Angular motion and circular profile measurements using the reversal method

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Abstract. Various disk type products are important for information technology, and need to have highly accurate flatness. When a profile of a disk is obtained by a scanning sensor, the output of the sensor is influenced by the parasitic motion of scanning. This article presents a reversal method to separate the profile and the angular motion of the turntable using just one displacement sensor. We also measured a hard disk using the proposed method and the experimental results showed the repeatability and usefulness of our proposed method.

1. Introduction
Some disk type products, for example, silicon wafers, DVDs and hard disks, have important uses in the field of information technology. These disk type products are required to have highly accurate flatness for high recording density. When a profile is obtained by a scanning sensor, the output of the sensor includes parasitic motions of the scanning, for example, pitching. Whitehouse showed some techniques to separate the profile from parasitic motions for measurements of roundness and straightness [1]. Further, some techniques using scanning displacement sensors to separate the circular profile and parasitic motions of a turntable have been proposed [2]~[4].

We have previously proposed an error separation technique using angular sensors [5]. This article again presents our error separation technique, based on our previous article’s theory, but here we use a displacement sensor.

2. Principle
Fig.1 (a) and (b) shows the first and second steps of the reversal method. This novel reversal separates a circular profile on a disk from the angular motions of a spindle. A sample disk is placed on a turntable. An angular sensor is placed on the disk, the radius is r and the center is the spindle of the turntable, to detect the tangent of the disk surface around the radius. The Z axis is defined as the extension of the spindle, X and Y axes are defined as on the turntable surface, shown in Fig.1. The output of the sensor is as follows:

\[ d_i(\theta) = \frac{e f_i(\theta)}{r\theta} + \alpha(\theta) \]  

where \( \theta \) is the rotation angle of the turntable, \( d_i(\theta) \) is the output of the sensor, \( f_i(\theta) \) is the circular profile of the disk surface, \( \alpha(\theta) \) and \( \beta(\theta) \) are angular motions of the spindle around the X and Y axes, respectively.
Next, the disk and the sensor are replaced with a 180 degree rotation of the turntable (see Fig.1(b)). The second measurement step gives the following sensor output:

\[ d_2(\theta) = \frac{\partial f_2(\theta)}{\partial \theta} - \alpha(\theta) \]  

(2)

Consequently, the tangent of the circular profile and the angular motion can be obtained as,

\[ \frac{\partial f_2(\theta)}{\partial \theta} = \frac{(d_1(\theta) + d_2(\theta))}{2} \]

(3)

\[ \alpha(\theta) = \frac{(d_1(\theta) - d_2(\theta))}{2} \]  

(4)

This reversal assumes that the angular motion does not include non-repeatable run out.

In this technique, the measurement system needs an angular sensor; however, this can be substituted by two displacement sensors to approximate the tangent (see Fig.2).

\[ \theta = \tan^{-1}\left(\frac{d_2 - d_1}{l}\right) \]  

(5)

Furthermore, when the angular motion does not include non-repeatable run out, the tangent can be calculated by the results of two measurements at different displacement positions a and b, as in Fig. 2. Then, the circular profile on the disk and the angular motion can be separated using just one displacement sensor.
3. Measurement system
Fig.3 shows the mechanical details of the measurement system. A sample disk is set on a tilt stage, which in turn is set on a theta stage. The theta stage is mounted on a turntable, which uses an air bearing and is rotated by a DC servo motor. The tilt stage is used to make the sample disk perpendicular to the axis of the turntable. The theta disk is used for the 180 degree reversal.

Figure 3. Mechanical details of the measurement system

The sample disk is rotated by the DC servo motor which is controlled by a PC. The output of the displacement sensor is acquired by a digital volt meter and the datum obtained by the PC using GP-IB.

4. Experimental results
A hard disk is used as the sample disk, which was measured 3 times on three different days. Fig.4 shows the results of calculating the circular profile of the disk. The average of the difference between the first and the second measurement results is 0.9 μm. The average of the difference between the second and the third results and that between the third and the first results are 0.6 μm and 1.1 μm, respectively; this shows the repeatability of the method.

Fig.5 shows the results of calculating the angular motion of the turntable. The 0 and 1 love/rev. components mean the position and the tangent of the disk, respectively; they do not mean the angular motion. 2 loves/rev. is the largest component and amplitude is about 0.2 to 0.3 arcmin.

5. Conclusions
A reversal method to separate the circular profile of a disk and its angular motion is proposed. This method needs just one displacement sensor. A hard disk is measured and the results show the repeatability and usefulness of the proposed method.

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Figure 4. Circular profile of the disk

Figure 5. Angular motion of the turntable

References
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