

博士論文（要約）

Development of the Multi-Profile Measuring Machine Using Multi-Beam Angle Sensor
(マルチビーム角度センサを用いたマルチ形状測定機の開発)

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With recent development in miniaturization and modularization of microsystem manufacturing, demand for improving the manufacture efficiencies of small size products with high accuracy has increased dramatically. As a result, it has become increasingly to concern with the surface metrology, like flatness measurement, roundness measurement and cylindricity measurement, also is becoming even more obvious now that nano and microstructures with uncertainties within $0.1\text{ }\mu\text{m}$. A question often asked is whether these geometrical features could be assessed by the same sensor with high precision.

In this dissertation, a multi-beam angle sensor (MBAS) has been proposed and discussed to meet effective high-precision measurement technique for multiple measuring profiles.

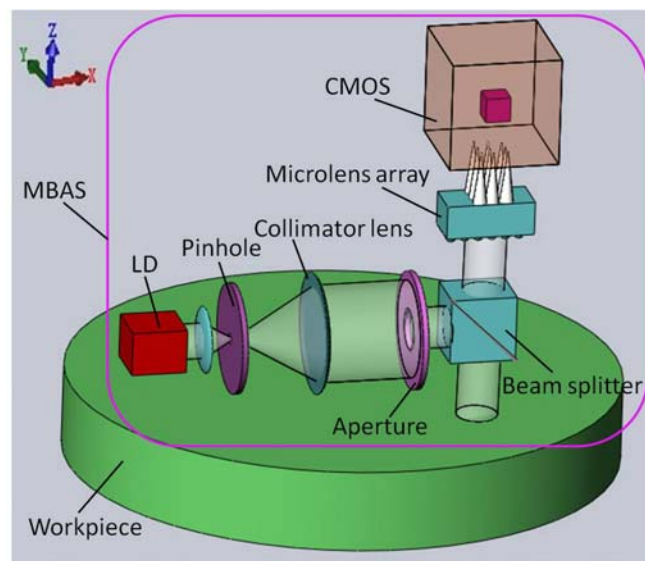


Figure 1 Construction of the MBAS

Figure 1 illustrates the construction of the MBAS. A laser beam passes through a pinhole and is collimated by a collimator lens. The beam is then bent by a beam splitter and projected through the workpiece surface. The reflected beam from the workpiece surface passes through the beam splitter and is focused on a microlens array, which divides the beams into several beams. The resulting pattern is observed and recorded by a CMOS camera mounted along the vertical axis. The image can be observed on a TV monitor. Further processing of the pattern is performed using a PC.

The summary of the thesis are shown as follows:

(1) The principle and data processing technique of MBAS were addressed for multiple measuring profiles.

(2) The performances of MBAS of configurations for flatness measurement evaluated by simulating the measurement

➤ From the simulation results, the MBAS can easily achieve the estimated measurement

uncertainty of nanometer order with specified parameter settings.

➤ Under similar experimental conditions, the standard deviation of repeatability is proportional to the random value. The simulation result implies that this system can measure roundness with nanometer order repeatability if the random angle error is less enough. Therefore, a further improvement of measurement accuracy could be achieved by reducing the random error of MBAS.

(3) How to choose the suitable data processing method in the processing of measured information to enable it to be used most effectively for design purposes has been discussed.

In order to develop a multi-beam angle sensor designed to measure the profile of the mirror, cylinder and cylinder lens, two significant factors should be considered. One is matching a proper probe system; the other is choosing the proper data processing method in the processing of measured information to enable it to be used most effectively for design purposes. According to the measuring range, choose proper measuring principle and the utilization number of the multi-beams) and choose the proper data processing method (calculate the profile from the curvature or slope) in the processing of measured information to enable it to be used most effectively for design purposes (high precision or high speed). Because the final purpose of the MBAS development project is to meet effective high-precision measurement technique for multiple measuring profiles, not only for flatness, roundness, but also for aspheric surface (as shown in figure 1). To achieve these requirements, the following processes should be performed following the requirement as shown in table 1.

Table 1 Specifications of data processing

Measuring range	Utilization of multi-beam	Precision	Speed
Wide	2	High	Normal
Narrow	Dozens	Normal	High

➤ For the wide range measurement (with high precision), I circumvent the problem of the zero-difference error by the circumferential scan technique. The profile can be denoted as a Fourier series by using an inverse Fourier transform. The characteristics of the algorithm can be estimated from its transfer function, which defines the relationship between the angle difference and the profile data.

