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# Infrared Laser Interferometer for Measuring Air-bearing Separation

**Abstract:** The design and characteristics are presented for an infrared instrument capable of measuring air-bearing separation distances over a mechanical bandwidth ranging from dc to 30 kHz. The measurement technique involves monitoring optical intensity variations of the interferometric cavity formed by two air-bearing surfaces. This intensity varies between a minimum at zero separation and a maximum at a distance equal to one-quarter of the optical wavelength. For air-bearing distances less than 1 $\mu$m, a convenient source is the 3.391 $\mu$m infrared line of the helium-neon laser. By continually monitoring a fraction of the intensity of the optical source, a real-time analog division can be performed on the spacing signals to produce an output independent of laser intensity variations. Room-temperature indium arsenide detectors were selected for their high responsivity and rapid rise time.

## Introduction

The first paper on the technique of measuring air-bearing separation was published by Stone [1] in 1921. During the 1950's the computer industry capitalized on the air-bearing concept for magnetic storage devices such as disk and tape memories. It was possible then to measure spacing on the order of 6 $\mu$m by using a capacitance probe embedded in an air-bearing slider [2].

In the 1960's, the monochromatic light interference technique was introduced to measure spacing in the range of 1 to 3 $\mu$m. A tunable monochromator was used and the fringe pattern was monitored and displayed by a CRT system [3]. With the more recent white light interferometry technique [4], steady state air-bearing separations smaller than 1 $\mu$m can be measured.

Basically, all existing techniques can be placed into one of two categories, steady state or dynamic. The light interference techniques described above belong to the first category. They possess accuracy in measurement but poor frequency response. Electrical techniques similar to the capacitance probe [2] have high-frequency response, but the slider must be physically altered. A detailed review of various techniques for measuring slider-to-disk spacing is given in Ref. [5].

While laser interferometers [6, 7] are capable of measuring both steady-state and dynamic conditions, our application did not lend itself to one of these devices. The technique of the infrared laser interferometer about to be described permits a measurement between the two actual surfaces of interest and no intermediate thickness corrections are necessary. By monitoring intensity variations of the first order interference fringe, high accuracy (standard deviation $\sigma = \lambda/270$) was obtained with sufficient range (0 to $\lambda/4$) for slider/disk evaluations.

### Laser interferometer system

Consider a parallel air bearing separated by a distance $h$ as shown in Fig. 1. The two paths between the source S and a point of interference P are SABCEP and SANDP. The optical path difference $\Delta P$ is

$$\Delta P = n' \, (\mathrm{AB} + \mathrm{BC}) - n\mathrm{AN},$$

where $n$ and $n'$ are the refractive indices of the two media. Both AB and BC are related to the gap $h$ as

$$\mathrm{AB} = \mathrm{BC} = h/\cos\theta' \tag{1}$$

and

$$\mathrm{AN} = \mathrm{AC} \, \sin\theta = 2h\tan\theta' \, \sin\theta. \tag{2}$$

By the application of Snell's law and Eqs. (1) and (2), the optical path is

$$\Delta P = 2n'h\cos\theta'.$$

The refractive index of air at one atmosphere is 1.00029 while at 42 atmospheres $n' = 1.00124$ [8]. Because the air bearing under study operates at just a few atmospheres, the refractive index will be assumed to be 1.0. The corresponding optical phase difference at normal incidence is

