Precision flatness measurement by an optical multi-beam angle sensor  
(1st Report)  
Experimental verification of flatness measurement  
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In this study, we describe a new technique using multi-beam angle sensor to measure flatness of the mirror. The flatness measuring machine (FMM) uses only one sensor and is less susceptible to instrumental errors, severe conditions of stress, temperature and in hostile environments. The ability quickly and accurately to measure flatness on the shop floor as well as in the inspection department gives us a distinct advantage over other techniques. The experimental results demonstrating the feasibility of the MBAS for flatness measurement are also presented.

Keywords: FMM, Multi-Beam Angle Sensor, Flatness, Metrology, Stage-independence

1. Introduction
Flatness is a critically important element in development of precision-tolerance capabilities. Because flat surface acts as reference surface for the inspection other workpieces. There are variety ways to assess the flatness of a surface. One of the oldest ways is to sweep the test surface in several places with a straight-edge and observe where and how much light leaks through. Other techniques of measuring flatness such as the coordinating-measuring machines (CMM), which is dependent on the spindle error exhibiting good repeatability during measurement cycle. Additional method of measuring flatness is the use of optical interferometric. In addition to the technique discussed above, there is another one in flatness measurement called autocollimators, levels and curvature devices as previously used in straightness measurement, have their attendant problems of noise generation[1].
In order to overcome some problems associated with the methods mentioned above, a method based on autocollimator principle using multi-beam angle sensor is proposed in this paper. The flatness measuring machine uses only one sensor and is less susceptible to instrumental errors, severe conditions of stress, temperature and in hostile environments. It is capable of evaluating the flatness on the shop floor as well as in the inspection department at high speed and at the nanometer level.

2. Principle of the FMM
The FMM configuration includes three main parts: an MBAS, a rotary unit, and a bearing system. The MBAS is based on a multi-autocollimator system using a microlens array.
Using the MBAS, we designed the experimental system shown in Fig. 1. A mirror is mounted on a tilt stage, and a rotary platform is mounted between two XY-platforms. For flatness measurement, the mirror is rotated by the rotary platform. Here, the axis of rotation of the workpiece spindle is represented by the Z-axis. In any flatness measuring instrument, the spindle of a rotary stage is the most important component in its assembly. Here, when the mirror is assembled, it is necessary to align the Z-axis and the axis of the rotary platform to be collinear, also align the Z-axis and the projected beam on the mirror to be parallel. The alignment is performed by adjusting the positions of the two XY-platforms.
Along with the upper XY-platform, which is used to achieve minimal spindle error between the workpiece and rotary stage, the lower one is used to approach an almost perfect position between the MBAS and rotary stage. Here, we use the tilt stage to align the Z-axis and the projected beam on the mirror to be parallel.

Figure 2 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 directly to the mirror surface. The reflected beam 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. Further processing of the pattern is performed using a PC.
To measure flatness errors of a mirror, it is important to calculate the circumferential profile on \( z \) axis with different radius. Figure 3 illustrates the calculation of circumferential profile on \( z \) axis with the radius of \( r, d \) and \( f \) are the distance between the workpiece and beam splitter, and focal distance of the microlens array, respectively. \( R \) and \( r \) is the radius of workpiece and measurement, respectively.

\[ \Delta c = c_a - c_b \]

Here, \( c_a \) and \( c_b \) is the angle data at point A and B, respectively. The profile data \( P \) can be denoted as a Fourier series by using an inverse Fourier transform [2]. The characteristics of the algorithm chart can be estimated by its transfer function, which defines the relationship between angle difference data \( \Delta c \) and profile data \( P \) [2].

3. Pre-experiment

In order to verify the standard deviation of the measurement taken by MBAS in the real environment, we measured the stability of angle and angle difference for two hours. The pre-experimental arrangement is shown in Fig. 4. Table 1 shows the specifications of the devices in Fig.4. Figure 5 shows the standard deviation of the angle data at point A was 2.45 \( \mu \)rad. However, the stability of angle difference output was 0.8 \( \mu \)rad. We note that the fluctuation of stability of angle difference was slight because it eliminated influence of thermal drift. Here, only the characteristics of the differential output to measure the flatness will be investigated.

Figure 6 shows the angle data \( c_a \) and \( c_b \) by MBAS system. The horizontal axis is the rotation angle and the vertical axis is the angle data. After four series of measurements, the roundness on average was 58.78 nm with standard deviation 9.92 nm (Fig. 7).

4. Conclusions

A high accuracy micro flatness measuring machine (FMM) for precision flatness measurement has been proposed. The multi-beam angle sensor (MBAS) has been incorporated in order to improve the motion accuracy of the FMM. The MBAS is less susceptible to instrumental errors for angle detection, can maintain high sensitivity with a miniaturized size. Experimental results confirm feasibility of the MBAS for flatness measurement is also presented.

References


Table 1 Specifics of devices in FMM (Fig. 4)

<table>
<thead>
<tr>
<th>Device</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Diode</td>
<td>Output power: 35 mW (CW)</td>
</tr>
<tr>
<td>Wavelength</td>
<td>658 nm</td>
</tr>
<tr>
<td>Pinhole</td>
<td>Diameter: 400 ( \mu )m</td>
</tr>
<tr>
<td>Aperture</td>
<td>Diameter: 1.4 mm</td>
</tr>
<tr>
<td>Micro lens array</td>
<td>Focal distance: 46.7 mm (( f ))</td>
</tr>
<tr>
<td>Pitch of the array</td>
<td>500 ( \mu )m</td>
</tr>
<tr>
<td>CMOS</td>
<td>Size: 5.6 mm x 4.2 mm</td>
</tr>
<tr>
<td></td>
<td>Valid pixels: 2560 pixels x 1920 pixels</td>
</tr>
<tr>
<td></td>
<td>Sensitive area: 2.2 ( \mu )m x 2.2 ( \mu )m</td>
</tr>
</tbody>
</table>

Fig.3 The calculation of circumferential profile on \( z \) axis

Fig.4 Flatness Measuring Machine

Fig.5 Stability of MBAS (two hours)

Fig.6 Angle and angle difference data

Fig.7 Profile data (four series)