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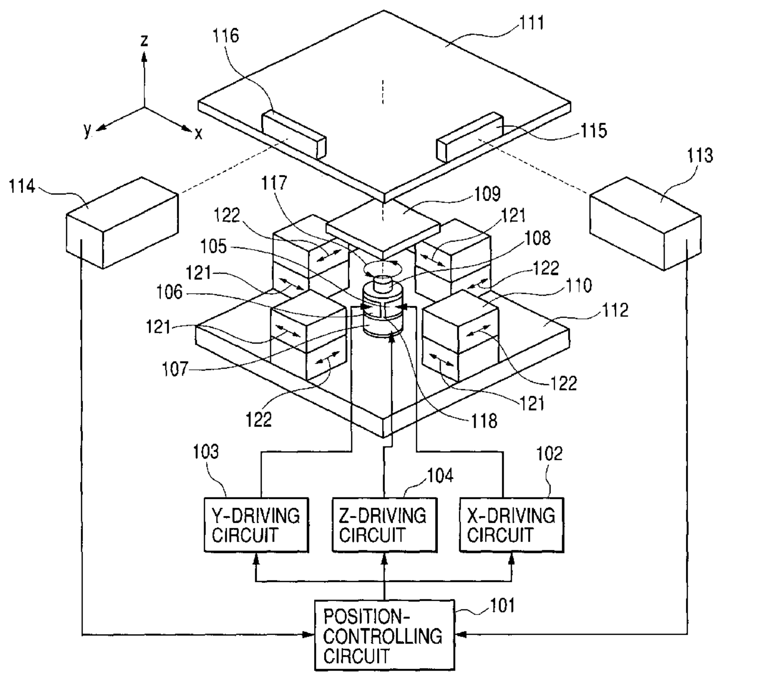
(54) Title: DRIVING APPARATUS



(57) Abstract: A B S T R A C TA driving apparatus, comprising an actuator having a tip displaceable in X,Y,Z three-axis directions, and a movable body having translational movement freedom in X,Y two-axis directions, wherein the tip of the actuator is placed to be displaceable in Z-axis direction to come into pressure contact with the movable body, and the tip of the actuator under pressure contact is displaced within an XY-axis plane to move the movable body translationally in the direction of displacement of the tip of the actuator.

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DESCRIPTION

DRIVING APPARATUS

TECHNICAL FIELD

The present invention relates to constitution of an oscillatory-wave actuator which drives an oscillator to move an object in contact with the oscillator, and a method of control thereof; and relates also to a positioning apparatus employing the actuator, and a method of control thereof.

BACKGROUND ART

Recently, as an actuator for a positioning stage or the like, so-called oscillatory-wave actuators are used widely. The oscillatory-wave actuator moves a movable member by pressing an oscillator fixed to a piezoelectric element against the movable member and oscillating the piezoelectric element at a frequency higher than the audible range. The structure thereof is disclosed in USP 5,453,653, 5,616,980, and 5,682,076.

The constitution of the oscillatory-wave actuators disclosed in the above patent publications is explained below. The actuator has an electrode on the both faces of a flat piezoelectric material, and the electrode on one face is divided into plural sections. Application of a voltage between the electrodes on the both faces causes fine deformation of the piezoelectric material. Thereby, the piezoelectric material can be deformed in a desired direction by applying a voltage to a selected appropriate electrode. At the end portion of the piezoelectric material, a spacer is provided. A movable member can be moved in one direction by an ellipsoidal movement of the spacer caused, for instance, by application of AC signals or pulse signals between the electrodes on the piezoelectric material.

Fig. 2 shows an example of a positioning stage which employs an oscillatory-wave actuator. Oscillator 108 of actuator 201 is driven by x-driving circuit 102 to oscillate in an ellipsoid at a high speed as shown by oscillator orbit 117 within the xy-plane in the drawing. This oscillation drives driving plate 109 fixed to moving table 111 which is movable in x-direction in the drawing. Displacement sensor 113 detects the actual position of the table. Position-controlling circuit 101 sends control signals generated by multiplying a control factor to the deviation of the detected position from the targeted position to x-driving circuit 102, constructing a so-called feedback positioning system.

The mechanism like this can be made compact in comparison with conventional mechanisms constituted of combination of a rotary motor such as a servo motor with a feed screw, and can be constructed from nonmagnetic members capable of holding the movable body by friction in a motor-stop state in contrast to the mechanism employing a linear magnetic motor, advantageously.

The conventional positioning stage for positioning in an xy plane employs generally a device having combination of two of the aforementioned mechanisms in layers with the movement axes directed perpendicularly. However, such a constitution causes increase in size and weight of the entire mechanism by the layer structure, resulting in lower dynamic response.

