# Inner surface profile measurement of a hydrodynamic bearing by an oblique incidence and two-wavelength interferometer

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## ABSTRACT

A collimated line beam is incident at an oblique incident angle of 0.61 rad into an inner surface of a hydrodynamic bearing whose inner diameter and length are 3 mm and 3.5 mm, respectively. Lights reflected in specified directions from the inner surface are selected to obtain an optical field whose phase distribution is proportional to the inner surface profile. This optical field interferes with a reference optical field in a two-wavelength interferometer using a tunable external cavity laser diode. Shapes of grooves with depth of about 5 μm and width of about 0.15 mm formed on the inner surface can be measured with an error less than 0.3 μm.

**Keywords:** inner surface, profile measurement, interferometer, two-wavelength, oblique incidence

## 1. INTRODUCTION

It is required to measure inner surface profiles of hydrodynamic bearings within a short time and with a high accuracy. Although a mechanical point probe and an optical probe can be used for the inner surface profile measurement, exact arrangements on the mechanical scanning are required to achieve high measurement accuracy. A newly designed white light interferometer was used to measure roundness of an inner surface of a long cylindrical object[1,2]. In this measurement the diameter size of the cylinder object is limited by the conical mirror which is put into the inside of the cylinder object.

In this paper a collimated line beam is incident obliquely into the inner surface of the hydrodynamic bearing. Lights reflected in specified directions from the inner surface are selected to obtain an optical field whose phase distribution is proportional to the inner surface profile. This optical field interferes with a reference optical field in a two-wavelength interferometer using a tunable external cavity laser diode. Shapes of grooves formed on the inner surface can be measured with the proposed interferometer with sinusoidal phase-modulation[3].

## 2. SETUP

Figure 1 shows a setup for inner surface profile measurement. A tunable laser diode (TLD) is used as a light source which provides two different wavelengths of $\lambda_1$ and $\lambda_2$ for two-wavelength interferometry. A collimated plane beam from the TLD is transformed to a collimated line beam by two cylindrical lenses of lens L2 and L3. The line beam is divided into two beams by a beam splitter BS1. One of the beams is incident to the inner surface of a cylindrical object at an angle of $\theta$ with respect to the x-axis which is a line along the length direction on the inner surface as shown in Fig.1. Since lights reflected from the inner surface are filtered by a slit SL on a

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focal plane of a lens L4, an optical field formed on a CCD image sensor by lens L4 and L5 corresponds to an optical field formed from the specular reflection component of the reflected lights on a plane MP, as shown in Fig.1. The plane MP is referred to as measurement plane here. The optical field formed on the CCD image sensor is referred to as object wave. The phase distribution of the object wave is proportional to the inner surface profile along the x-axis. This object wave interferes with a reference wave which is formed from the other beam from BS1.The reference wave is phase-modulated with a mirror M3 vibrated sinusoidally by a piezoelectric transducer (PZT). The interference signal detected with the CCD image sensor at the wavelength $\lambda_i$ (i=1,2) is expressed as

$$S_i(t)=A_i+B_i \cos \{z \cos(\omega_c t)+\alpha_i\}, \qquad (1)$$

where $A_i$ and $B_i$ are constant, and the modulation amplitude z is proportional to the vibration amplitude of M3 whose vibration angular frequency is $\omega_c$. The phase $\alpha_i$ is given by

$$\alpha_i=(2\pi/\lambda_i)2r \sin\theta, \qquad (2)$$

where r(x) is the profile of the inner surface of the object. Since the variation of $\alpha_i$ between two measuremnt points is larger than $\pi/2$, r(x) is obtained from

$$r(x) = (\Lambda/2\pi)\Delta\alpha,$$

where $\Delta\alpha=\alpha_2-\alpha_1$ and $\Lambda=\{\lambda_1\lambda_2/(\lambda_1-\lambda_2)\}/2\sin\theta$ in the condition of $\lambda_1>\lambda_2$.

