

DEVELOPMENT OF AN ULTRA-PRECISE POSITIONING STAGE ENGAGED WITH GRATINGS

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1. Introduction

Nowadays, an ultra-precise positioning stage is an indispensable component of a precise machine tool, a measuring instrument or a semiconductor manufacturing equipment. The ultra-precise positioning stages requires not only mechanical performance of high stiffness, accurate guidance, and the minimum lost motion but also control performance of precise positioning, minute resolution, dependable repeatability, and smooth driving. Some integrated ultra-precise stages with a devised mechanism and an intelligent control system have been developed.¹⁾²⁾³⁾⁴⁾ One integrated stage consists of a ball screw, an air slider and a laser interferometer.¹⁾ Another stage is formed into a linear electric motor with a precise linear encoder.²⁾ Other stage composes an inchworm mechanism moving on a guide rail.³⁾ The last stage composes an inchworm mechanism travelling on a micro-pitch rack which pitch is 120 micrometer. However, the first stage is bulky because individual instruments are assembled without merging. If stiffness of the ball screw and the air slider should be more rigid and if measurement accuracy of the laser interferometer should be higher, those elements become bigger and heavier. The second stage is compact; yet a control system is complicated because the linear motor can not control the position without regulating of electric current accurately. Control system of the third stage is constructed easily because inchworm motion is accomplished by using an open-loop control system; still, the stage can not position every step without slipping even if driving plates grip on a guide rail tightly. The last stage has some advantages for the compact feature, the open-loop control system and the positioning without slipping; nevertheless, the minimum resolution of positioning is larger than 30 micrometer.

In this paper, we present a novel ultra-precise positioning stage in which two gratings engage with a ruler grating in an inchworm motion. The stage is accurately positioned every one pitch of a grating without feedback control system composed of a laser interferometer and a complicated control algorithm. The structure becomes compact and its table is positioned by the open-loop control system.

2. Structure of the ultra-precise positioning stage

The ultra-precise positioning stage is consists of a linear guide, a ruler rail, a linear slider and a drive

