New deflectometry measurement system for a wide variety of sphere and asphere figures

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Abstract
A high accurate figure measurement system without a reference optic has been required. Nikon has developed a new deflectometry measurement system "PSM (Precision Slope Master)". Our goal is to achieve single nm accuracy with the PSM for a wide variety of sphere and asphere figures. In deflectometry field, a high accurate auto collimator is commonly used as an angle sensor. This is the reason why measurement targets for deflectometry have been confined to flat and large curvature radius mirrors. To expand deflectometry’s targets, we have developed a new angle sensor for the PSM. Due to the new sensor, the PSM makes measurements of small curvature radius lenses and mirrors possible. There is one more issue for measuring small curvature radius optics with the PSM. The issue is a precise measurement of distance and angle between the sensor and a sample. To overcome the issue, the PSM adopts a metrology loop system designed specially. The metrology loop system was constructed from several sensors and a special metrology frame. The metrology frame was designed to avoid any deformation from environmental temperature change and stage positions change. We have evaluated the repeatability by using sphere and asphere samples. The results of repeatability indicated their variation within single nm in RMS. From these evaluations, we concluded that the PSM has the possibility to achieve single nm accurate measurements. The PSM has a potential of being a useful tool for measuring high accurate optics.

Keywords
Measurement, Deflectometry, Asphere, Sphere, Lens, Mirror, Figure, Form, Profile, Accurate, Precise, Mould

1. Introduction
A very high accurate measurement is all time demanded. Many types of measurement device are developed. Variety of interferometers and a coordinate measuring machine (CMM) will be a most popular method for measuring sphere and asphere figure, but it is difficult to achieve single nm accurate measurement [1]. For example, an interferometer indicates very high repeatability in measurements. All of other measurement device doesn’t achieve same level repeatability. However measured figure is the deference from reference optics. So measured accuracy depends on reference’s figure. Off course, many types’ calibration methods are developed and improved. In the other hand, CMM doesn’t need reference optics for measurement. But it is difficult to achieve single nm accuracy in wide variety of sphere and asphere optics.

As a new measuring method, deflectometry systems have actively developed. In the X-ray mirror field, Nanometer Optical Component Measuring Machine (NOM) at Helmholtz Zentrum Berlin (HZB)/BESSY-II indicates very good accuracy [2]. However measurable target figure is restricted. Especially radius of curvature is one of the issues for deflectometry measurement. To overcome strict limitation for curvature, Nanoprofiler used focused beam to measure sphere and asphere figure [3],[4]. And to achieve more accurate measurement and more realize wide variety of sphere and asphere, Nikon has developed a new deflectometry measurement system "PSM (Precision Slope Master)".

2. Measurement principle
PSM calculate figure profile from angle data. With scanning along with measured sample, the sensor takes the angle data of measured sample at each point. And this time, several sensors take data with same timing to compensate measured angle profile data. All of the data is used to construct measured sample’s angle profile. From this angle profile, PSM calculate measured samples figure by using integration. Above sequence make one line profile. And rotate measured sample by rotary stage, it is possible to take one more profile. By repeating this sequence, diameter direction’s profile data set is taken. From data set, PSM calculates 3D figure profile. Several calculation methods are used for PSM. In this report data, we used Zernike polynomials fitting to calculate 3D figure profile.

Figure 1. Scanning image of sensor and integration calculation and system specifications
3. Sensor and Metrology loop system

3.1. Sensors

In general, deflectometry has difficulty for small radius curvature’s sample measurement. Because high accurate auto-collimator is used as an angle sensor. It has high accuracy for flat mirror or large radius mirror, however small radius mirror measurement is not good target.

To achieve high accurate measurement and wide variety targets, we have developed a new angle sensor for PSM. We designed focused beam sensor system for variety targets. This sensor make measure small radius curvature sample possible. As a principle, each sensor detects reflected light position by Detector. Angle sensor changes position to angle and Length sensor changes positon to length. And more we have combined length sensor into angle sensor. It would be possible to take angle and position difference between sensor and sample. This data is used for compensation for angle measured data.

Figure 2. Angle and length sensor is combined as a main sensor

3.2. Metrology loop system

One more issue to measure small radius sample is a precise measurement of distance and angle between the sensor and a sample. To overcome the issue, we specially designed the metrology loop system. The metrology loop system was constructed from several sensors and a special metrology frame. Sensors measure distance and angle between the sensor and a sample. All of sensors need high stability for the measured time. The metrology frame was designed to avoid any deformation from environmental temperature change and stage positions change. Before construct mechanical system, we simulated the most stable frame’s figure and material (fig.3). In estimation, deformation value from thermal and stage positions change indicate lower than 5nm. And after making frame, we checked frame’s mode of vibration. From estimate data we set controlled weights on the frame to compensate vibration.

In the figure 4, one of the position sensor measured main angle sensor from metrology frame and interferometer measure stage mirror on optical table form metrology frame and one more position sensor measured rotary stage position optical table. These 3 sensors construct 1 metrology loop. Each sensor data is set on high stability frame. By this loop, relative position and angle between sensor and measured sample is guaranteed and compensated.

Figure 3. Deformation calculation of stage position change and thermal deformation analysis

4. Evaluation

As an evaluation, we measured sphere sample. Measured diameter is 96mm. Radius of couverture is 173mm. We evaluate repeatability data set. From continuous 5 measurements, we calculate average data. And subtract average data from each 5 data. These 5 data is defined as a repeatability data. This evaluation method will be possible to evaluate single measurement’s variation well. Minimum value of 5 set repeatability were 1.6 nm in PV and maximum value was 2.6 nm in PV. From this evaluation, we conclude that PSM has the possibility to achieve single nm accuracy.

Figure 4. Metrology frame and metrology loop

Figure 5. Repeatability evaluation results

These data is fitted Zernike polynomials. Lower than 10th order Equation is used.

5. Conclusion

For a wide variety of sphere and asphere measurement, the new system PSM is reported. Sensors and metrology loop system make precise measurement possible. From repeatability evaluation, repeatability indicated 1.6 to 2.6 nm in PV. From this data, we concluded that the PSM has the possibility to achieve single nm accurate measurements. However to guarantee accuracy we must measure sample which is measured another high accurate measuring systems. And we need more estimations and error budget from PSM’s fundamental data. And finally we think round robin test with any type’s measurement systems will be best way to evaluate.

References