$$\delta = \frac{2\pi}{\lambda} \Delta P + \pi = \frac{4\pi}{\lambda} h + \pi,$$

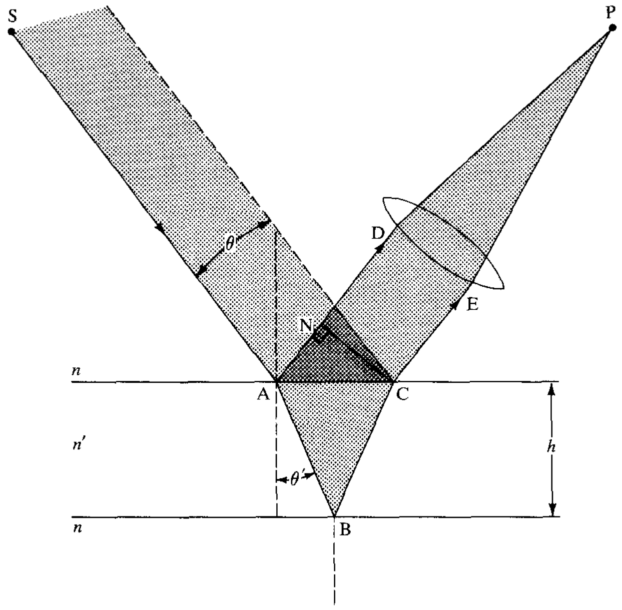


**Figure 1** Parallel-plate interferometer.

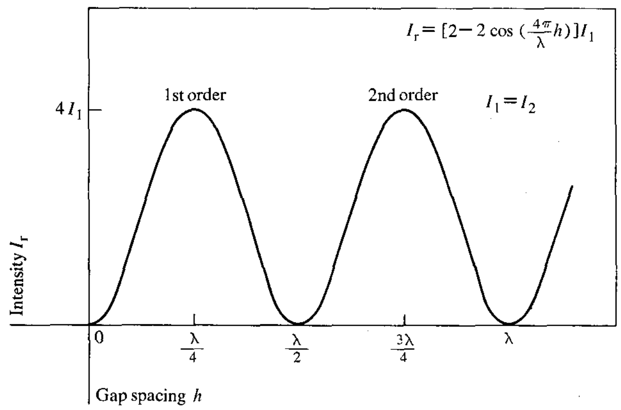


**Figure 2** Intensity behavior of interference fringes.

where λ is the optical wavelength, and $\pi$ is a term added to correct for phase change which occurs on reflection at the air-dielectric interface.

The total intensity $I_T$ at $P$ detected by a linear detector is given as

$$I_T = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\delta, \tag{3}$$

where $I_1$ and $I_2$ represent the reflected intensity along paths ADP and BCEP, respectively. Figure 2 illustrates the intensity at P as the gap $h$ is varied, assuming $I_1 = I_2$. Intensity maxima occur at $h = \lambda/4, 3\lambda/4, 5\lambda/4, \cdots$, and intensity minima occur at $h = 0, \lambda/2, \lambda, 3\lambda/2, \cdots$.

By using the above relationships between intensity and gap $h$, an instrument has been fabricated to examine air-bearings designed near $\lambda/8$. In actual practice, multiple reflections alter Eq. (3). An exact solution taking these refinements into account is given by Born and Wolf [8]. Because of surface finish reflectance variations, and possible nonlinearities in the detection scheme, a calibration procedure has been developed to determine the actual intensity/gap relationship, Eq. (3). The derivative of Eq. (3) is a sine function which is the instrument sensitivity. At both maximum and minimum ($h = 0$, $h = \lambda/4$) the sensitivity approaches zero, thus the real instrument range is somewhat less than $\lambda/4$.

The described instrument operates on the first order interference fringe with a minimum intensity at $h = 0$ and the first maximum at $h = \lambda/4$. To study sliders being designed near 0.5 $\mu$m, we selected λ to be 3.391 $\mu$m. Some of the important equipment component selections are illustrated in Fig. 3.

The source is a He-Ne laser operating in the $TEM_{00}$ mode at 3.391 $\mu$m wavelength at an output power of a few milliwatts. To minimize the effects of power variations with time, the laser output was monitored via beam splitter 1 and a reference detector. The real-time analog signal containing the gap information, divided by the reerence signal, exactly compensates for laser power drift with time.

