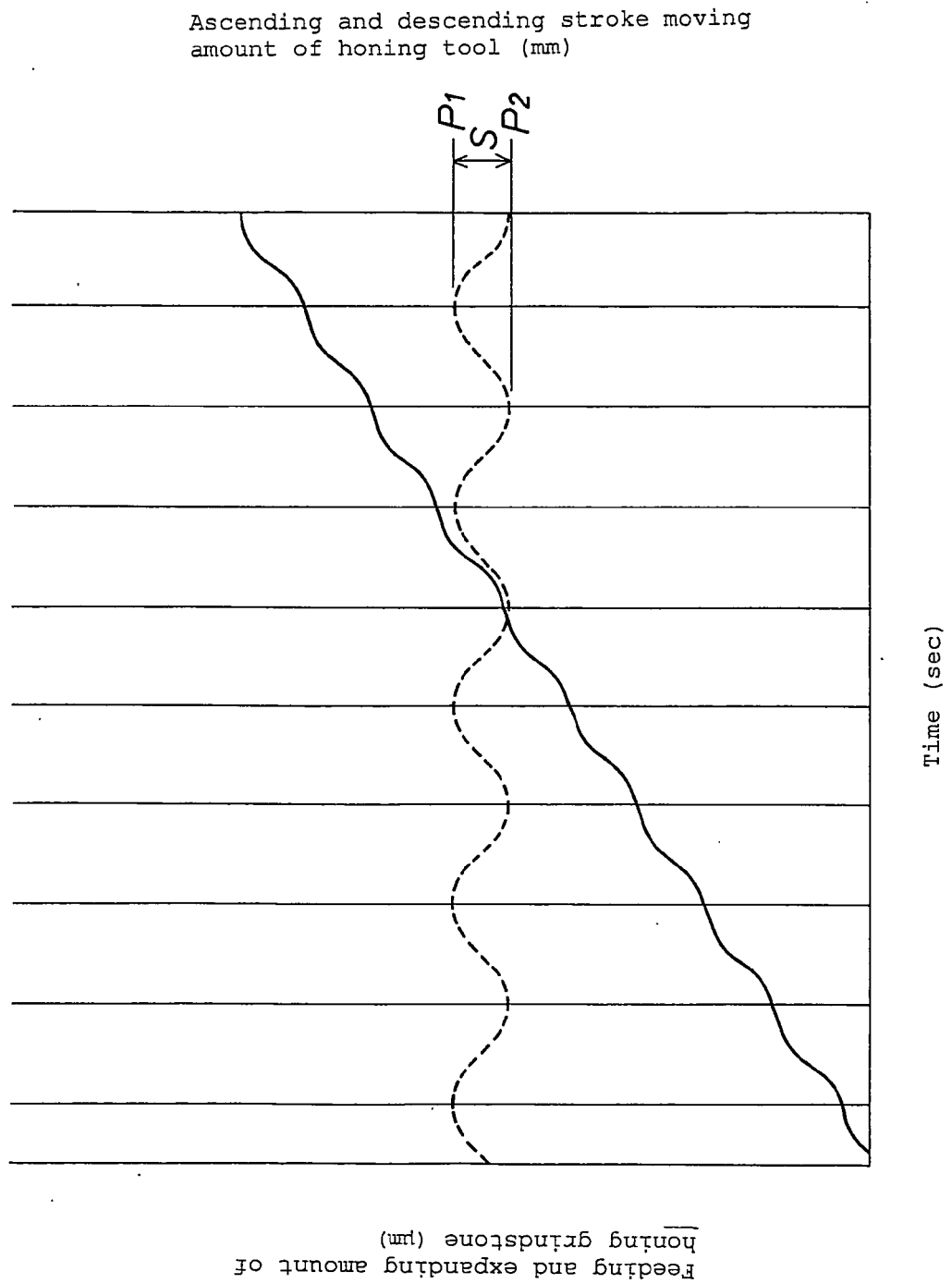
