論文の内容の要旨

Nanometer Profile Measurement Methods of Large Aspheric Optical Surface

（大型非球面光学形状のナノメートル計測手法に関する研究）

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Large aspheric optical surfaces are widely used for huge telescopes and X-ray facilities. The accuracy of these surfaces is usually less than hundreds of nanometers. However, there are challenges on profile measurement with high uncertainty less than tens of nanometers, which is essential for manufacturing. Interferometric methods are widely used when measuring optical flat and spherical surfaces because of their high efficiency and high accuracy. However, if the designed surface is not known before the measurement or the departure from perfect spherical surface is too large, this kind of method does not work.

In this dissertation, I proposed new measurement methods based on deflectometry to enlarge the measuring range of the scanning deflectometry method. The measurement targets are aspheric optical surfaces with diameters more than 300 mm and angle change more than 10 arc degrees. The measurement uncertainty is aimed to be less than 100 nm. To achieve this objective, I have done theoretical error analysis and experiments to verify the basic principle and accuracy of my proposed methods. In this dissertation the following works are done.

1. Proposal of new measurement methods

A new method based on scanning deflectometry is proposed to measure large aspheric optical surface. Rotation devices are introduced into the transmission module so that the angle measuring range of the deflectomery method can be enlarged. Methods are proposed to improve the measurement accuracy of rotation angle. The pitching angle solutions are also proposed. The data processing methods including angle connection method and numerical integration method are proposed to calculate the raw angle to get the profile of measured surface. Furthermore, least square method is applied to define the slope standard of two-dimension profile data.

2. Error analysis

We conduct error analysis to estimate the measurement uncertainty of our proposed method. The random error analysis and systematic error analysis is done separately. In the random error analysis, we first listed all the error factors that may affect the detected angle data. Then by error calculation equation, the key error factors are found. Then we can know a simplified raw angle error function. Then by using uncertainty propagation method, a simulation system is built to see how the raw angle error propagates to the final profile error. The key factors then analyzed with the simulation system and the error curve of them is obtained. The systematic error analysis is also done. Relative position are considered cause systematic error to the final profile data. The environment is also considered make big contribution to the systematic error.

3. Two-dimension measurement experiments

Two-dimension Experimental setup is designed for the principle verification. The measurement object in this experiment is not large aspheric surfaces but spherical concave mirrors with diameter of 50 mm instead. A small laser autocollimator, equipped with photo diode as the sensing device, is used as an angle sensor. Experimental setup with Two-mirror reflection method is built first. Experiments are done to see the elimination effect of pitching angle of linear stage. From the experiment result we found that less precision rotation stage causes measurement failure. Then precision stages are applied to make improvement. With the improved experimental setup, concave mirror is measured successfully and high repeatability is also achieved. However, big systematic error is detected from the measurement result. To solve this problem we have proposed several methods after further investigation.

4. Three-dimension experimental setup and measurement process design

Using pitching angle pre-measurement method, we designed and assembled a three-dimension experimental setup based on the two-dimension measurement devices. The available of Because of the translation distance limit of the of the translation stage, the experimental setup is also suitable for normal size mirror with less than 200 millimeters in diameter. The second translation is done by rotary stage under the sample surface. So the surface under measurement should be rotational symmetric surface. At last, the measurement process is designed.

From the research result in this dissertation, it is proved that my proposed methods are able to measure profile of large aspheric optical surfaces with uncertainty less than 100 nm with less dependence on the motion accuracy of translation stages. Experimental result proved the basic principle of my proposed methods. High repeatability less than 20 nm is achieved by using common accuracy translation stages and common accuracy angle sensor. The main systematic error factors are found by experiments and solutions are proposed. As a result, my research is considered to be strong support to the development of large prototype measuring machine with our proposed methods in future.