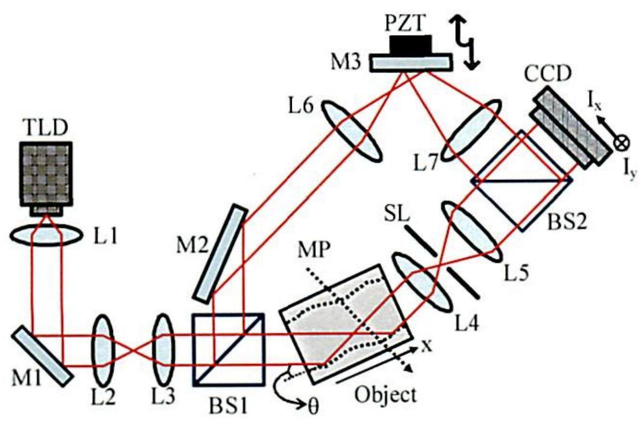


**Fig. 1** Setup for inner surface profile measurement.

## 3. IMAGE OF THE INNER SURFACE

Figure 2 shows the configuration of the hydrodynamic bearing and its expansion plan of the inner surface whose inner diameter and length are 3.0 mm and 3.5 mm, respectively. The parts of gray color in the expansion plan indicate grooves. One of them is a V-shaped groove whose depth is between 5 and 6 microns. The other is a line-shape groove. A collimated line beam with width $W_b$ of 1 mm is incident onto the inner surface at angle θ of

0.61 rad. The reflected lights are collected by the Lens 4 of focal length $f_4$=50 mm, and the slit SL is put on the focal plane of the Lens 4 as shown in Fig.2. Length $S_y$ and $S_z$ of the slit are 200 μm and 1 mm, respectively. The length $S_y$ limits the observation region to a narrow width of about 3 μm along the circumferential direction for the line beam. The length $S_z$ selects the lights reflected around the specular direction.

Figure 3 (a) shows the intensity distribution of the object wave detected with the CCD image sensor when the slit SL was not used. This intensity distribution is an image of the inner surface projected on the measurement plane MP. The transverse line $A_mB_m$ corresponds to a line AB along the length direction on the bottom of the inner surface. The side of $A_m$ is the entrance side for the light beam. The width of the image changes along the length direction, and the longitudinal line on which the image width is about $W_b$=1 mm indicates the intersectional line between the inner surface and the plane MP. The graves appear as dark parts in the image, and the image indicates that the inner surface is not a complete specular surface. Figure 3 (b) shows the intensity distribution of the object wave when the slit SL was used. Because of the slit, the image corresponds to a profile of the inner surface on the line $A_mB_m$ shown in the Fig.3 (a) and the inner surface appears as a nearly specular surface in the image. The image intensity distribution along the longitudinal direction follows a sinc function. Profiles of the two graves a and b indicated by the arrows in Fig.3 (b) are measured in the next section.

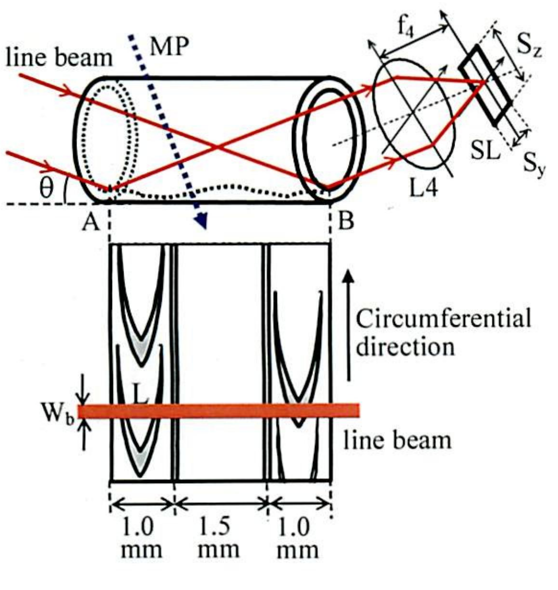


**Fig.2** Configuration of the hydrodynamic bearing and selection of the reflected lights by the slit SL.

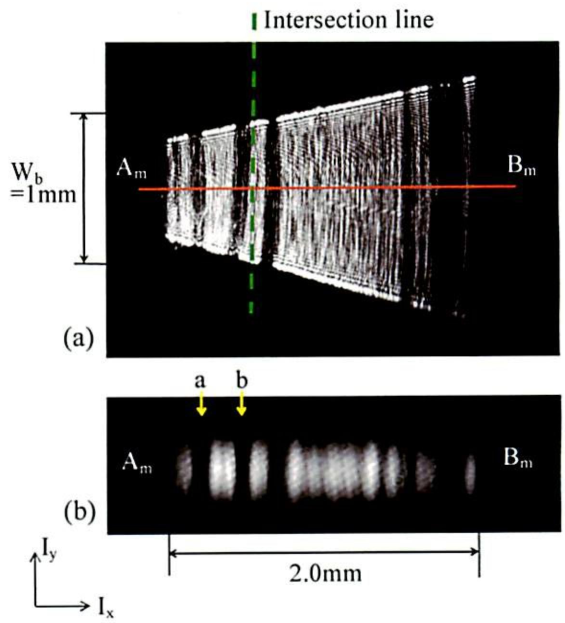


**Fig.3** Intensity distribution of the object wave detected with the CCD image sensor (a) when the slit SL was not used, and (b) when the slit SL was used.