Further, the difference in the loading mass on the two axes causes a problem of low route-controllability owing to asymmetry of dynamic characteristics of the axes, especially in applications requiring precision of the movement route, like in direct laser writing.

DISCLOSURE OF THE INVENTION

To solve the above problems, the present invention provides a driving apparatus which comprises an actuator having a tip displaceable in X,Y,Z three-axis directions, and a movable body having translational movement freedom in X,Y two-axis directions, wherein the tip of the actuator is placed to be displaceable in Z-axis direction to come into pressure contact with the movable body, and the tip of the actuator under pressure contact is displaced within an XY-axis plane to move the movable body translationally in the direction of displacement of the tip of the actuator.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a drawing for explaining constitution of the apparatus of Example 1 of the present invention.

Fig. 2 is a drawing for explaining an example of constitution of an apparatus of a prior art technique.

Fig. 3 is a drawing for explaining constitution of the apparatus of Example 2 of the present invention.

Fig. 4 is a drawing for explaining function in Example 1.

Fig. 5 is a drawing for explaining operation in Examples 1 and 2.

Fig. 6 is a drawing for explaining operation in Examples 1 and 2.

Fig. 7 is a drawing for explaining operation in Examples 1 and 2.

BEST MODE FOR CARRYING OUT THE INVENTION

In embodiment of the present invention, the driving apparatus is constituted of an actuator having a tip displaceable in X,Y,Z three-axis directions, and a movable body having translational movement freedom in X,Y two-axis directions. The tip of the actuator element deformable in the direction of X,Y,Z axes (hereinafter referred to as "three axes") is brought into pressure contact with the movable body having translational movement freedom in directions of X and Y axes (hereinafter referred to as "plane-defining axes"). In the pressure contact state, displacement of the actuator in an XY plane moves the movable body by friction between the actuator tip and the movable body.

When the actuator tip is allowed to oscillate in Z-direction and synchronously in XY-directions, the tip is moved in an ellipsoid within a plane including the Z-axis, namely the plane perpendicular to the XY plane. In one cycle of this ellipsoidal movement, at the phase where the Z-axis displacement is greater, the tip is pressed more strongly against the movable body by a stronger frictional force. Thus, the movement of the actuator tip in the XY axis direction drives the movable body in the same direction by the frictional force. Desirably, this frictional force is a static frictional force to allow the movable body to follow completely the displacement of the actuator. However, a certain extent of slippage is acceptable.

On the other hand, at the phase where the Z-axis displacement is small, the tip is not in contact with the movable body, or is in loose contact with it by a weaker pressing force. In this phase, the actuator can be returned to the original position by displacement in the direction reverse to the displacement with close contact while the movable body is left unmoved, since no or little frictional force is applied, resulting in slippage.

By repeating the above oscillation, the movable body can be moved translationally in one direction by accumulation of the resultant displacement in a cycle of the actuator's ellipsoidal movement.

As described above, a mechanism can be constructed in which a tip of an element deformable in three-axis directions is brought into contact with a movable body having movement freedom in the planar two-axis directions, and is moved in an ellipsoid within an arbitrary plane perpendicular to the aforementioned plane to move the movable body in a desired direction within the aforementioned plane. This mechanism can be made compact and is capable of moving the movable body in any directions within the aforementioned plane with less asymmetry of the dynamic characteristics in the two axis directions by allowing the tip to move in an ellipsoid within a plane perpendicular to the aforementioned plane.

Further, the driving apparatus of the present invention enables highly precise movement of a movable body within a fine region in the plane by deforming the element in the two-axis plane direction with retention of the static friction between the tip and the movable body. By employing the aforementioned element in plurality, a movable body having a rotational movement freedom in the above plane as well as the two-axis plane direction can be turned in addition to the above translational movement in the plane by similar operation of the elements.

(Example 1)

A first example of the present invention is explained below.

A positioning stage according to the present invention is explained by reference to Fig. 1.

Fig. 1 illustrates a mechanism which moves a moving table 111 designed to be movable in an xy-plane which is defined by fixed base 112. Moving table 111 is used for moving a body placed thereon, and is called a stage when the displacement distance thereof is controllable.

Guides 110 comprise respectively two sliding devices therein for x-direction and y-direction shown by arrows 121 and 122 having arrowheads at both ends in the figure. Guides 110 are respectively fixed to base 112 at one end and fixed to moving table 111 at the other end, whereby moving table 111 is not movable in z-direction, but is movable freely in xy-directions.

