PLANESERV PLANAR SERVOMOTOR

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Recently the need for a more precise and high-contact positioning XY stage is increasing dramatically in line with the greater demand for fine fabrication of semiconductor devices and for reducing Co0 of those manufacturing equipment. We have therefore developed a completely new type of servo XY-stage system called PLANESERV. It employs a slider consisting of a three-axis laser interferometer and integrated three-axis drive motor, which moves along the surface of a platen without generating friction due to being elevated with air bearing. The PLANESERV boasts high resolution (0.1 μm), high precision (linearity: 1 μm), lighter movable part, and high settling time (20 ms at 1 μm settling) positioning. The drive motor used with the non-interactive digital control system also achieves high performance.

INTRODUCTION

There has been increasing demand for high accuracy and precise contact positioning with further miniaturization of the semiconductor, LCD and electronic parts. However, the task of obtaining even higher accuracy with a conventional XY stage combining a linear motor and ball screws, has reached its limitations. We have developed the PLANESERV with a lightweight movable part by adopting a planar motor structure. High contact positioning is also realized by feedback control of end points on the XY stage through the incorporation of an interferometer into the movable part. An originally developed laser diode of the interferometer uses a distributed bragg reflector (DBR) structure to stabilize the wavelength. Figure 1 shows an external view of the PLANESERV. This paper describes the features and fundamental technologies of the PLANESERV.

FEATURES

(1) High Accuracy and Resolution
A position sensor resolution of 0.027 μm is achieved with the laser interferometer and heterodyne signal processing. The accuracy or linearity of XY-stage is ±1 μm or less, and positioning repeatability is ±0.1 μm or less by feed back control of end points on three axes (XYθ) and averaging effects of the air bearing on the plane.

(2) Fast Settling
A settling time of 20 ms is obtained for a ±1-μm width by a high-accuracy, high-speed inverter with increased response for minimal current and non-interactive control of XYθ axes, as well as by eliminating friction through an air bearing, and realizing a lightweight and extremely stiff movable part from the adoption of a planar motor structure.

(3) Compact and Lightweight
Because of an interferometer using a laser diode and a planar structure integrating an XYθ drive motor, the movable part weighs only 6 kg, approximately one third that of a

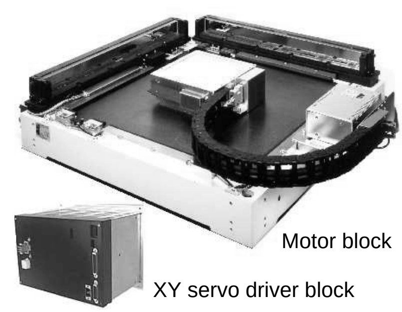

Figure 1 PLANESERV Planar Servomotor

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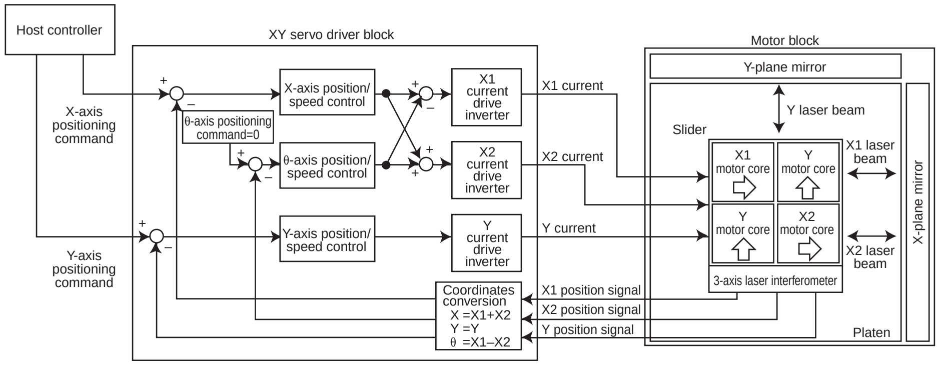

Figure 2 PLANESERV System Configuration

conventional model featuring the same stroke. The following shows other specifications.