➤ For the narrow range measurement (with high speed), I circumvent the problem of the zero-difference error by calibrating the MBAS with the aid of the tilt-stage to ensure the motion move step by step. The conversion of the angle is computed by comparison to a predetermined surface location (by measuring a flat mirror). After conversing angle from the position of the spots, the mathematical algorithm (shown in Chapter 4) is applied to a line integral along a path

through the measurement grid (i.e. a line integral along each path parallel to one of the coordinate lines), the 3D topography can be reconstructed, namely angle-stitched method.

(4) The pre-experiments of flatness measurement machine (FMM) of the configuration of multi-beam angle sensor have been conducted to measure the mirror and plastic plate.

- The MBAS can reduce of the influence of the zero-difference error and the automatic eliminate of the influence of the tilt error that is caused by the rotation of the workpiece.

- The stability results from the pre-experiments verified that MBAS performed the measurement extremely well.

- Confirm the feasibility of MBAS for flatness measurement as compared with CMM to measure the same specimen (plastic).

- Moreover, the MBAS can also measure the mirror profile with a small standard deviation of nanometer order.

(5) The pre-experiments of roundness measurement machine (RMM) of the configuration of multi-beam angle sensor have been conducted to measure cylinder.

- From the experiment results, the worst error under nanometer that is appropriate to the result between the profile measured by MBAS and Radius method (EC3400).

- Under similar experimental conditions, the standard deviation of repeatability is proportional to the random value. The simulation result implies that this system can measure roundness with repeatability under several nanometers if the random angle error is less than 0.8 μ rad. Therefore, a further improvement of measurement accuracy could be achieved by reducing the random error of MBAS.

- The repeatability of the measurement is several nanometers.

(6) The optical devices arrangement of MBAS have been designed and built to measure aspheric surface.

- An application of multi-beam angle sensor (MBAS) for high precision three dimensional surface profile measurement of aspheric surface has constructed.

- In the wide range, the MBAS can eliminate zero-difference error by circumferential scan and automatically eliminates the tilt error caused by the rotation of a workpiece. Using the tracking technique, the MBAS can automatic determine the position of the focal spots from the centroid measurement of light intensity, which is directly related to the accuracy of the angle measurement.

- In the narrow range, based on tracking technique, I have developed an angle stitching technique which can reconstruct the profile in the X and Y direction, and calculate the 3D topography of the measured surface. The MBAS was designed to address curvature-range and accuracy problem by using circumferential scan, tracking and angle-stitched technique. The experimental results confirming the feasibility of the multi-beam angle sensor for three

dimensional surface profile measurement of cylindrical plano-convex lens.

(7) The calibration for the sensitivity of multi-beam angle sensor using cylindrical plano-convex lens

➤ For the determination of the sensitivity of MBAS, two independent calibration methods can be applied using plane mirror and cylindrical plano-convex lens has been proposed to measure the sensitivity of the MBAS. Comparison of the two methods confirms that the second method (using cylindrical plano-convex lens) is more adapted for measurement with ultra high level of uncertainty. Further, the second method is simple, corresponding to a direct calculate in the sensitive parameters aiming to minimize the cost.

Throughout the whole dissertation, the advantages and disadvantages of the MBAS can be concluded as follows:

(1) Advantages:

- Measuring multiple profile with proper measuring method and data processing;
- An effective high-accuracy measurement sensor which is less susceptible to spindle error;
- The repeatability of the measurement is around 10 nm;
- Calibration the sensor with a simple and ultra high level of uncertainty;
- Small size and low cost without employing high-accuracy reference reflector;
- Reconstructing three dimensional surface profiles with high speed and a simple way.

(2) Disadvantages:

- Time consuming process for data analyst;
- Curvature-range limitation in the circumferential scan technique (in wide range);
- Accuracy limitation in the 3D surface profiles reconstruction (in narrow range);

To improve these disadvantages, the following suggestions have been proposed:

- (1) Use high precision calibration to eliminate the non-linearity error;
- (2) Find a proper method to evaluate accuracy of measurement using the MBAS;
- (3) Improve the measurement precision.