Cylindrical piezoelectric element 118 is provided on base 112. Oscillator 108 at the top of the element is pressed against driving plate 109 which is fixed to moving table 111, and drives the table together with the plate. Cylindrical piezoelectric element 118 and base 112 are connected by a spring not shown in the drawing. This spring gives the above contact pressure. The contact pressure (applied pressure) may be caused by air pressure or oil pressure other than the spring force.

x-Displacement sensor 113 and y-displacement sensor 114 measure the actual position of moving table 111 in x-axis direction and y-axis direction by detecting the distance from x-displacement mirror 115 and the distance from y-displacement mirror 116. Position-controlling circuit 101 compares the actual position with the target position, and transmits the control signal to x-driving circuit 102, y-driving circuit 103, and z-driving circuit 104 in real time.

Next, the function of cylindrical piezoelectric element 118 is explained by reference to Fig. 4.

Fig. 4 shows cylindrical piezoelectric element 118 of Fig. 1 viewed from the plus side toward the minus side of the y-axis. The cylindrical piezoelectric element 118 is formed by fabricating a piezoelectric element in a shape of a cylinder, and is polarized such that it extends in z-direction at a positive potential of the outer wall relative to the inner wall, and shrinks in z-direction at a negative potential of the outer wall relative to the inner wall in the drawing. The inside wall is covered entirely with an electrode and is grounded (not shown in the drawing). The electrode covering the outside wall is divided into an upper electrode part and a lower electrode part. The lower electrode part surrounding the lower part of the element serves as z-driving electrode 107. The upper electrode part is divided into four sections along the circumference at angles of 45° relative to the x-axis or y-axis: the pair of the sections in the x-axis direction serve as x-driving electrodes 105, and the pair of the sections in the y direction serve as y-driving electrodes 106. For instance, when a voltage is applied to x-driving electrodes 105, a positive potential to the plus side of x-axis direction and a negative potential to the minus side thereof, the positive side of the element extends and the negative side of the element shrinks, displacing oscillator 108 in the arrow direction in Fig. 4.

Oscillator 108 fixed to the tip of this cylindrical piezoelectric element 118 is pressed by a spring against driving plate 109 fixed to moving table 111. Therefore, extension of cylindrical piezoelectric element 118 in z-direction increases the pressure of oscillator 108 against driving plate 109, whereas shrink of cylindrical piezoelectric element 118 in z-direction decreases the pressure of oscillator 108 against driving plate 109.

By utilizing the change of the frictional force between oscillator 108 and driving plate 109, moving table 111 can be driven in a desired direction. That is, moving table 111 is displaced by extension of cylindrical piezoelectric element 118 in z-direction and synchronous displacement thereof in x- and y-axis directions, by the frictional force between oscillator 108 and driving plate 109 for displacement in the same direction as the oscillator. On the other hand, cylindrical piezoelectric element 118 itself is returned to the original position by the shrink in z-axis direction and movement in x- and y-axis directions leaving the moving table 111 unmoved owing to weak frictional force and resulting slippage between oscillator 108 and driving plate 109. Thereby moving table 111 is moved at a certain distance in xy-directions in the one extension-shrink cycle of cylindrical piezoelectric element 118. The movement distance in the one cycle depends on the deformation in xy-directions and also on extension in z-direction of cylindrical piezoelectric element 118.

The spring force between cylindrical piezoelectric element 118 and base 112 may be adjusted to detach oscillator 108 from driving plate 109 on shrink of cylindrical piezoelectric element 118 in z-direction.

In response to the indicated control variables, x-driving circuit 102, y-driving circuit 103, and z-driving circuit 104 output respectively driving signals to x-driving electrode 105, y-driving electrode 106, and z-driving electrode 107 to oscillate oscillator 108 in an ellipsoid at a high speed within a plane perpendicular to the xy-plane in Fig. 1. For instance, movable table 111 moves to the direction turned by $\pi/4$ rad from the x-axis plus-direction to the y-axis plus-direction by application of a voltage in the waveform of Fig. 5 to x-driving electrode 105 and y-driving electrode 106 respectively at the plus side of the electrode axes, and a voltage of the waveform of Fig. 6 to x-driving electrode 105 and y-driving electrode 106 respectively at the minus side of the electrode axes, and application of a voltage of the waveform of Fig.

7 to z-driving electrode 107.

The movement distance in one cycle of the oscillation can be adjusted by changing the voltage amplitudes of x-driving electrodes 105, y-driving electrodes 106, and z-driving electrode 107. The movement direction can be changed from the direction of $\pi/4$ rad by changing the amplitudes of the voltages applied to x-driving electrodes 105 and y-driving electrodes 106, the movement being directed by the sum of the deformation vectors by in x-direction and y-direction.

Speed of the translational motion of the moving table 111 can be controlled by changing the amplitude and/or the frequency of the actuator's oscillation. Phase difference between the Z-directional oscillation and the XY-plane directional oscillation is also adjustable to change the speed.