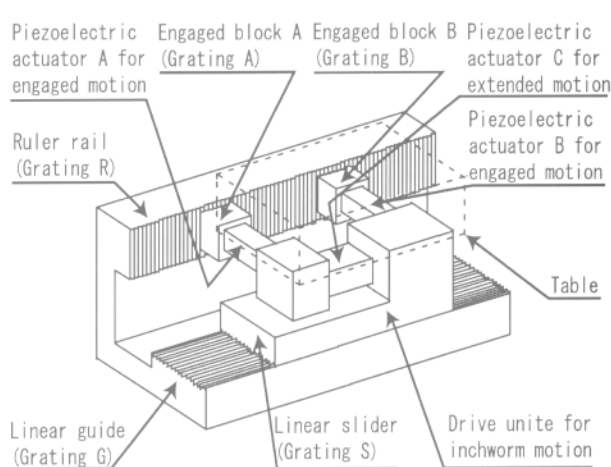


Figure 1. Structure of the ultra-precise stage

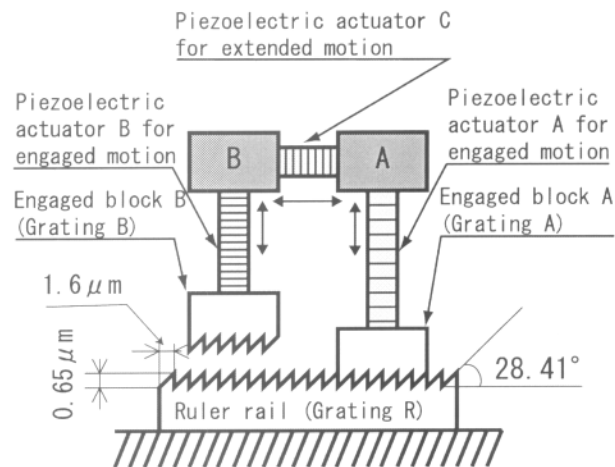


Figure 2. Inchworm mechanism

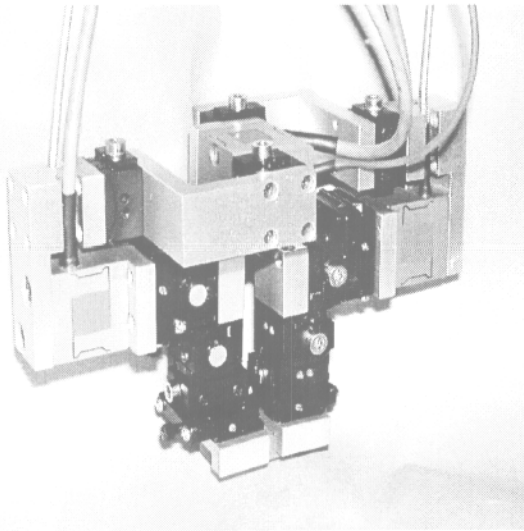


Figure 3. The drive units for inchworm motion

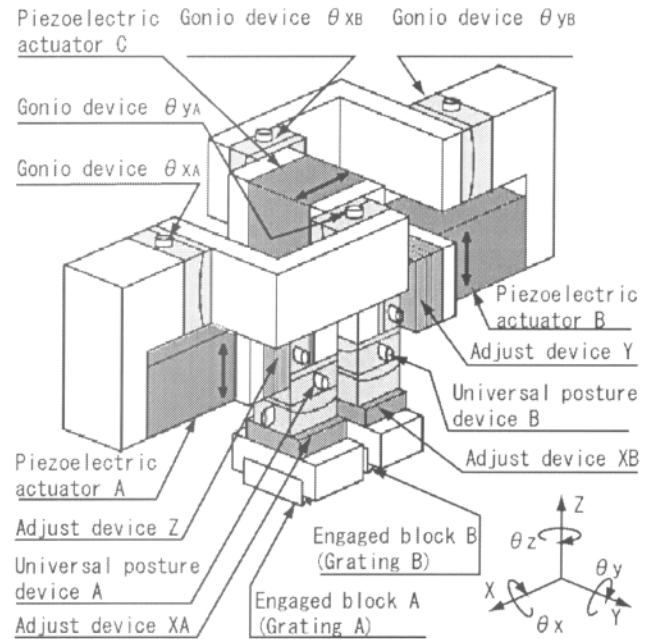


Figure 4. Structure of the drive units

unit for inchworm motion as shown in figure 1. The linear guide and the linear slider are gratings, and they compose an ultra-precise slide guide. The drive unit is consists of two engaged blocks and three piezoelectric actuators on the linear slider as shown figure 2. Two engaged blocks and the ruler rail are gratings, and both engaged blocks are meshed on the ruler rail step by step as shown in figure 2. The inchworm motion of the engaged block are generated by the piezoelectric actuators. As the pitch of gratings is usually about 1 micrometer, and depth of the grating is less than 1 micrometer, inchworm motion does not need any expander for displacement of the piezoelectric actuator. Thus the table is positioned at every one pitch of the grating.

The driving unit is shown in figure 3 and figure 4. The drive unite is consists of three piezoelectric actuator attached four gonio devices and two engaged blocks attached two universal posture devices and some adjust devices for x and z directions. The moved directions of those piezoelectric actuators are ultra-precisely adjusted by using four gonio devices, so two pairs of the piezoelectric actuator (C) for extend motion and the piezoelectric actuators (A or B) for engaged motion are perpendicularly moved each other. Both surfaces of the gratings are ultra-precisely adjusted into the same plane and both grooves of the gratings are adjusted in parallel by using the adjust device (Z) for z direction and two universal posture devices composed of three miniature gonio devices. The adjust devices (XA and XB) for x direction is used to adjust interval between both gratings into the distance multiplied pitch distance of grating by a certain integer. The adjust method for theses adjustment is appeared in the experimental result.

3. Experimental results

In the experiments, capacity of the gratings as a mechanical part was qualitatively measured, and an adjust method for the gratings of the engaged blocks was confirmed. Figure 5 showed the relationship between vertical cramping force and the maximum resisting force which acted into parallel direction against the grating grooves or acted into perpendicular direction against the grating grooves when the gratings were meshed with a certain vertical cramping force. In this figure, the maximum resisting force which acted into the parallel direction was proportional to the cramping force, and coefficient of static friction between the gratings was 0.31. The maximum resisting force which acted into the perpendicular direction without breaking the meshing was proportional to the vertical cramping force, and the maximum resisting force was approximately one and half of the minimum slide force.

