Precision Measurement of Rail Profiles in Aerostatic Stages

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Abstract

In this paper, we propose a measuring device and method for measurement of profile errors of the guide rails in aerostatic stages. The measuring device is similar to normal air bearing table equipped with several displacement sensors. Measurement principle is basically based on the sequential two point method. The rail profile errors are measured and measurement method is verified by comparing the linear motion errors of the measuring device.

1 Introduction

The 5-DOF motion errors of precision stages can be predicted from the rail profile errors [1]. From this simulation, we can estimate the motion errors before fabrication of the stages, and understand the effect of design parameters on the motion errors. The simulation results are verified from the experiment. Therefore, it is required to measure the rail profile errors accurately.

In this paper, we propose a measuring device and method for measurement of profile errors of the guide rails in aerostatic stages. Measurement principle is basically based on the sequential two point method [2,3]. The measuring device is similar to normal air bearing table which has four opposite air bearings in vertical direction, and two opposite air bearings in horizontal direction. At least three displacement sensors are installed inside the measuring device and a laser interferometer is also installed to compensate angular error between two abreast displacement sensors. Linear motion errors of the measuring device and parallelism errors between two rails can be also calculated. The rail profile errors are verified by comparing the linear motion errors of the measuring device.

2 Design of a measuring device

2.1 Measurement principle

Sequential two point method is basically used to measure the rail profile errors, as shown in Figure 1. A rail profile error $e_{h1}(x)$ and a linear motion error $\delta_h(x)$ of a measuring device are calculated from sensor A(output: $R_A(x)$), sensor B($R_B(x)$), and angular error $\theta_y(x)$. Displacement difference between two abreast sensors A and B, caused by angular error of a measuring device, is compensated (Equation (1)). Rail profile error $e_{h2}(x)$ is calculated from sensor C($R_C(x)$) and the linear motion error $\delta_h(x)$ of the device. On the other hand, the rail profile errors $e_{h1}(x)$, $e_{h2}(x)$, and the motion error $\delta_h(x)$ of the device can be calculated from sensor C, sensor D, and sensor A. Therefore, the rail profile errors are verified by comparing either the linear motion errors of the device or the rail profile errors which are calculated from different combination of sensors. In this paper, the linear motion errors are compared. It is great merits that parallelism errors and linear motion errors of a moving table as well as the rail profile errors can be measured without reference surface like straightness edge in this system.

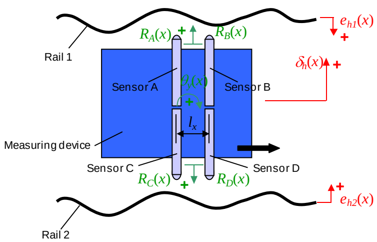

Figure 1: Measurement principle

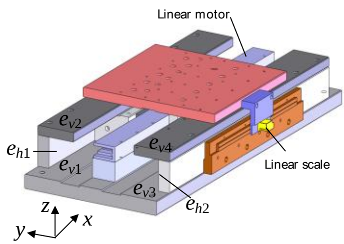

Figure 2: Air bearing stage

$$
\begin{aligned}
&R_A(x_i) = e_{h1}(x_i) + \delta_h(x_i),\ R_B(x_i) = e_{h1}(x_{i+1}) + \delta_h(x_i) - l_x \cdot \theta_y(x_i) \\
&R_A(x_{i+1}) = e_{h1}(x_{i+1}) + \delta_h(x_{i+1}),\ R_B(x_{i+1}) = e_{h1}(x_{i+2}) + \delta_h(x_{i+1}) - l_x \cdot \theta_y(x_{i+1}) \\
&e_{h1}(x_{i+1}) = e_{h1}(x_i) + R_B(x_i) - R_A(x_i) + l_x \cdot \theta_y(x_i) \\
&\delta_h(x_{i+1}) = \delta_h(x_i) + R_A(x_{i+1}) - R_B(x_i) - l_x \cdot \theta_y(x_i) \\
&e_{h2}(x_i) = R_C(x_i) + \delta_h(x_i),\ e_{h1}(x_0) = \delta_h(x_0) = 0
\end{aligned} \tag{1}
$$