In addition to the above-described operation, the present invention can be applied to operation in a finer region. For this operation, a DC voltage of about +20 V is applied to z-driving electrode 107 to press oscillator 108 strongly against driving plate 109. With retention of this contact state between oscillator 108 and driving plate 109, arbitrary voltages are applied respectively to x-driving electrode 105 and y-driving electrode 106 to move the moving table 111. In this operation, the positional resolution is very high, although the movement region is limited within the deformation range of cylindrical piezoelectric element 118.

The stage can be moved by combination of coarse movement and fine movement: the coarse movement for moving a movable body by deformation in x-direction and y-direction synchronously with deformation in z-direction, and the fine movement for moving the movable body by deformation in x-direction and y-direction with the deformation fixed in z-direction.

(Example 2)

Example 2 of the present invention is explained below in detail by reference to Fig. 3.

A positioning stage according to the present invention is explained by reference to Fig. 3. In Fig. 3, moving table 111 is placed on base 112 constituting an xy-plane in a non-contact state kept by an air pressure (so-called air-slide constitution). Thus moving table 111 is turnable in the xy-plane in addition to the translational movability in xy-axis directions.

x-Shearing piezoelectric elements 301, y-shearing piezoelectric elements 302, and z-extendable piezoelectric elements 303 have respectively an electrode on each of the top and bottom faces. The top-face electrodes are grounded, and the elements are driven by application of driving voltages to the bottom-face electrodes in x, y and z direction shoun by arrows 121, 122 and 123 having arrowheads at both ends, respectively, in Fig. 3. Each of the elements is polarized to be displaceable toward the minus axis direction when the bottom face is positively charged relative to the top face. Driving elements 304 through 307, which are respectively constituted of the set of the aforementioned three elements in layers, are fixed at the top face relative to base 112. Oscillator 108 fixed to the bottom face of the each driving element has been being pressed previously to each of the four driving plates 109 fixed to moving table 111. The table is moved by the driving plates. Position-controlling circuit 101 sends control signals to x-driving circuit 102, y-driving circuit 103, and z-driving circuit 104 in real time.

In response to the indicated control variables, x-driving circuit 102, y-driving circuit 103, and z-driving circuit 104 output respectively driving signals to the bottom-face electrodes of x-shearing piezoelectric elements 301, y-shearing piezoelectric elements 302, and z-extendible piezoelectric elements 303 to oscillate oscillator 108 in an ellipsoid at a high speed within a plane perpendicular to the xy plane in the drawing. For instance, movable table 111 moves to the direction turned by $\pi/4$ rad from the plus direction of the x-axis to the plus direction of the y-axis by application of a voltage in the waveform of Fig. 5 to the bottom-face electrodes of x-shearing piezoelectric elements 301 and y-shearing piezoelectric elements 302 of all of the driving elements, and application of a voltage of the waveform of Fig. 7 to the bottom-face electrodes of z-extendible piezoelectric elements 303 of all of the driving elements.

The movement distance by one cycle of oscillation can be adjusted by changing the amplitudes of the applied voltages. The movement direction can be changed from the direction of $\pi/4$ rad by changing the amplitudes of voltages applied to x-shearing piezoelectric elements 301 and y-shearing piezoelectric elements 302, the movement being directed to the sum of the movement vectors caused by x-shearing piezoelectric elements 301 and y-shearing piezoelectric elements 302.

Moving table 111 is turned from the x-axis plus-direction to the y-axis plus-direction in the drawing by application of the voltage of the waveform in Fig. 5 to the respective bottom-face electrodes of y-shearing piezoelectric element 302 of driving element 304 and x-shearing piezoelectric element 301 of driving element 307; application of the voltage in Fig. 6 to the respective bottom-face electrodes of x-shearing piezoelectric element 301 of driving element 305 and y-shearing piezoelectric element 302 of driving element 306; and application of the voltage of the waveform in Fig. 7 to bottom-face electrodes of all of z-extendible piezoelectric element 303.

The turning speed can be adjusted by changing the voltage amplitude or the frequency. The turning center can be shifted from the center of four driving elements 304 through 307 by such a procedure that the movement distances by the each of the driving elements are made proportional to the distance between the turning center and that the driving element and the movement direction by the respective driving element is set to be perpendicular to the line connecting the turning center with the driving element.

In addition to the above operation, the present invention can be applied to finer operation. In this operation, a DC voltage of about +20 V is applied to the bottom-face electrodes of all of z-extendible piezoelectric elements 303 to press the respective oscillators 108 strongly against driving plates 109. With retention of this contact state between oscillator 108 and driving plate 109, a suitable voltage is applied to any of x-shearing piezoelectric elements 301 and y-shearing piezoelectric elements 302 to displace or turn finely the moving table 111.