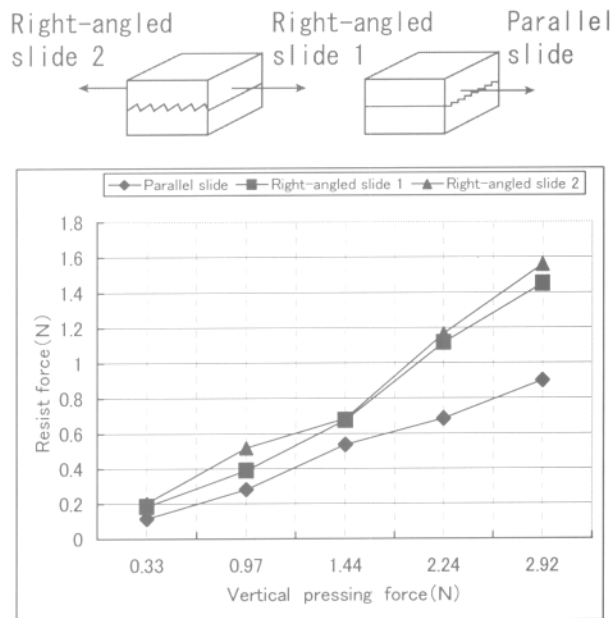


Figure 5. Experimental Result

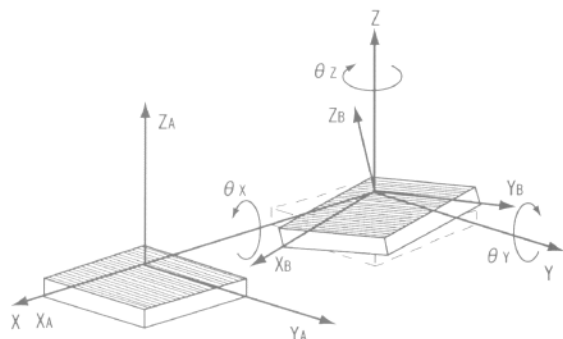


Figure 6. Coordinate frame of the gratings

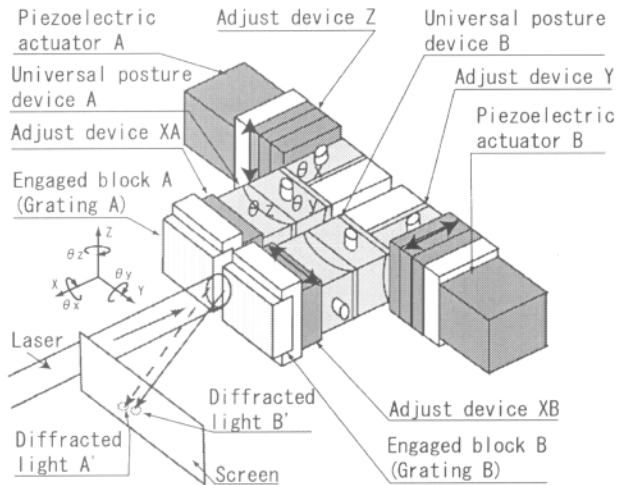


Figure 7. Experimental Equipment

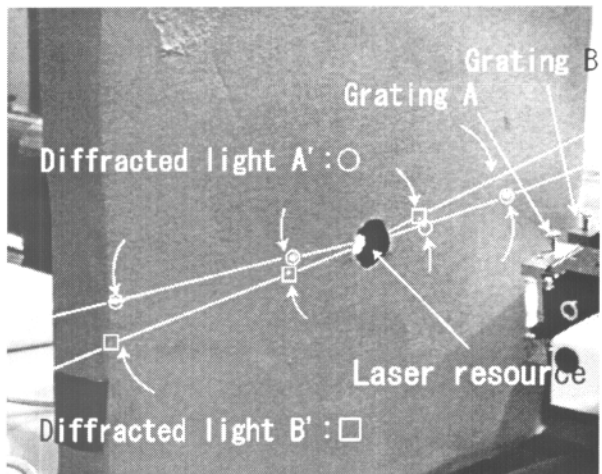


Figure 8. Adjustment result of θ_z

Figure 6 showed the coordinate frame of drive units for the inchworm motion and the engaged blocks (A and B). When the piezoelectric actuators for engaged motion move into the z direction and the piezoelectric actuator for extend motion move into the x direction, the grating of the engaged block (A) must be adjusted as its surface becomes parallel against x-y coordinate plain and its grating grooves become parallel against y coordinates axis. Moreover, the grating of the engaged block (B) must be adjusted as its surface is in the same plane in which another grating (a) is adjusted and its grating grooves become parallel against another grating grooves and also interval between both gratings becomes the distance multiplied pitch of grating by a certain integer. The grating of the engaged block has five degree of freedom in the adjustment. For this adjustment, diffracted lights is used as shown in figure 7. If the angle of θ_z is not regulated, a series of spots of the diffracted light B' crosses to a series of spots of diffracted light A' as shown in figure 8; therefore, an adjust screw of θ_z is regulated as both series of spots of the diffracted lights become parallel. If the angle of θ_x is not regulated, both series of spots of diffracted lights (B' and A') are separated in parallel as shown in figure 9; therefore, an adjust screw of θ_x is regulated as both series of spots of diffracted lights become the same line. If the position of z is not regulated, interval between each spot is not same as shown in figure 10; therefore, position z is regulated. If the angle of θ_y is not regulated, both spots of the diffracted lights dose not corresponded as shown in

