COMPARISON OF OPTICAL AND CAPACITIVE MEASUREMENTS OF SLIDER DYNAMICS

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Abstract - A simultaneous slider air bearing thickness measurement is made using capacitive and optical techniques. The first technique measures the capacitance between a conducting disk and a probe attached to the slider, and the other measures the optical path length using interferometry. A quartz disk with a transparent conductive coating is used for this experiment. Measurements are made simultaneously at three corners of the slider from DC to 100 kHz. The DC flying height measurements agree to within 7 nm while the AC fluctuations agree to within the noise level of each technique (0.2 nm).

INTRODUCTION

In rigid disk magnetic recording a hydrodynamic air bearing is formed between the media and a slider containing the magnetic head element. The flying height of the slider is a critical dimension as it directly influences both magnetic performance and system reliability. Optical interferometric techniques have been used to measure the absolute flying height of the slider above the disk to within a few nanometers[1,2]. Slider vibrations of less than a nanometer have also been measured from 0 to 100 kHz[3,4,5]. These experiments required a transparent disk, and only measured one spot of the slider at a time. Multiple sensor capacitance measurements have been made of slider dynamic variations while flying on a particulate disk[6]. These measurements allowed slider flying height, pitch and roll to be computed, but unfortunately required a special slider to be fabricated. Also, the absolute calibration depended on careful measurement of probe size as well as the dielectric constant and thickness of the disk lubricant and magnetic coating. The equivalence of optical and capacitive techniques for measuring slider dynamics or static attitude has never been established.

Presented here is a detailed comparison of optical and capacitive measurements of slider dynamics. For the first time, both measurements were taken simultaneously on the same disk with the same slider. Vibration amplitudes agree to within 0.2 nm from 0 to 100 kHz, and absolute flying height agrees to within 7 nm.

THEORY

Optical

A slider flying on a transparent disk can be illuminated with monochromatic light focused through the disk. This beam is partially reflected at the interface between the disk and the slider air bearing. The rest of the beam propagates through the air bearing and is reflected off the slider. This assumes the slider is a perfect mirror. Actually the slider absorbs some of the energy and transmits an even smaller amount. This has an extremely small effect on the beam intensity, but can shift the phase angle of the reflected light. The beam reflected off the slider is then transmitted through the air bearing with minimal absorption and is partly transmitted through the disk. Some of the light is reflected back to the slider by the disk where it is again reflected back to the disk. This process continues, resulting in multiple beams returning from the slider. By imaging these beams and the reference beam initially reflected off the disk, an interference pattern dependent on the slider flying height is formed. From this image, the DC flying height of any point of the slider can be approximated using a two beam interference model[4], or a more exact calculation can be made by accounting for the multiple reflections. The two beam model assumes only the initial beam reflected off the slider provides significant interference with the disk reference beam. The flying height calculated using the two beam model oscillates around the value calculated using multiple beams by about one to two percent. This is because the errors caused by assuming only two beam interference are greatest in the region between light and dark fringes. At the fringe maxima and minima, the error is zero.

For more accurate measurement of the slider flying height, the exact multiple beam theory can be used[7]. Multiple beam interferometric theory for a single film reduces to the following equation:

$$\frac{I_{out}}{I_{in}} = a\frac{1+\cos\alpha}{1+d\cos\alpha}$$

where:

$a =$ normalizing constant
$d =$ reflection coefficient constant
$\alpha = \dfrac{4\pi h\cos\beta}{\lambda} + \gamma$
$h =$ flying height
$\lambda =$ wavelength of the illuminating light
$\beta =$ angle of incidence
$\gamma =$ phase shift on reflection (material dependent)

The normalization constant, a, and the reflection coefficient constant, d, can be determined experimentally for a given slider and disk combination. A reflection coefficient constant of 0.25 was used for this experiment. It agrees well with the actual data. By measuring the flying height at three points on the slider, the pitch and roll also can be calculated.