This operation can be conducted with extremely high resolution although the region of the movement and turning is limited within the range of the deformation of the respective driving elements.

CLAIMS

1. A driving apparatus, comprising an actuator having a tip displaceable in X,Y,Z three-axis directions, and a movable body having translational movement freedom in X,Y two-axis directions, wherein the tip of the actuator is placed to be displaceable in Z-axis direction to come into pressure contact with the movable body, and the tip of the actuator under pressure contact is displaced within an XY-axis plane to move the movable body translationally in the direction of displacement of the tip of the actuator.

2. The driving apparatus according to claim 1, wherein the tip of the actuator oscillates in the X, Y and Z-axis directions; the tip of the actuator is displaced in a direction on the XY-axis plane within a first period including the time of maximum displacement of the Z-axis direction in one cycle of the oscillation to move the movable body, and the tip of the actuator is displaced in a reverse direction to the direction on the XY-axis plane within a second period including the time of minimum displacement of the Z-axis direction.

3. The driving apparatus according to claim 2, wherein the second period includes a period in which the tip of the actuator is not in contact with the

movable body.

4. The driving apparatus according to claim 2, wherein the second period includes a period in which slippage is caused between the tip of the actuator and the movable body.

5. The driving apparatus according to claim 2, wherein the synthesis of the oscillation in the Z-axis direction and the displacement in the XY-axis plane gives ellipsoidal movement in a plane containing the Z axis.

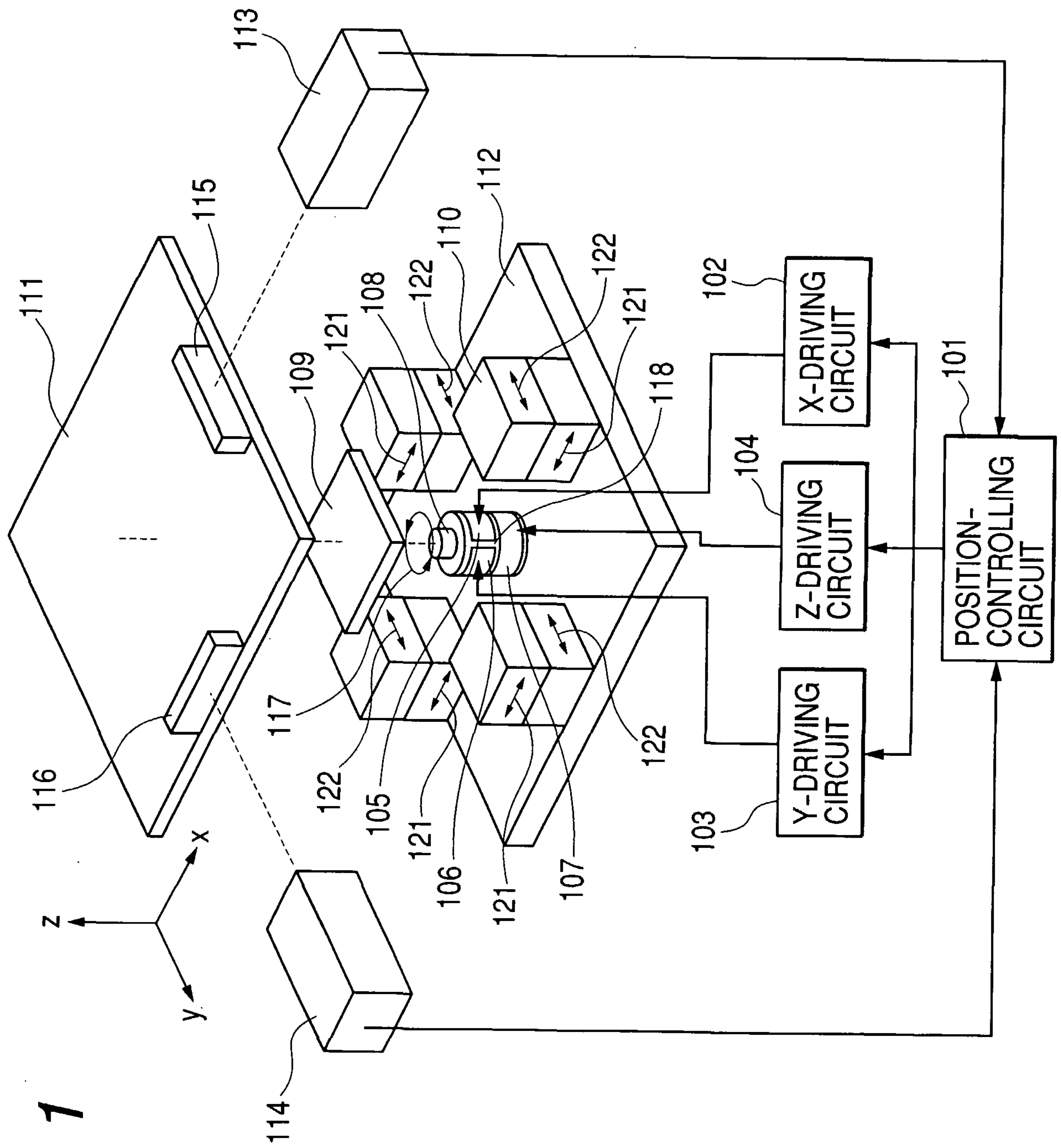
6. The driving apparatus according to claim 2, wherein the movable body is moved beyond the range of the oscillation of the actuator in the XY-axis plane by accumulation of a resultant displacement of the movable body in a cycle of the oscillation of the actuator.