Various combinations of disk and slider materials are possible, but one of them must necessarily be significantly transmissive at the λ selected. The disk material selected for use at 3.391 $\mu$m is fused quartz which transmits approximately 80 percent. The reflectance of the fused quartz is approximately 4 percent per surface. As indicated in Fig. 2, the optimum contrast $(I_{max} - I_{min})/(I_{max} + I_{min})$ is achieved when $I_1 = I_2$, hence a slider material with a reflectance comparable to that of quartz should be selected for optimum contrast performance.

To provide a reasonably high spatial resolution at the slider-disk interface, the one mm collimated laser beam was expanded by fused quartz lenses $L_1$ and $L_2$ and then focused by a plano-convex arsenic tri-sulfide lens $L_3$. The nearly diffraction-limited spot diameter at the interface was 62 $\mu$m measured to the $1/e^2$ intensity level. The spot diameter was measured with a scanned 12-$\mu$m slit and an indium arsenide detector.

Indium arsenide (InAs) photovoltaic detectors operating in the current mode were used to detect both the reference and signal. Lenses $L_4$ and $L_5$, also fused quartz, reduce the large beam diameter to a fraction of a millimeter because the active diameter of the detector is about one mm. The detectors have a detectivity ($D^*cmHz^{\frac{1}{2}}$/watt) of $7 \times 10^9$ at 3.391 mm [9].

Two unexpected problems occurred using these detectors. The first was that interference was observed on the reference detector even when the signal detector and lens $L_4$ were removed. This was caused by the slider/disk interfering wavefront reflecting back to the laser mirror, which redirected the wavefront back to the reference detector. These multiple reflections were sufficient to produce a 7 percent variation in the reference detector. This effect was reduced by inserting a heat-absorbing glass plate in the reference beam path that brought the reference signal level close to the average gap-produced signal level. The reflected slider/disk interfering wave intensity was also reduced by a factor of ten. This reduction was sufficient to lower the interference amplitude to the instrument noise level. Even with a reference signal and the analog division operational, unexplained drifts in the calibration curves would randomly appear. Further investigation revealed a 50 percent variation in responsivity over the detector's sensitive area. This variation would not be a problem except that the laser beam was observed to drift randomly causing the reference and signal spots to move on the detectors. Because the detectors were randomly aligned with the light beams, random beam motion would cause each beam to move to a region of different responsivity. This effect was minimized by adjusting each detector so that the beam motion drift did not change a particular A/B ratio by more than one percent. An alternate solution would be to use pyroelectric detectors which are uniform in responsivity to 2 percent or better.

Lenses $L_6$ and $L_7$ form a microscope with internal and external beam splitting mirrors. Lenses $L_3$ and $L_6$ are adjusted to a common focal point at the disk-slider interface. The microscope when illuminated by a white light source, serves to visually position the focused infrared beam and simultaneously gives the viewer a white-light interference pattern. The color observed for a steady-state condition gives the gap dimension $h$ [4]. The white light interference pattern gives, in addition, the order of the infrared interference signal.

The system frequency response is 0 to 30 kHz. The risetime of the InAs detectors is stated to be one $\mu$s. The response of the system was limited to 30 kHz by the voltage divider circuit. The disk resolution is proportional to the disk velocity divided by twice the band pass.

The electronic circuit is illustrated in Fig. 4. For a ferrite slider and a fused quartz disk, the final signal-to-noise ratio was 25. A photograph of the instrument appears in Fig. 5.

### *Calibration*

A piezoceramic stack of eight 2.54 cm diameter by 0.635 cm thick disks were bonded together and mounted on a stage capable of both angular and height adjustments. A sample of the slider material was mounted on top and positioned in place of a flying slider. Voltage applied to the piezoceramic stack produced a gap change. The sensitivity of the stack, measured photo-electrically with a visible He-Ne laser interferometer, was 0.00155 $\mu$m/V with a calibrated standard deviation of 0.007 $\mu$m. As mentioned earlier, a calibration of a particular slider material and fused quartz was always initiated on the second-order fringe [Fig. 1(b)] to avoid actual contact at the zero-spacing condition. This procedure