The maximum and minimum of the DC intensity can be used to determine the flying height variation. The best signal to noise ratio for this measurement is obtained at a disk speed that maximizes the slope of the intensity versus linear velocity curve. Since the errors in using the two beam model are small, it has been used for this calculation. At each point of the slider image the flying height variation, Δh, causing an observed intensity fluctuation, ΔI, is given by [4]:

$$\Delta I = \pm 4\pi\cos\beta\,\frac{\sqrt{4I_sI_d - (\bar{I} - I_s - I_d)^2}}{\lambda}\,\Delta h$$

Capacitive

Flying a special slider on an electrically conductive disk provides a means by which capacitance can be used to measure the air bearing thickness. The slider must have special conducting probes at 3 separate points. The capacitance between each probe and the disk is measured, and the flying height at each point computed. By using three probes, the flying height, pitch and roll can be calculated. For each probe the capacitance is given by[6]:

$$C = \epsilon_o \int_0^W \int_0^L \frac{dx\,dy}{h + x\tan\theta - y\tan\phi}$$

where:

$W =$ width of capacitance probe
$L =$ length of capacitance probe
$h =$ slider flying height above conducting surface
$\theta =$ slider pitch angle
$\phi =$ slider roll angle

This equation has three unknowns and can be solved numerically if the capacitance is known for three probes, each at different points of the slider. At each probe, the flying height variation, Δh, causing an observed capacitance fluctuation, ΔC, is given by:

$$\Delta C = \frac{\epsilon_o WL}{h(h+\theta L+\phi W)}\,\Delta h$$

EXPERIMENT

A 100 nm transparent conductive coating of tin oxide was sputtered on a 14 inch quartz disk. This coating allowed optical and capacitive flying height measurements to be taken simultaneously. A special slider containing a capacitance probe at each corner[6] was flown on this disk, and illuminated with monochromatic light through the disk. The interference pattern caused by the reflections off the disk and the slider was imaged to three EG&G UV 250 silicon detectors. Each detector was aligned to measure the slider flying height at one of the capacitance probe locations. At each detector the flying height variation causing an observed intensity fluctuation was calculated[4]. Similarly, for each capacitance probe the flying height variation causing an observed capacitance fluctuation was calculated. This data was

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collected simultaneously from DC to 100 kHz using an FFT analyzer. Each probe and detector output was also read by a digital voltmeter and averaged for 1.7 seconds. This data was used to compute the absolute flying height, h, pitch, θ and roll, ϕ attitude of the slider. The experimental setup is shown in Figure 1.

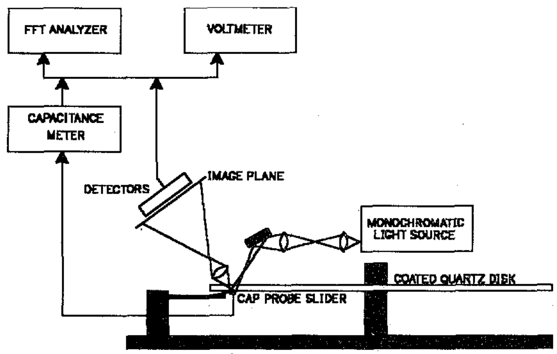

Figure 1: Experimental setup for measuring slider air bearing thickness on a quartz disk. Both optical and capacitive techniques were used simultaneously.

The capacitance meter used for measuring the capacitance was accurate to within ± 0.02 pf, and the probe area was measured to within 8 μm^2 out of 400 μm^2. The total capacitance per probe ranged from 3 to 6 pf, so the capacitively calculated flying height should be accurate to ± 4 percent. The optical data errors arise from inaccuracies in placement of the detector on the slider image, and errors in the computation of the maxima and minima of the intensity versus linear velocity curve. The detectors were placed to within ± 1 mm on the slider image. The effect of errors in the maxima and minima calculation are directly related to the number of data points taken between fringes. This resulted in a possible 5 nm error for the trailing edge data and a 10 nm error for the leading edge data. The total error for the optical flying height measurements is about ± 6 percent.

RESULTS

Figures 2, 3, and 4 show the calculated hub trailing edge flying height, pitch, and roll of the slider tested. For the velocities examined the two techniques agree to within their respective errors. In the worst case, the flying height agrees to within 7 nm, the pitch to within 5 microradians (μrad), and the roll to within 1 μrad. The discrepancies in pitch and roll can be accounted for by assuming an offset or scale factor error in the capacitance measurements of only a few hundreths of a picofarad in a measurement of about 5 picofarads. Accuracy and stability to these levels are difficult to achieve with the current apparatus. In addition, probe edge effects were not included in the capacitance calculations. This can add an additional one to two hundreths of a picofarad.