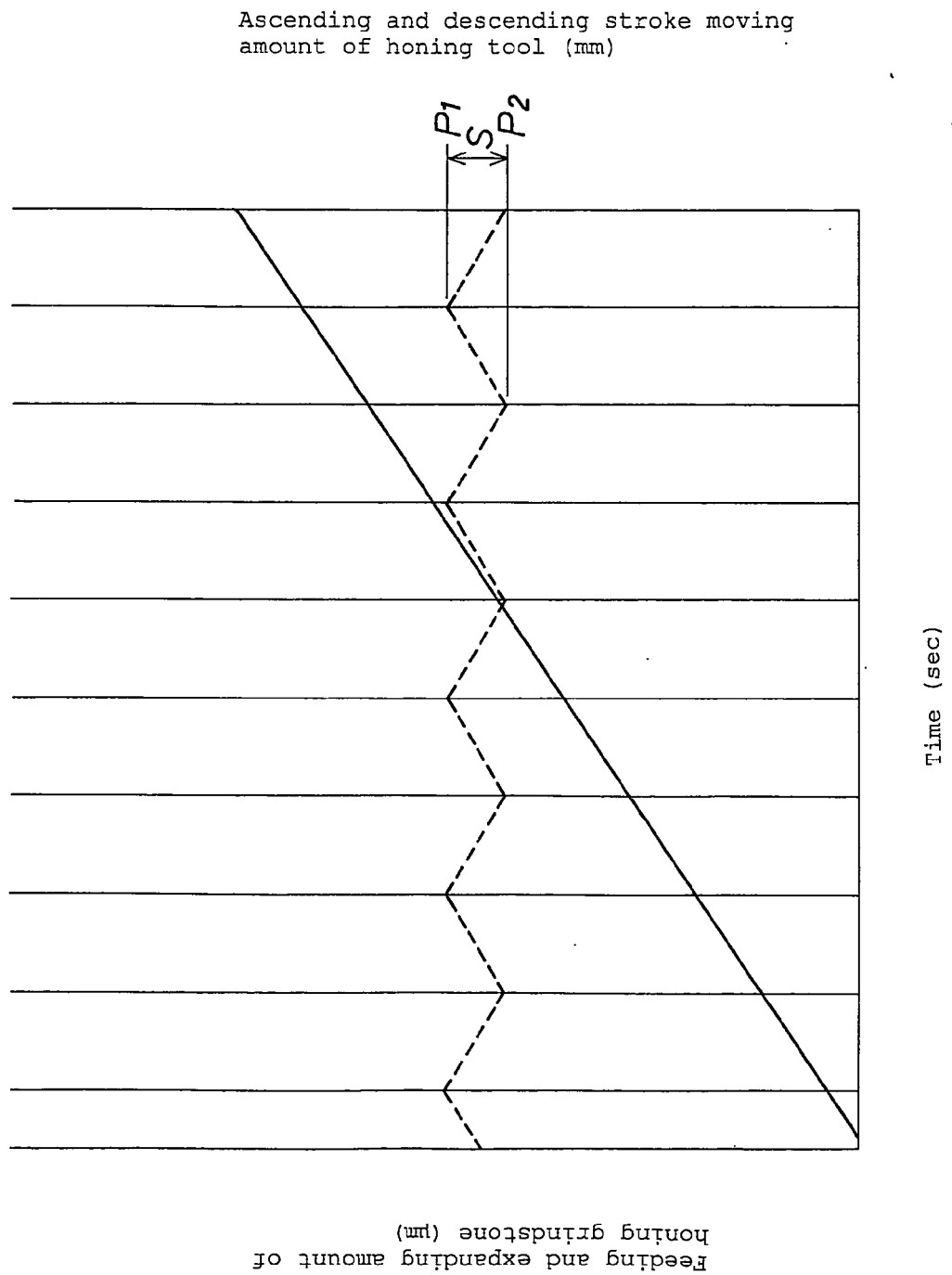