Force: 100 N or more
Travel range: 500 × 500 mm or less
Max. velocity: 0.5 m/s
Load weight: 20 kg or less
Z-axis (vertical) pressing force:
50 kg (center of movable part) or less
Positioning resolution: 0.1 μm
Pressure of air supply for bearing: 0.2 MPa
Bearing stiffness: 100 N/μm or more

CONFIGURATION

Figure 2 shows the system configuration of the PLANESERV. It consists of the motor block and driver block. The motor block comprises a movable slider, a platen base, and two plane mirrors for the laser interferometer that senses positions. The driver block drives electrical current of the motor and controls the slider position according to the positioning command from a host controller. The slider comprises a planar motor and laser interferometer, and X1, X2 and Y motor cores are arranged symmetrically with respect to a point on the planar motor. X1 and X2 motor cores are connected to a different current drive inverter and feeding a current through them in the opposite direction to each other can generate rotation torque.

The 3-axis laser interferometer in the slider senses the X1, X2, and Y positions. The signal of each sensed position is transferred to the servo driver and converted into X, Y, and θ coordinates. The θ-axis angle is calculated from the difference between the X1 and X2 positions.

The servo driver controls the position and speed on the X, Y, and θ axes independently, and applies a non-interactive process to the X and θ axes when converting the position and speed signals into commands to be sent to the X1, X2, and Y current drive inverters. This allows the control gains for the X, Y, and θ axes to be set individually.

While the servo driver moves and positions the slider according to the positioning commands from the host controller for the X and Y axes, it must suppress an angle deflection to zero for the θ axis. If the angle deflection of a position exceeds ±0.1 degree, light reflected from the X- and Y-axis mirrors cannot return to the laser interferometer, and thus the position cannot be sensed. Thus the importance of θ-axis control is greater than that of X- and Y-axis control. The servo driver of the PLANESERV successfully reduces the angle deflection of the θ axis to 1/60 degree or less by employing the non-interactive 3-axis control technologies and the I-PD control technologies developed for the DYNASERV direct drive motor. Figure 3 shows the angle deflection on the θ axis for an 8-kg load decentered by 40 mm. We verified the control system using a simulator and confirmed that the simulation results agreed with the actual measured values.

THREE-AXIS LASER INTERFEROMETER

The PLANESERV makes light emitted from a single laser diode branch to realize a 3-axis laser interferometer. The semiconductor laser used has a steady wavelength. Table 1 shows the main specifications.

Figure 4 shows the configuration of the 3-axis laser interferometer for a single axis. The semiconductor laser beam is branched by means of a half mirror (HM) and then is passed through a polarizing beam splitter (PBS) and a quarter-wave (λ/4) plate, and then emitted from the slider. The emitted light is returned to the slider by reflecting it against a plane mirror fixed to the motor block, then made to travel back to the reflection

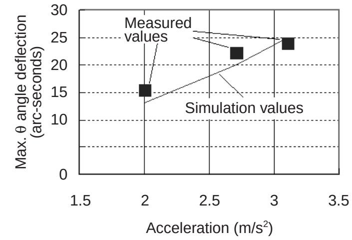

Figure 3 θ Angle Deflection for Eccentric Load

Table 1 Main Specifications of Semiconductor Laser

Wavelength	852 nm	typical
Beam output	5 mW	typical
Wavelength stability	2 pm	Actual results over 20,000 hours
Spectrum linewidth	1 MHz	Max.

mirror by reflecting it against a corner cube prism, where it finally forms interference fringes by combining with the reference beam. As the fringes make traversal movement when the slider travels, they are converted by a photo diode array (PDA) into electrical signals to sense displacement. The laser beam travels from the slider to the reflection mirror and back twice, which creates a single light and dark band or pitch at a displacement a quarter that of the laser beam's wavelength λ.