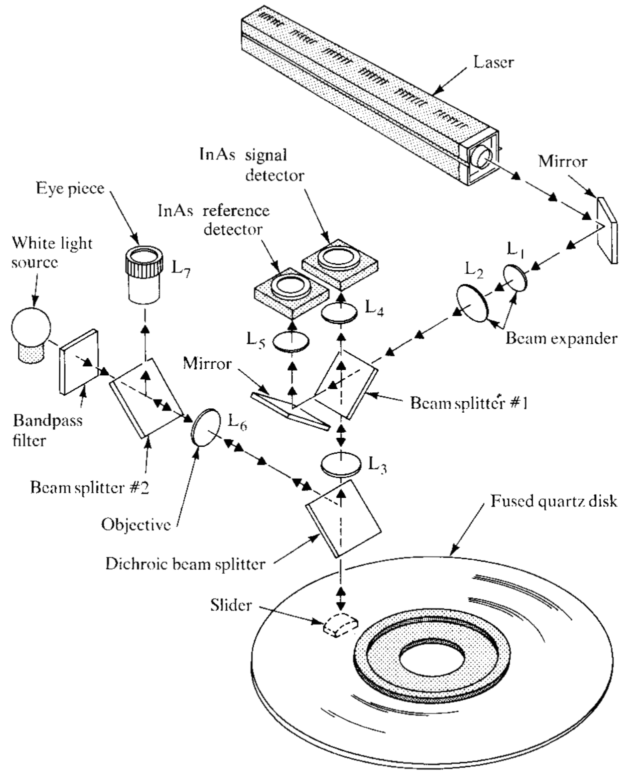


**Figure 3** Optical components of the infrared laser interferometer for measuring air-bearing separation.

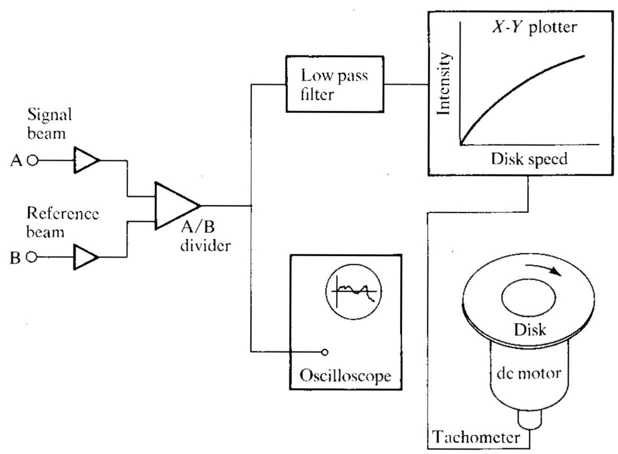


**Figure 4** Electrical components of the experimental apparatus as shown in Fig. 3.

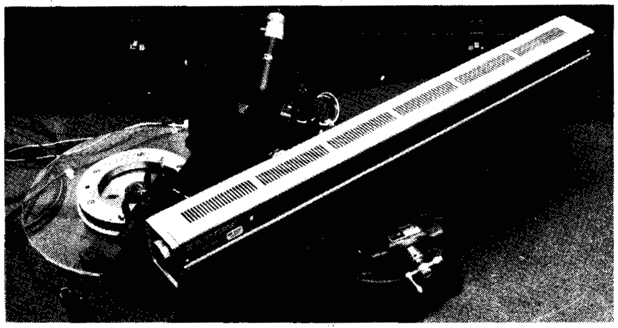

**Figure 5** Photograph of the experimental instrument.

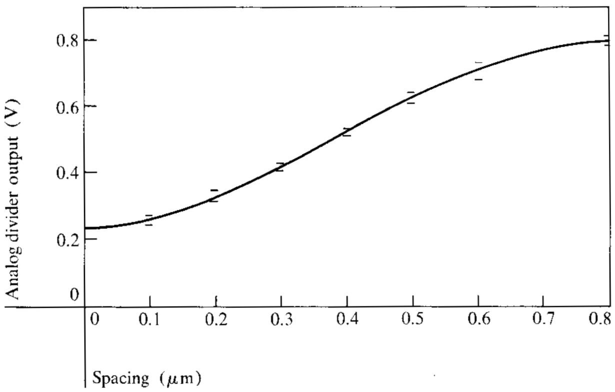


**Figure 6** Composite curves on intensity vs spacing calibration for five ferrite samples on quartz.

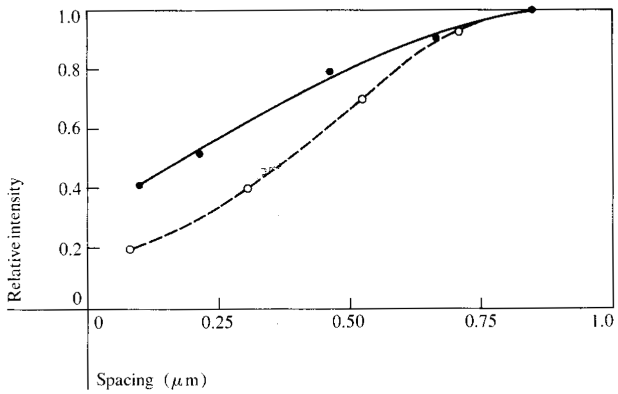


**Figure 7** Calibration curves of intensity vs spacing for $SrTio_3$ on magnetite (closed circles) and $BaTiO_3$ on quartz (open circles).

was necessary to avoid instability and problems present when breaking an optical contact bond, and often it was difficult to achieve optical contact.

A composite calibration for five ferrite samples and the quartz disk was obtained with the piezoceramic test fixture as shown in Fig. 6. A total of 75 data points between 0.254 and 0.66 $\mu$m for the five sliders produced a standard deviation of 0.0125 $\mu$m. The optical contrast observed was 0.57 with a maximum signal at the detector near 25 $\mu$A. Other material combinations were investigated; the results are presented in Fig. 7. The variations in response shapes are attributed to material reflectance differences.

## *Applications and results*

The application of the interferometer is described in terms of four separate areas. Steady state and dynamic spacing measurements are the major applications. The other two related applications are the spectral analysis of the instrument signal, and the monitoring of the slider-to-disk spacing continuously as the disk speed varies over a wide range. The results in the experiments were obtained with ferrite sliders on a fused quartz disk. The disk used had a 0.025 $\mu$m valley-to-peak roughness. The finish on the slider surfaces was of the same order. The experiments were performed on a stable granite test bed on which both the interferometer and the disk drive were mounted. The disk rotation is controlled by a variable speed motor through a belt drive.

