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A surface shape test method for a thin flat mirror

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ABSTRACT

An optical test method of the surface shape for very thin flat mirrors is presented and discussed. The effect of gravity on the mirror shape is greatly reduced by floating the mirror on water while the surface is measured using a Zygo interferometer. The floating mirror is supported by the buoyant force and surface tension. Mechanical analysis and error analysis show that the tested flat mirror can be considered as a rim supported mirror with a reduced gravity. The surface error caused by the rim constraint can be rather small because of the reduced effective gravity. The surface error of a flat mirror which is Φ102 mm, 0.6 mm thick was tested using this method. The results were compared to the method successfully used for the Hinode project. The Hinode method supports the mirror at three points and measures the surface for both the mirror facing up and facing down. The average of the face up and face down measurements yields the zero gravity shape. The test results including the surface error and the fringe of the surface shape by these two methods were in good agreement. Compared to the Hinode method, the method can be carried on before the mirror's coating and can to be employed during the polishing process.

Measuring the surface error for a zero-gravity mirror on the ground with gravity is important especially for large aperture mirrors and thin mirrors not only for space based optical systems but also for large ground based optical systems.

Metrology mounts [1] frequently strive to simulate a zero-gravity environment. Many metrology mounts were developed, such as the 36-point pneumatic metrology mount [2], the 27-point hydraulic metrology mount [3], the 52-point spring matrix metrology mount [4], and so on. A problem with these methods is that it is hard to determine the support forces for the mirror, because it is hard to know the exact mass distribution of the mirror precisely. Support forces have to be determined assuming an ideal uniform density mirror first and the errors analyzed after the measurement [5].

To assemble and test the Hinode [6] space telescope, Suematsu et al. [7] employed a method to test its Solar Optical Telescope. They tested the telescope twice while the mirror was facing up and down respectively which stand for 1 g and −1 g gravitation, then averaged them together, so they achieved the result of the wave front error under 0 g gravitation condition. The perfect images from the Hinode telescope in space verified the correctness of the method. But it is not convenient for the large optical system because of the necessity of making measurements in two different mirror orientations.

Gu Wei et al. patented a method [8] to test weight deflection of a mirror which measures the different wave fronts for a mirror submerged in different depths of a heavy liquid and calculating the weight deflection for the different floating depths.

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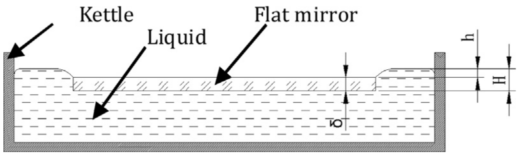

Fig. 1. Flat mirror floating on the liquid.

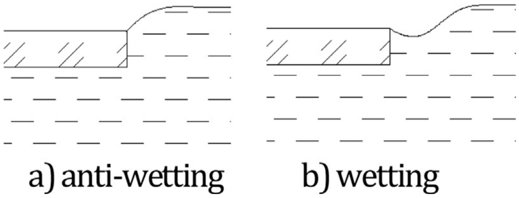

Fig. 2. Contact boundary between the liquid and the mirror.

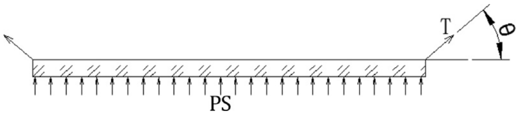

Fig. 3. The forces applied to the flat by water.

He assumed that the liquid could remove the gravity effect, but indeed it could not. Liquid can just apply a pressure force to the bottom of the mirror, and at the same time, the error of sinking depth can also change the surface shape of the mirror.

In this article, a method is presented and discussed about how to test a thin mirror's zero-gravity surface error on the ground. And as an example, a thin mirror [9] with a thickness is 0.56 mm and diameter of101.48 mm, was tested. It was a fused silica plate, with a mass of 10.9 g.

Surface tension [10] and the anti-wetting phenomenon allows, the mirror to float on water. A mechanical analysis of the floating mirror reveals that the gravity effect on the mirror surface is small and can be corrected using FEA calculations. A Zygo interferometer was used to measure the surface shape.

The results of the floating mirror measurements were compared to measurements done using the Hinode's method. In that method, the surface error was tested by two statuses of the mirror: facing up and facing down. The average of the result of facing up and the result of facing down, was the zero-gravity result of the mirror. The difference of them was the twice of the gravity effect. It was calculated by the finite element method (FEM).

The two sides of very thin flat mirrors are usually polished to be parallel in order to improve the precision of the surface shape. The parallel surfaces make it hard to use interferometric methods to measure the surface shape before coating. The reflection of the bottom surface contacting the liquid will be reduce the reflection from the bottom surface making it easier to measure the top surface before coating.

1. Concept

We have the experience that coins with density that is greater than water can afloat on the water. A flat mirror is thin enough can also float on water or other liquids supported surface tension and anti-wetting phenomenon. Fig. 1 shows a flat mirror floating on the water in a glass dish. The anti-wetting phenomenon makes the water near the mirror rim curve, and the water that is pushed away by the mirror is more than the volume of the mirror, so it can float the mirror whose density is greater than the water. In addition the rim of the mirror is the boundary between the solid and the liquid, and there a surface tension force at the rim of the mirror. The vertical component of the surface tension can also help to support against the force of gravity. The forces making the mirror float are the water pressure under the mirror and the vertical component of the surface tension. The surface tension between the water and the flat mirror makes the water level higher than the mirror. Though the density of the mirror is larger than that of the water, the mirror does not sink.

Fig. 2 is and enlarged view at the contact boundary between the liquids and the mirror rim. If mirror liquid interaction is anti-wetting the curve of the liquid is a bulge, and the surface tension is upward. Conversely, if the interaction is wetting between then the liquid and the mirror the curve is concave, which means that the surface tension will drag the mirror into the liquid. The actual curve of the liquid surface maybe very complicated for the wetting or anti-wetting interaction between the liquid and mirror, but the forces can be simplified as that shown in Fig. 3.

Shown in Fig. 3, the forces applied to the mirror by the water are the surface tension noted as T, and the floating force which is a distributed force that can be expressed by PS, which P is the pressure, and S is the area of the mirror. The direction of the surface tension T is inclined an angle of θ, while the floating force is vertical upward.