7. The driving apparatus according to claim 6, wherein the speed of the movement is variable by variation of the amplitude, frequency or phase of the oscillation of the actuator.

8. The driving apparatus according to claim 1, wherein the tip of the actuator is moved in the XY-

axis plane direction with the displacement in the Z-axis direction fixed, and thereby the movable body is moved within the range of oscillation of the actuator in the XY-axis plane direction.

9. The driving apparatus according to claim 1, wherein the movable body has translational movement freedom in the X- and Y-axis directions and rotational movement freedom in the XY plane, and the actuator is provided in plurality at plural positions.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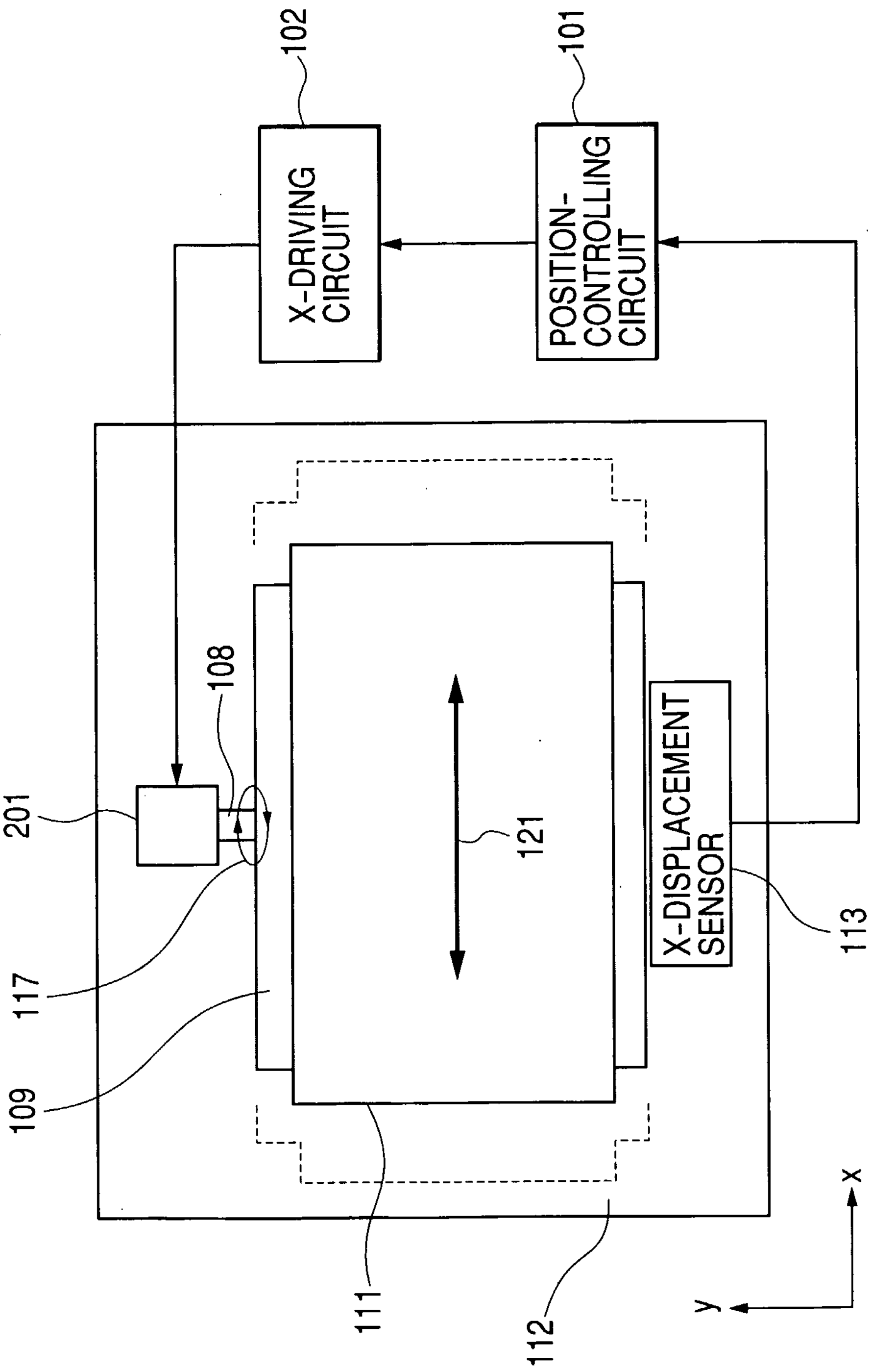
115
113
112
110
122
108
121
109
122
121
118
102
X-DRIVING CIRCUIT
104
Z-DRIVING CIRCUIT
101
POSITION-CONTROLLING CIRCUIT
103
Y-DRIVING CIRCUIT
116
117
122
105
121
106
121
107
122
114
z
x
y