2.2 Desing and fabrication of a measuring device

Figure 2 shows an air bearing stage which rail profile errors should be measured. The shape of each rail is like '⊏'. The proposed measuring device is like normal porous air bearing table as shown in Figure 3, and it has several displacement sensors to measure the rail profile errors using the sequential two point method. And a laser interferometer is used to measure angular error between two abreast displacement sensors. A direct drive rotary motor and a wire rope system are used to move the device with constant speed.

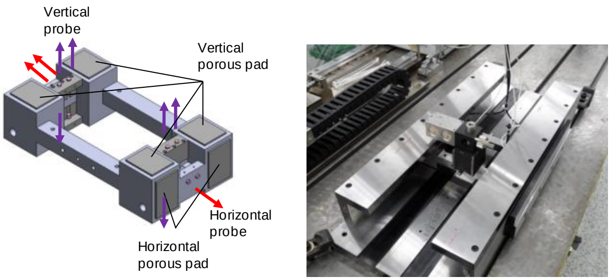

Figure 3: Measuring device for measurement of rail profile errors

3 Experiments

Figure 4 shows the rail profile errors measured in horizontal direction. These profile errors are drawn after the elimination of slope. $e_{h1}(x)$ and $e_{h2}(x)$ are profile errors in left and right rail surfaces as shown in Figure 2. Linear motion error (horizontal straightness error) of a moving table can be calculated from either sensor A, B or sensor C, D with angular error (yaw error). δ_{h1} is a motion error that calculated from sensor A and B. δ_{h2} is a motion error calculated from sensor C and D. The two motion errors are very similar each other as shown in Figure 5, which proves validity of the measurement method.

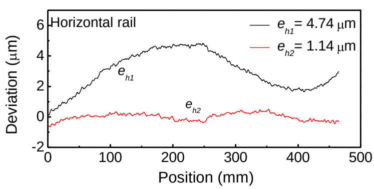

Figure 4: Horizontal rail profile errors

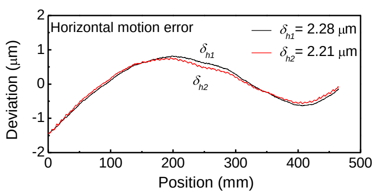

Figure 5: Motion errors of a moving table

Figure 6 shows parallelism error between two horizontal rails. This is difference between two horizontal rail profiles before the elimination of slope.

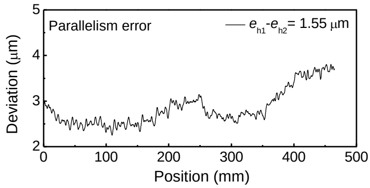

Figure 6: Parallelism error between horizontal rails

Figure 7 shows the rail profile errors measured in vertical direction. Measurement method is the same as one of the horizontal rail. $e_{v1}(x)$ and $e_{v2}(x)$ are lower and upper profile errors in left rail, and $e_{v3}(x)$ and $e_{v4}(x)$ are lower and upper profile errors in right rail, as shown in Figure 2.

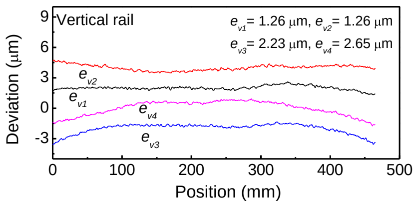

Figure 7: Vertical rail profile errors

4 Conclusions

In this paper, we propose a measuring device and method for measurement of profile errors of the guide rails in aerostatic stages. The rail profile errors are measured and verified.

References:

[1] Khim, G., Park, C. H., and Oh, J. S., “Estimation of 5 DOF Motion Errors in Linear Motion Bearing Stage,” Proc. of the 11th euspen Int. Conf., Vol. pp. 359-362, 2011.

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