Fig. 7



Ascending and descending stroke moving
amount of honing tool (mm)

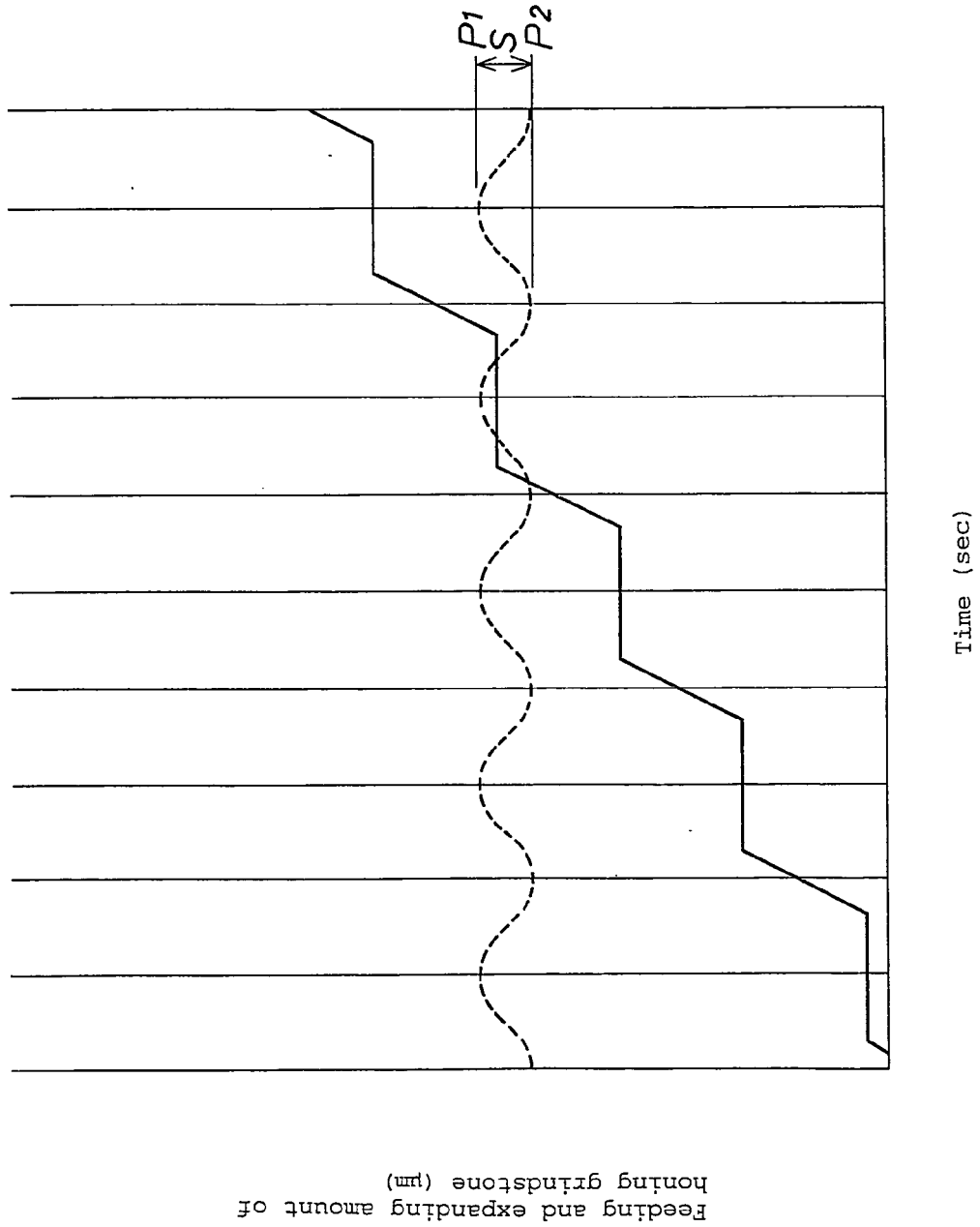


Fig. 8



EUROPEAN SEARCH REPORT

Application Number
EP 09 25 1518

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
D,A	JP 2003 170344 A (NISSHIN SEISAKUSHO KK) 17 June 2003 (2003-06-17) * paragraphs [0004] - [0006], [0009], [0010], [0013], [0014], [0018] - [0022], [0027], [0028], [0031] - [0037], [0040] - [0042], [0044], [0050], [0051] * * figures 1-7 * * abstract *	1-14	INV. B24B33/02 B24B33/06 B24B33/08
A	FR 1 177 438 A (DELAPENA & SON LTD) 24 April 1959 (1959-04-24) * page 1, left-hand column, paragraph 3 - right-hand column, paragraph 3 * * page 2, left-hand column, paragraph 2 * * page 2, right-hand column, paragraph 3 - page 3, left-hand column, paragraph 2 * * figures 1-7 * -----	1-14	TECHNICAL FIELDS SEARCHED (IPC) B24B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 9 October 2009	Examiner Eder, Raimund
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 09 25 1518

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09-10-2009

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