The PLANESERV modulates the output signals of the photo diode array with a 6-MHz sine wave and transfers them to the XY driver. The driver detects the signal phase using interpolation, thus achieving a superior resolution of 0.027 µm as well as allowing for a margin for the fluctuation of the laser signal strength.

Since the PLANESERV performs feedback control based on the interferometer signal, it loses control if the movable part deflects in the θ direction and thus prohibits the laser beam from returning to the interferometer. To avoid this, we optimized the optical parts, such as the lens, to allow the position to be sensed as long as the angle deflection is within ±0.1 degree even if the slider is placed farthest from the reflection mirror.

HIGH-ACCURACY, HIGH-SPEED INVERTER

The PLANESERV is friction free because it adopts an air bearing for static pressure. Therefore, only a slight amount of current flows when the slider stops. This means that the enhanced characteristics for controlling minimal current greatly reduce vibration inevitably generated during slider stoppage.

Normally, a current drive inverter requires a deadtime during which all the elements are turned off to avoid an instantaneous short circuit when electronically changing the current flow direction through the motor coil. The output voltage becomes unpredictable during the deadtime and thus may distort the current waveform over a very small area. With the PLANESERV, we developed a motor driver that improves response for minimal current by providing an output voltage feedback circuit. Consequently, the vibration for the slider stoppage was greatly reduced to ±0.1 µm or less.

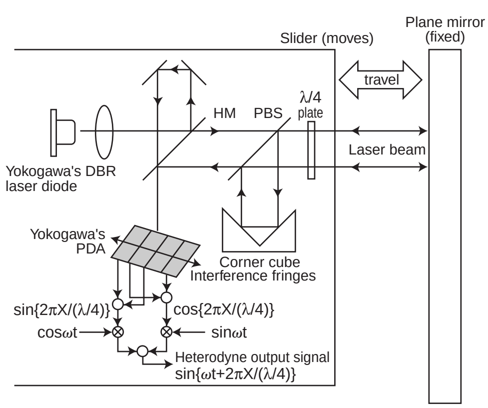

Figure 4 Structure of Laser Interferometer (Single Axis)

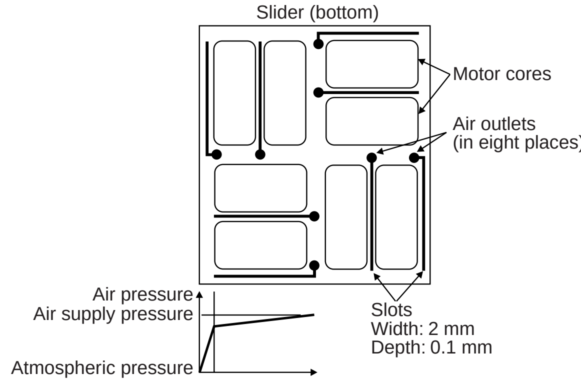

Figure 5 Structure of Air Bearing

AIR BEARING

The PLANESERV employs an air-bearing with slots in the slider. Figure 5 shows the structure of the air bearing and Figure 6 the bearing characteristics at an air supply pressure of 0.2 MPa. The air supplied for the slider is blown through the eight outlets and along the slots on the bottom of the slider. The slider stops moving at the point where a balance is created between the air-levitating force and the (1) the attraction force between the motor and platen caused by the permanent magnet; (2) slider weight; (3) load weight; and (4) vertical pressing force. As the attraction force between the motor and platen is approximately 2000 N, the bearing clearance of the PLANESERV is about 13 µm, which changes depending on the load weight and pressing force. The greater the bearing stiffness, the less the clearance changes. The PLANESERV has a bearing stiffness of 150 N/m, which is