The built-in white light viewing system/interferometer in the instrument allows a comparison to be made directly between the two techniques. A cross hair in the eyepiece located the focused spot on the slider. A total of sixteen sliders were examined. The output of the interferometer was displayed on a digital voltmeter. Results obtained with both techniques are summarized in Table 1. Good correlation is observed between the two techniques with a maximum deviation of 0.05 $\mu$m, which is well within the accuracy of the white-light interference technique.

One feature of the instrument is its ability to monitor continuously the spacing change over a wide speed range such as when a slider takes off from the disk as the disk accelerates from rest. For convenient recording of the slider spacing as a function of disk speed, the dc tachometer output of the drive motor was used to drive the ordinate of an *X-Y* recorder while the output of the instrument was fed into the abscissa axis. The schematic of this arrangement is shown in Fig. 4. The spacing/acceleration curve of a slider sample is shown in Fig. 8. The stability of the air-bearing for different disk speeds can also be easily monitored in this mode.

Another application of this instrument is the measurement of both time-averaged and dynamic slider-to-disk spacing. The frequency response is sufficient to capture high frequency spacing fluctuations as a result of the dynamics of the system (Fig. 9). These results include disk flatness and suspension dynamics. The dynamics of the system can be readily analyzed by feeding the output signal into a spectrum analyzer, so that the major resonant frequency components can be identified. Figure 9 presents an example of such an application.