FIG. 1

FIG. 2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POSITION-CONTROLLING CIRCUIT
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108
117
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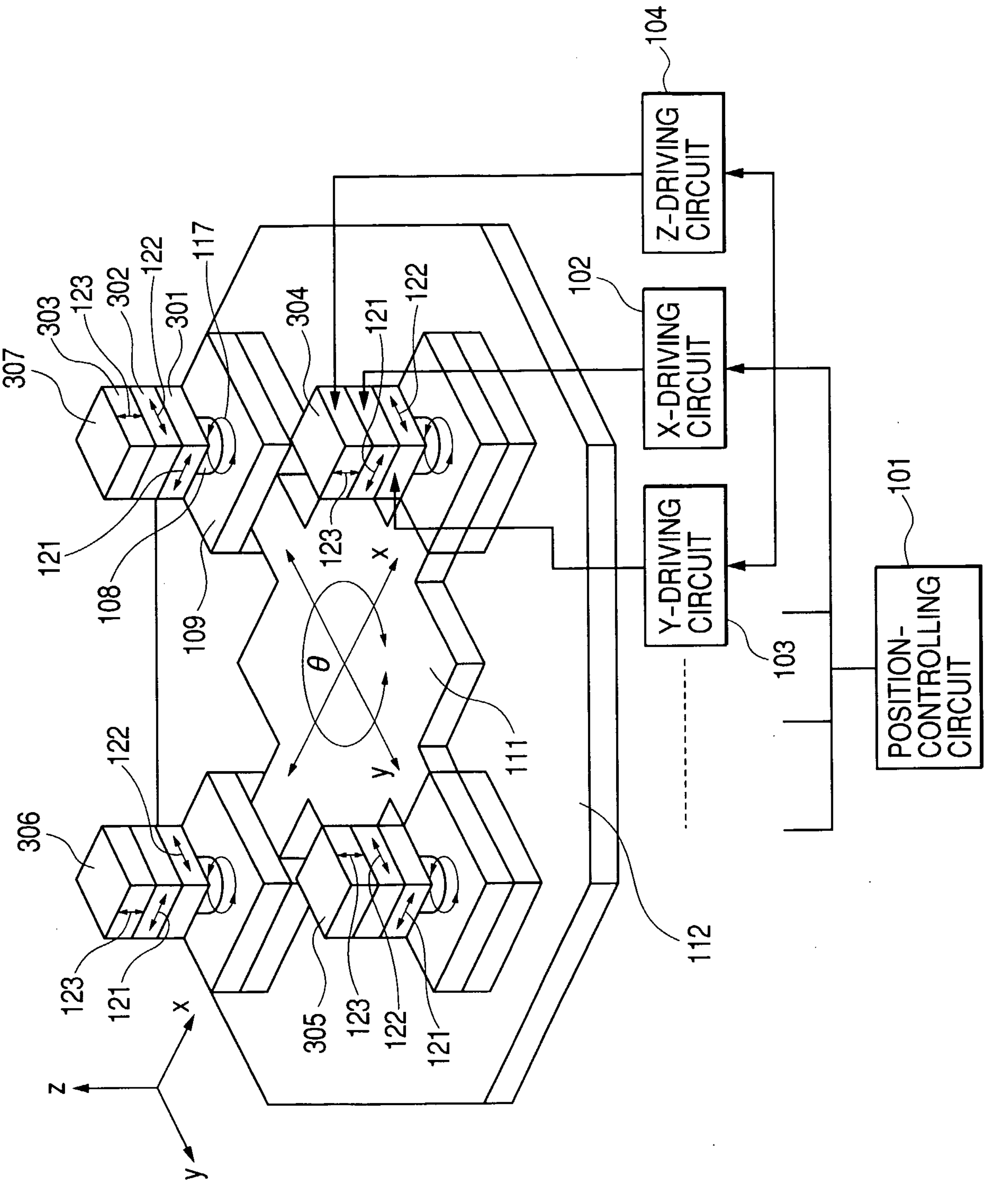
X-DISPLACEMENT SENSOR
113
111
112
x
y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Y-DRIVING CIRCUIT
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POSITION-CONTROLLING CIRCUIT
101
307
303
123
302
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117
304
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122
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108
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FIG. 3

