A Method for High Precision Spindle Motor Eccentricity Measurement

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***Abstract*—Measuring accurately the rotor eccentricity is important in the performance analysis and fault diagnosis of spindle motor. In this paper, a method based on vision technology is presented for measuring the eccentricity. In the measurement, an area of interesting (AOI) is selected and saved as template image. In the measurement procedure, the rotor image is captured and synchronized by spindle motor back-EMF zero crossing signals. A sub-pixel object detection algorithm is applied and the spindle motor eccentricity is can thus be calculated accurately. The experiments show that the resolution of the measurement can be better than 5 nanometers.**

Index Terms—**Spindle motor, Eccentricity measurement, High precision, Vision metrology, Non-contact measurement.**

I. INTRODUCTION

Measuring accurately the rotor eccentricity is important in the performance analysis and fault diagnosis of spindle motor. [1]. The eccentricity between stator and rotor is inevitably introduced during manufacturing process, such as mass unbalance and bearing tolerances [2].

The eccentricity maybe caused due to component quality. For example, when the magnet ring is not symmetrically magnetized or the stator core dimensions are not correct. The eccentricity can also be induced by the problems in the motor assembling procedure. On the other hand, the unbalanced electromagnetic pull in the motor can also induce the eccentricity [3].

Fig. **1** shows the basic structure of a spindle motor used in HDD. This is a permanent magnet (PM) synchronous motor driven by brushless DC drive mode.

In the paper, we present a method to measure spindle motor eccentricity based on vision non-contact metrology. The method is designed based on vision microscopy and the illuminator intensity is software controllable. The measurement system is shown in **Fig. 2**.

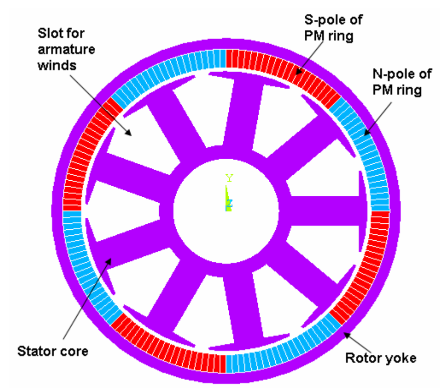

Fig. 1 EM structure of the spindle motor

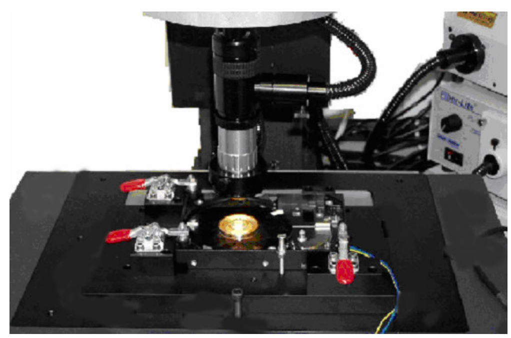

Fig. 2 Spindle motor eccentricity measuring system

II METROLOGY

The eccentricity measurement method is intended to provide a general purpose analysis capability for a variety of motor types, the spindle motor surface is search through joystick or measurement stage motor controller and the auto-focus is applied and make sure the focus surface is found. **Fig. 3** (a) shows the spindle motor surface image. A specific feature that is known as area of interesting (AOI) is selected, In order to provide the maximum flexibility, so that the AOI size is changeable according to the feature characteristic and set the AOI as a pattern. **Fig. 3** (b) illustrates

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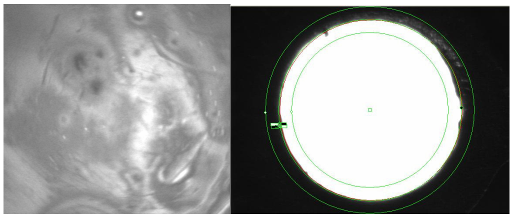
the spot feature pattern image, it is important prerequisite to definite identify pattern.



(a) (b)

Fig. 3 (a) Spindle motor surface, (b) Spot feature pattern image

Capturing image is triggered by motor mechanic phase position signal; the signal is generated by spindle motor back-EMF zero crossing signal detector. **Fig. 4** illustrates the spindle motor phase position trigger signals; the channel 1 is the back-EMF zero crossing signals, the channel 2 is zero phase position signals and channel 3 is the shift phase position signal, the shift phase position signal is used to trigger camera.

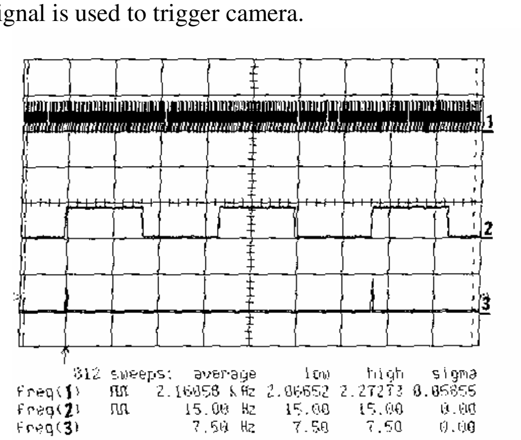


Fig. 4 Spindle motor phase position trigger signals

The images are captured at different phase and saved in sequence. There is translation and rotation between the measurement image and template image due to spindle motor rotation. The transformation of template image is shown as follows:

$$\begin{pmatrix} x_1 \\ y_t \end{pmatrix} = \begin{pmatrix} x_0 \\ y_0 \end{pmatrix} + \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \quad (1)$$

where the point (x, y) is original template image point and point (x_1, y_1) is transformation point. Point (x_0, y_0) can be set to zero because the spindle motor only rotates. Φ can be calculated by phase index.

The cross-correlation between measurement image and transformation template image is calculated using the following equation. The measurement image I(i,j) size is IxJ, and the template image P(m,n) size is MxN.

$$C(i,j) = \frac{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\left(\left(I(i+m,j+n) - E_I(i,j)\right)\left(P(m,n) - E_p\right)\right)}{\sqrt{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\left(\left(I(i,j) - E_I(i,j)\right)^2\right)}\sqrt{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\left(\left(P(m,n) - E_P\right)^2\right)}} \quad (2)$$

where

$$E_I(i,j) = \frac{1}{M \times N}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} I(i+m, j+n) \quad (3)$$

$$E_p = \frac{1}{M \times N}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} P(m,n) \quad (4)$$

m=0…M-1, n=0…N-1, i=0…I-1, j=0…J-1

The c(i, j) represents the similarity measurement between images. The spindle motor phase position can be detected while the minimum c(i,j) is calculated.

III EXPERIMENTS

The some types spindle motors eccentricities have been tested by this system. Fig. 4 illustrates a series of spindle motor surface images at different phase position where back-EMF is at zero crossing point.

Fig. 5 illustrates the measurement result in the polar coordinate system.

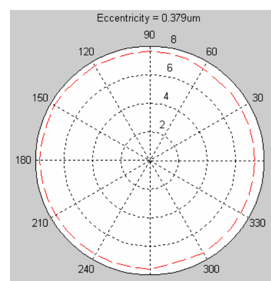


Fig. 5 Spindle motor phase position at polar coordinate system

IV CONCLUSION

The spindle motor eccentricity measurement method efficient and robust to measure all types of motors in hard disk drive and the system measurement resolution is less than 5nm. The system has been tested and the results have proved that the system has satisfied resolution.

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