**Table 1** Steady-state spacing measurements.

| *Sample* | *White light interferometer* ($\mu$m) | *Infrared light interferometer* ($\mu$m) |
|---|---|---|
| 1 | 0.437 | 0.467 |
| 2 | 0.594 | 0.546 |
| 3 | 0.465 | 0.467 |
| 4 | 0.465 | 0.467 |
| 5 | 0.414 | 0.411 |
| 6 | 0.594 | 0.546 |
| 7 | 0.465 | 0.467 |
| 8 | 0.465 | 0.467 |
| 9 | 0.414 | 0.419 |
| 10 | 0.610 | 0.559 |
| 11 | 0.414 | 0.419 |
| 12 | 0.381 | 0.376 |
| 13 | 0.465 | 0.513 |
| 14 | 0.383 | 0.457 |

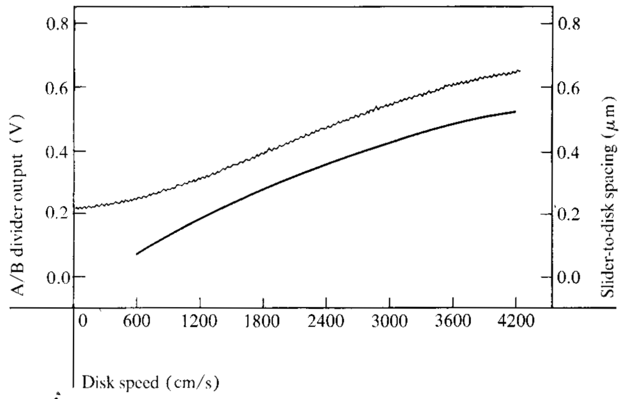


**Figure 8** Spacing vs speed characteristics for a ferrite slider on a quartz disk.

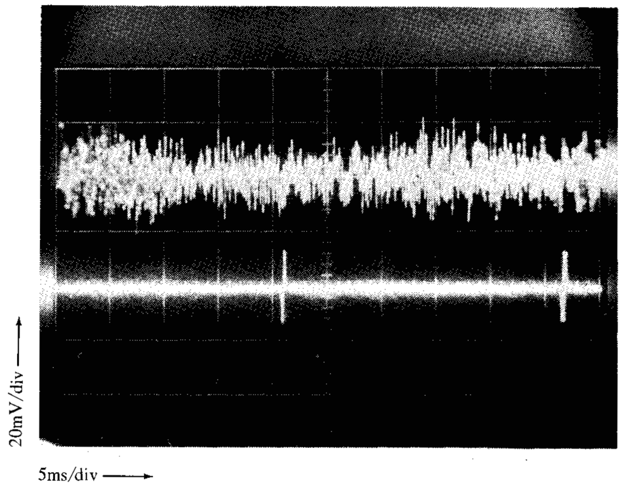


**Figure 9** Dynamic spacing (intensity) characteristics of a ferrite slider on a quartz disk rotating at 2400 rpm. Horizontal scale: 5 ms/div.; vertical scale: 20 mV/div.


### Summary

A measurement technique is presented using an infrared laser interferometer to evaluate, dynamically to 30 kHz, air-bearing gaps that are less than one $\mu$m. This technique gives gap information at a point, without the necessity of correcting for intermediate material thicknesses, and with high precision ($\sigma = \lambda/270$ over a range limited to one quarter of the optical wavelength). Extensions of this technique to gaps greater than or less than one $\mu$m are possible with the wide range of lasers and detectors available today. One disadvantage of this measurement technique is that the slider or disk must be transmissive at the $\lambda$ selected. It would be desirable to magnetically record and correlate dynamic flying height, or to study spacing behavior over real nonideal production surfaces. Both are possible if one is willing to fabricate the slider from a transparent material.



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