FIG. 4

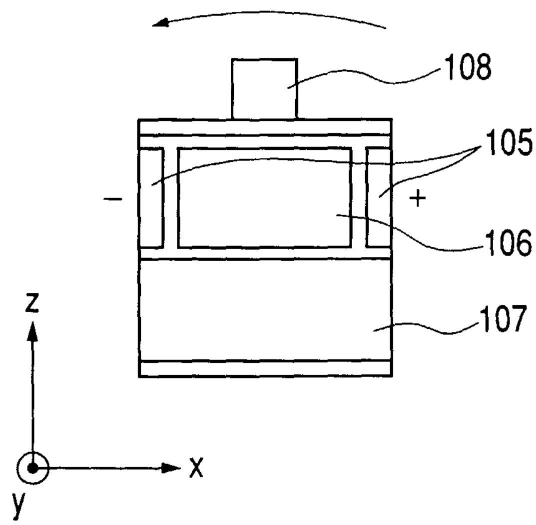

FIG. 5

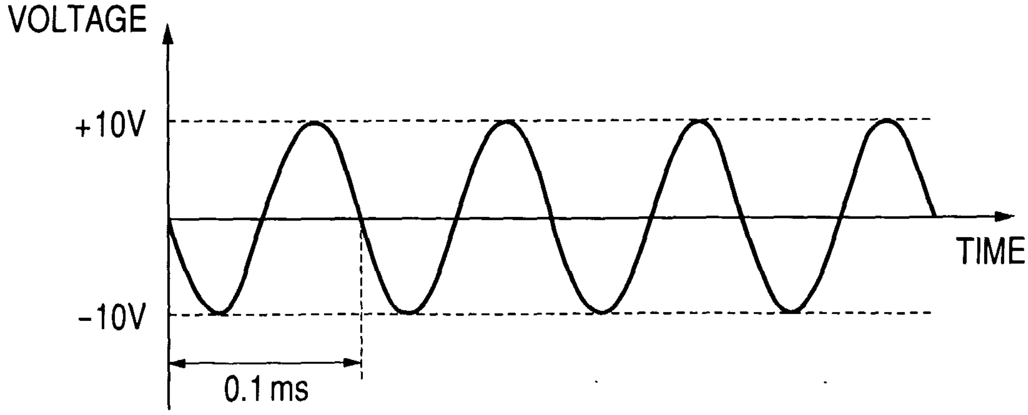

FIG. 6

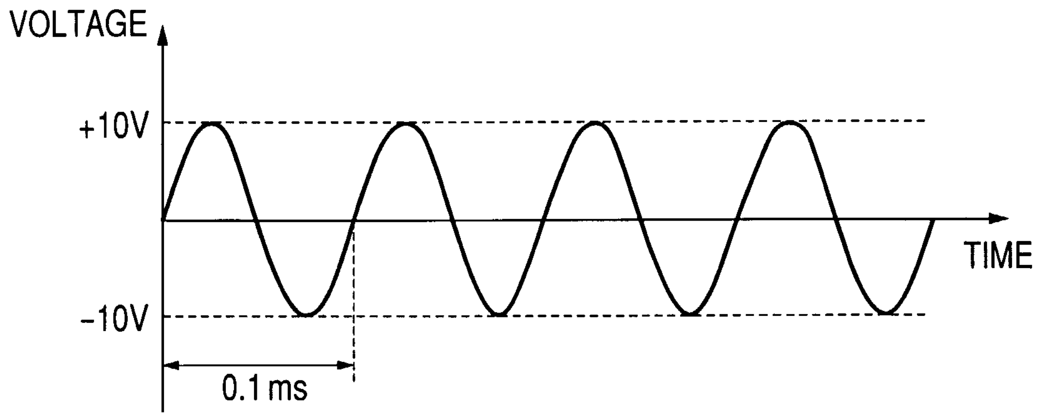

FIG. 7