Flying Height Measurement of Magnetic Disk Using Double Common-path Heterodyne Interferometer

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Abstract. The magnetic storage capacity depends significantly on the area density, which is close related to the flying-height (FH) of magnetic head. In this paper a double common-path heterodyne interferometer is proposed to measure the FH. The resolution of FH measurement reaches 0.1nm by means of phase measurement method. The influence of vibration of magnetic disk and work table is considered in the configuration design so as to reduce the system error. The experimental results show that the error compensation is better than 10nm when the vibration of disk is 1.2\(\mu m\).

1. Introduction
The storage capacity of hard disks has been developing steadily in the past few decades by increase of the areal density. One of the most effective and critical methods in increasing areal density is to reduce the flying height (FH), as the areal density of information storage is inversely proportional to FH from the slider to the disk [1]. As an important design and quality-control parameter, the FH has been reduced to 10 nm to achieve 100Gbit/in², and it is feasible to achieve 1Tbit/in² at an ever lower FH [2]. As the FH decreases for increasing the recording density, head/disk interface stability and head/disk spacing variation (FH modulation, or FHM) are becoming of more concern. In such an ultra-low FH regime, head/disk contact—intermittent or sustained—is virtually unavoidable, and maintaining dynamic stability is a challenge to higher recording density [3]. Consequently, instruments are necessary for studying the dynamic properties of the flying slider in detail.

Conventional methods for FH measurement are either absolute or relative. Three-wavelength interferometry [4], polarization interferometry [5], and dual-beam normal-incidence polarization interferometry [6] are examples of absolute FH measurement methods. These optical measurement methods utilize a simulative FH testing system, which consists of a transparent glass disk along with a production of test slider, and are not suitable for studying the real characteristic of head disk interface in real hard disk device. Examples of relative methods includes laser Doppler vibrometry, capacitive and inductive technique [7, 8]. These methods for FH testing offer the advantage of using both commercially available sliders and magnetic disks.

To meet the requirement of high resolution and quick frequency-response, we propose a novel measurement method using the common-path heterodyne interferometer with transverse Zeeman laser. The Abbe error of rotating pitch over the measurement of FH is compensated by the double interferometers that are symmetrical to each other. It takes the advantages of strong ability of resisting
environmental disturbance and feasibility for both relative and absolute measurement. The resolution reaches 0.01nm in terms of phase measurement, and the frequency of data sampling reaches 100kHz.

2. Principle and System Setup

![Diagram of FH measurement system](image)

**Figure 1.** The schematic setup of FH measurement system.

The principle of our proposed FH measurement system is shown in Figure 1. The light source is low beat frequency transverse Zeeman laser which omits a laser beam with orthogonally polarization states (p light and s light). A small amount of the output beam is directly received by the detector 13 to produce a reference signal $S_r$, and the main part of light is splitted by BS 2 and used for two symmetrical interferometers, as demonstrated by red and blue lines respectively in Fig. 1. Both beams pass through Wollaston prism 5 with definite angle (equaling to the splitting angle of Wollaston prism). Regarding the red line interference path, the beam is divided by Wollaston prism 5 to be two beams, which are parallel to and leaning against the optical axis. After converged by lens 6, they are projected on the glass disk and slider respectively. The reflected light are collected by lens 6 again and combined by Wollaston prism 5 to generate one measurement signal $S_{m1}$, received by detector 10.

In a similar manner the blue line optical path is analyzed, we can get the other measurement signal $S_{m2}$, collected by detector 11. Thereby the phase difference between the measurement signal ($S_{m1}, S_{m2}$) and reference signal ($S_r$) is given by

$$\Delta \phi_i = \int_0^t 2 \pi f_{D,i} dt = \int_0^t 2 \pi \frac{v_i}{\lambda} dt \times 360^\circ = \frac{720 h_i}{\lambda}$$

where $\lambda=632.8$nm, is the wavelength of He-Ne laser; $h_i$ is the flying height to be measured; $f_{D,i}$ is the Doppler frequency shift of the reflected light from the slider. $i=1, 2$, refers to the 1st and 2nd measurement signals respectively. Eq. (1) yields

$$h_i = \frac{\Delta \phi_i}{720 \cdot \lambda}$$

From Eq. (2) we can determine the resolution of FH measurement is 0.09nm when the resolution of phase measurement reaches 0.1°.
The Abbe error of rotating pitch over the measurement of FH is introduced because of the vibration of the magnetic disk. The two beams in Fig. 1 form a certain angle equal to the split angle of the Wollaston prism. They are split into 4 beams after passing through the Wollaston prism and the polarization states of the 4 beams are p, s(p) and s, as is shown in Figure 2. The middle path is composite of the p polarization of red light and the s polarization of blue light. We can adapt the Wollaston prism to make the two polarizations superposed.

Therefore the result in Eq. (2) includes two components, i.e., the practical flying height and the pitch of disk when the disk is rotated in high-speed. In order to diminish the influence of pitch of disk, we use two reference points that are placed symmetrically at both sides of slider, then the results, h₁ and h₂, given by Eq. (2) include the same Abbe error resulted from pitch angle. So the real FH of disk can be calculated by

$$h = \frac{h_1 - h_2}{2}$$  \hspace{1cm} (3)

The vibration of the optical system has an influence on the results as well. The system can be regarded as a Vibrometry, and the vibration of the environment will be detected and represented by the vibration of the signals. A better result will be obtained when the optical system is placed on the air-floating work table. Moreover, spatial filters are also used for reducing the effect of stray light on the detector.

3. Experimental Results

Figure 3 describes one group of experiment result when a movable hard disk (Hitachi HTS54-1040g9at00) is utilized for the measurement. It can be observed that the flying-height modulation is no larger than 10 nm when the vibration of disk is around 1.2 μm.
Double interferometers are used in the experiment to compensate the errors from the disk vibration. The correlation of the two interferometers is an important criterion to estimate the results, which is demonstrated by the standard deviation (SD) of the linear fitting. SD is equal to zero in ideal condition. Comparing the results shown in Figure 4 and Figure 5, it can be found that the performance is considerably improved when the air-floating table and spatial filter are adopted. From the result of FFT, we can see a further decrease of harmonic disturbance in the low frequency domain.

![Figure 4](image1.png)  
**Figure 4.** The result without air-floating work table and spatial filters: $R=0.99983$, $SD=0.02761$.

![Figure 5](image2.png)  
**Figure 5.** The result with air-floating work table and spatial filters: $R=0.99995$, $SD=0.01458$.

### 4. Conclusion
A double common-path heterodyne interferometer based on transverse Zeeman laser is employed to test the flying height of the magnetic hard disk. The resolution of FH measurement reaches 0.1nm by means of phase measurement method. The influence of vibration of magnetic disk and work table is considered in the system design so as to reduce the error. The system takes the advantages of strong ability of resisting environmental disturbance and feasibility for both relative and absolute FH measurement. It is expected to apply this system to inspect the quality of magnetic disk production.

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