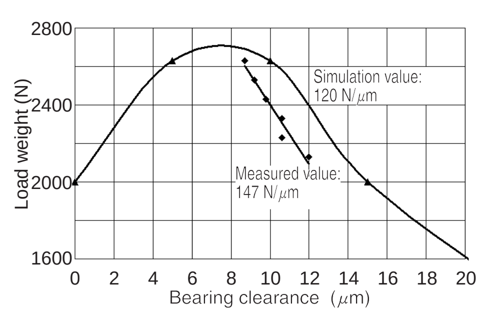

Figure 6 Characteristics of Air Bearing

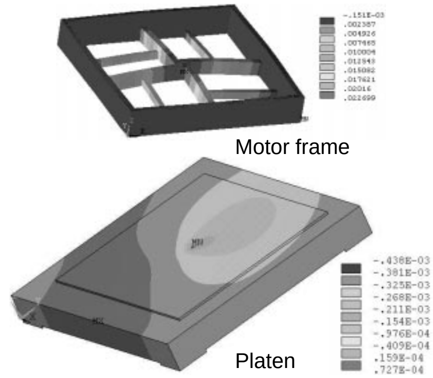

Figure 7 Analysis Results of Finite-element Method

sufficient compared to the mechanical rigidity of XY stacked-type stages.

STRUCTURAL ANALYSIS USING FINITE-ELEMENT METHOD

The effects of deformation of the slider or platen over which the slider travels cannot be ignored for positioning in the order of micrometers. Therefore, we optimized the structural design of each element by analyzing the stiffness of the slider, platen, and even the rack, using the finite-element method as we developed the PLANESERV. Figure 7 shows an example of the analysis results. The amount of deformation of the platen with a 20-kg load was calculated to be 3.7 μm during the simulation, compared to a measured value of 4 μm. As for the motor frame, 22 μm was obtained during the simulation, compared to a measured value of 22.5 μm. In both cases, the measured values and simulation values were extremely close.

OVERALL PERFORMANCE

Figure 8 shows the measurement results of the settling time at positioning. The PLANESERV provides a settling time of 15 ms for a ±1-μm width under the conditions of a 6-kg load, 10-mm travel, position control bandwidth of 40 Hz, and speed control bandwidth of 120 Hz. This has been reduced to a sixth of that of the conventional XY stacked-type stages whose settling time is at least 100 ms.

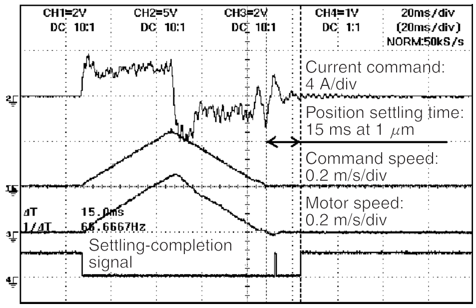

Figure 8 Settling Time of PLANESERV

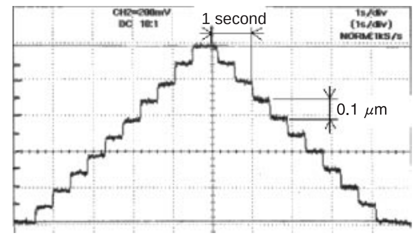

Figure 9 Response to Move Command in 0.1-μm Increments

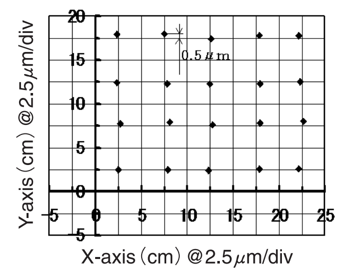

Figure10 Measurment Results of Linearity of Plane Division Positioning

Figure 9 shows the position waveform when the motor is sent command pulses to move in 0.1-μm increments. The minimal vibration generated during slider stoppage of the PLANESERV is less than that of conventional XY stages, leading to a positioning repeatability of ±0.1 μm. Figure 10 shows the results of measuring the linearity of the plane division positioning. A superior accuracy of ±1 μm or less can be obtained through calibration.

CONCLUSION

We have introduced the features and fundamental technologies of the PLANESERV. Shipments began in August 2000, and to further meet the needs of users we are now working on obtaining a higher thrust and longer stroke. ◆

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