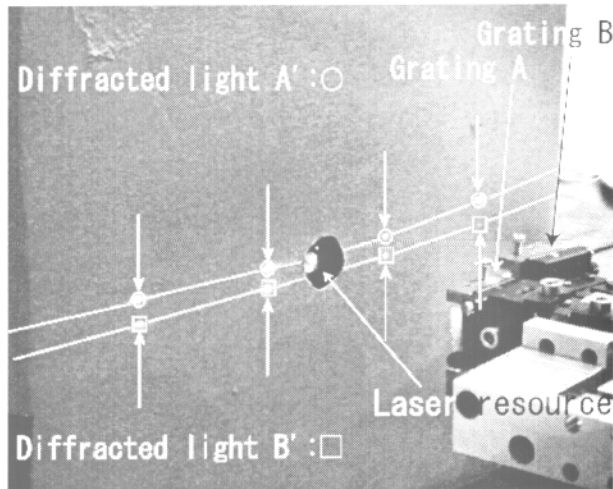


Figure 9. Adjustment result of θ_x

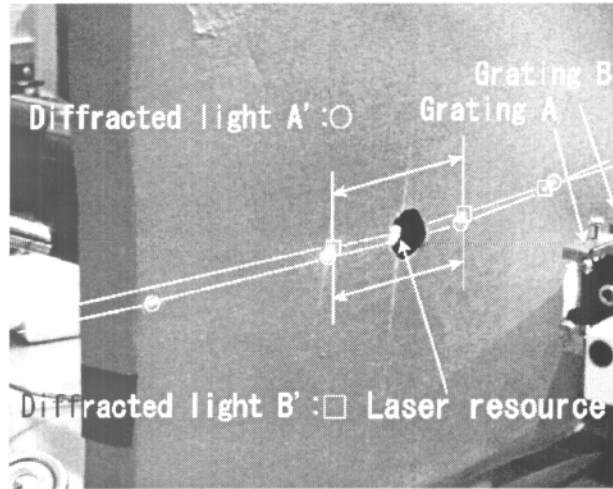


Figure 10. Adjustment result of x

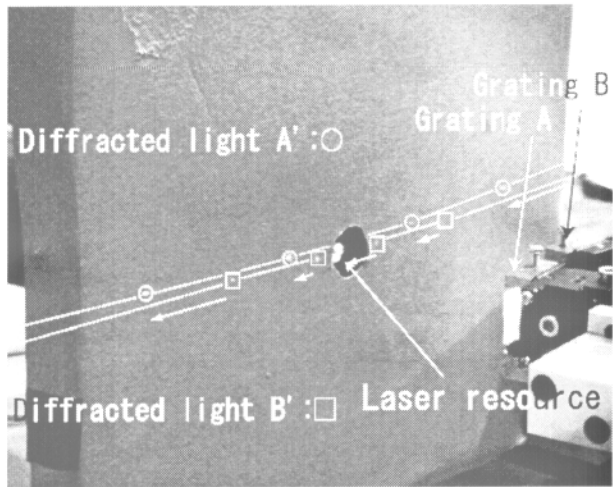


Figure 11 Adjustment result of θ_y

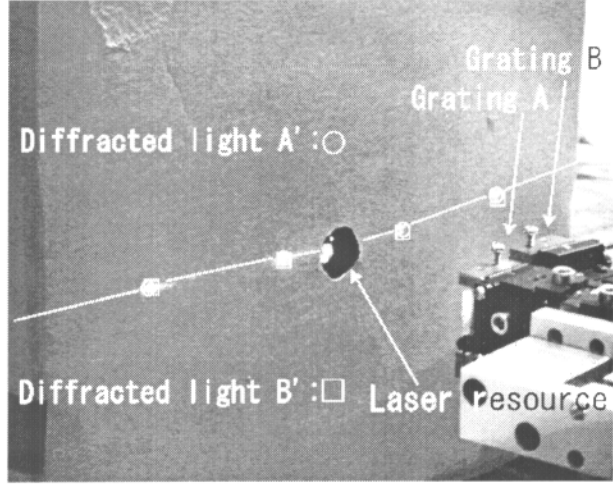


Figure 12. Final adjustment result

figure 11; therefore, an adjust screw of θ_y is regulated as both spots become same point. Figure 11 showed the final regulated spots.

4. Conclusions

Novel ultra-precise positioning stage engaged with gratings was developed. The stage can position at every one pitch of the grating by meshing the engaged blocks to the ruler rail of the grating. The pair of grating is meshed tightly as the mechanical parts and the upper gratings side into parallel direction against grating grooves. The engaged blocks of gratings are ultra-precisely adjusted into the same plain and into parallel grooves by using diffracted lights.

References

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