Figure 5 shows the FFT analyzer output for the capacitance detector located at the hub leading edge of the slider rail. Figure 6 shows the same measurement made with the optical detector located at the same place on the slider. The linear velocity of the disk was 56 m/s. This was chosen to provide a slider leading edge flying height that maximized the signal to noise ratio of the optical signal. The S/N of the capacitance measurement does not depend on absolute slider flying height. From 2 to 30 kHz the spectra agree to within the claimed 0.2 nm peak to peak measurement accuracy of the optical technique. Above 30 kHz the slider vibration amplitudes are less than the noise level (0.2 nm p-p) of the measurements, and hence are not shown. Both sensors show a large signal below about 2 kHz. This is due to disk run and its harmonics. The low frequency noise level is larger in the optical spectrum because the light scattered off the tin oxide coating was not uniform. This noise is not seen for uncoated disks[4]. For both signals, strong peaks corresponding to suspension resonances are seen below 10 kHz, and at about 15 kHz a characteristically broad air bearing resonance can be seen. This air bearing mode has suspension resonant modes superimposed on top of it, producing the structure seen in the plots. Figures 7 and 8 show the measured spectra at the hub trailing edge of the slider rail at 45 m/s. Once again the increased low frequency noise in the optical signal is seen, but the 2 kHz suspension resonance is

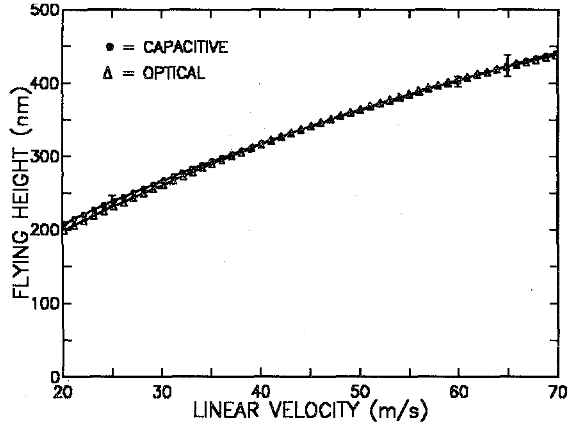

Figure 2: Slider hub trailing edge flying height computed from optical measurements versus flying height computed from capacitive measurements. Error bars for capacitive technique are at 25 and 65 m/s. Error bars for optical technique are at 30 and 60 m/s.

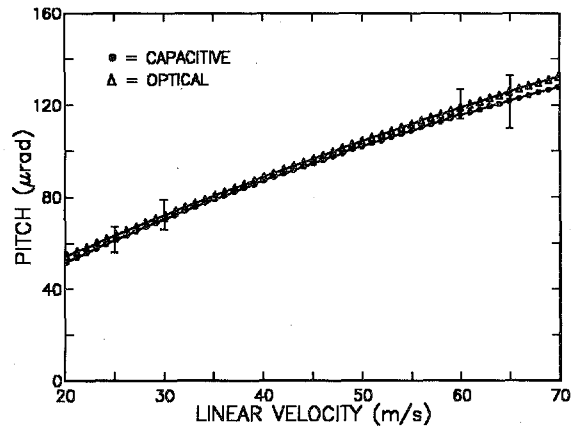

Figure 3: Slider pitch computed from optical measurements versus pitch computed from capacitive measurements. Error bars for capacitive technique are at 25 and 65 m/s. Error bars for optical technique are at 30 and 60 m/s.

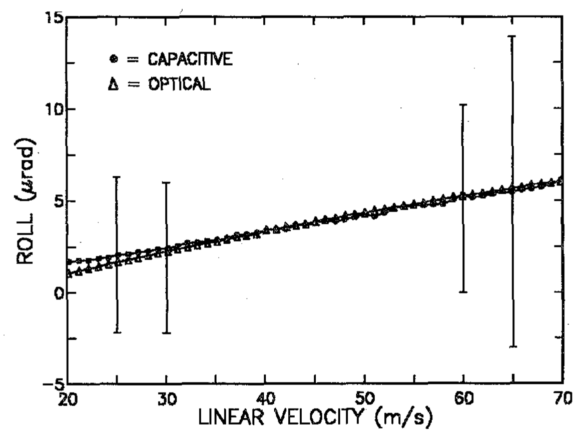

Figure 4: Slider roll computed from optical measurements versus roll computed from capacitive measurements. Error bars for capacitive technique are at 25 and 65 m/s. Error bars for optical technique are at 30 and 60 m/s.

still discernable In addition, the air bearing mode frequency has increased to around 25 kHz. This increase is due to the lower flying height of the trailing edge in this experiment.

SUMMARY

A technique for simultaneously measuring the thickness of an air bearing with both capacitive and optical techniques has been presented. A quartz disk was coated with a transparent conductor so the capacitance between the disk and a probe mounted on the slider could be used to measure the slider flying height. Simultaneously, optical interferometry was used to make the same measurement. The signal to noise ratio for both techniques was large enough for air bearing thickness variations of as little as 0.2 nm to be measured from DC to 100 kHz. The signal above 30 kHz was less than the noise level of 0.2 nm. The accuracy of these techniques for making DC flying height, pitch and roll measurements was also good. Both techniques agree to within 7 nm in flying height and 5 *μrad* in pitch and roll for the data set shown.

The dynamic behavior of both the leading and trailing edges of a slider flying over a quartz disk was shown for both methods. Air bearing variations were caused by resonant vibrations of the slider and its suspending system. The measured resonant mode amplitude were within 0.2 nm p-p of each other, and the resonant frequencies agreed to within the FFT analyzer accuracy.

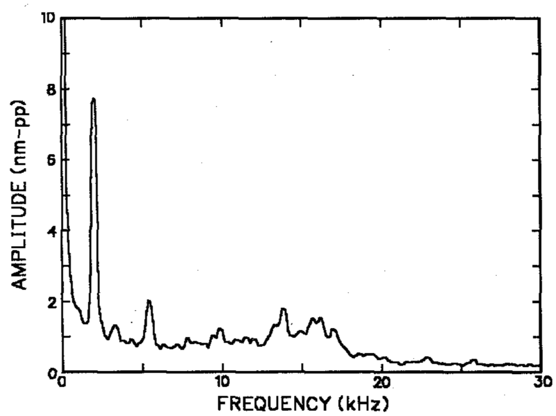

Figure 5: Capacitively measured amplitude vs. frequency plot of the leading edge of a slider flying on a tin oxide coated quartz disk at 56 m/s.

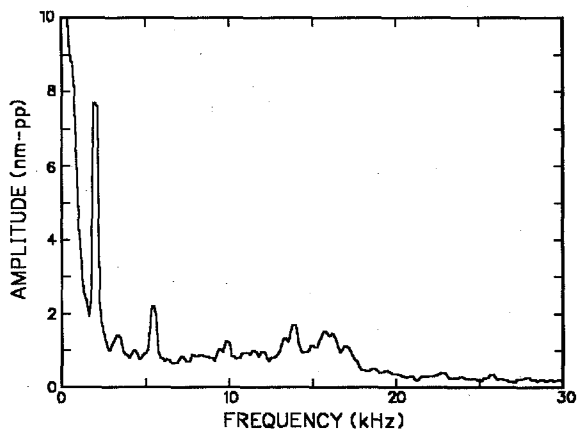

Figure 6: Optically measured amplitude vs. frequency plot of the leading edge of a slider flying on a tin oxide coated quartz disk at 56 m/s.

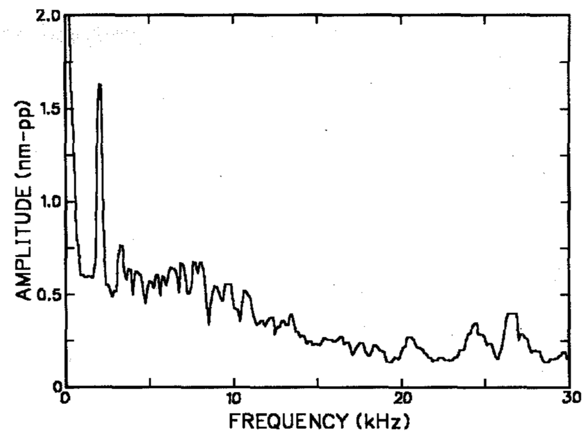

Figure 7: Capacitively measured amplitude vs. frequency plot of the trailing edge of a slider flying on a tin oxide coated quartz disk at 45 m/s.

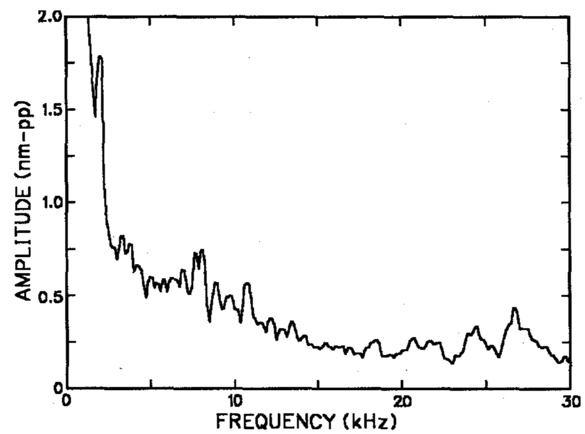

Figure 8: Optically measured amplitude vs. frequency plot of the trailing edge of a slider flying on a tin oxide coated quartz disk at 45 m/s.

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