## 4. MEASUREMENT OF THE INNER SURFACE PROFILE

The two wavelengths $\lambda_1$ and $\lambda_2$ were 785 nm and 762 nm, respectively, which provied the equivalent wave length of 22.7 μm at θ=0.61 rad. The vibration ferequency $\omega_c/2\pi$ of the mirror M3 was about 94 Hz. The focal length $f_5$ of the lens L5 was 100 mm, which provided the image magnification of 2 on the CCD and the interval of 3.7 μm between the measuremnt points on the measurement plane MP. Figure 4 shows the interference fringe pattern without the sinusoidal phase modulation at $\lambda_1$=785 nm. This fringe pattern was generated by superimposing the reference wave on the object wave whose intensity is shown in Fig.3 (b). Figure 5 shows the amplitude $B_1$ and $\alpha_1$ of the interference signal $S_1(t)$ detected on the measurement points on the line $A_mB_m$. The horizontal axis shows the position of the inner surface which is denoted by number $I_x$ of the elements of the CCD. The relative coordinate of x is given by 6.46×$I_x$ μm. Figure 6 shows the amplitude $B_2$ and $\alpha_2$ at $\lambda_2$=762 nm. Figure 7 shows the phase distribution of $\Delta\alpha = \alpha_2 - \alpha_1$, and the profile r is given by 3.6×Δα μm. The depth and width of grave a were 5.0 μm and 0.15 mm, respectively. The distance between the two graves was 0.45 mm. The measurement repeatability was about 0.3 μm. The CCD was moved along the optical axis to measure the surface profile at three different positions of the measurement plane MP at intervals of 0.6 mm. The three measured results were almost the same.

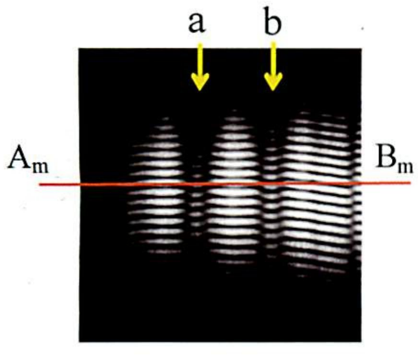


**Fig.4** Interference fringe pattern detected with the CCD image

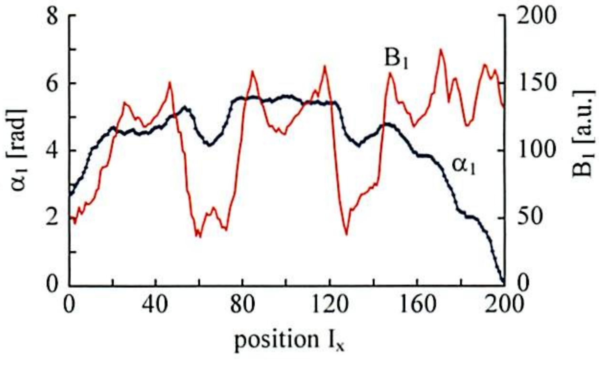


**Fig.5** Distributions of $\alpha_1$ and $B_1$ detected at $\lambda_1$=785 nm.

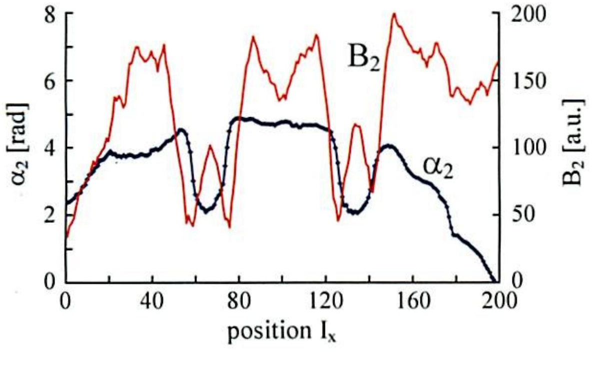


**Fig.6** Distributions of $\alpha_2$ and $B_2$ detected at $\lambda_1$=762 nm.

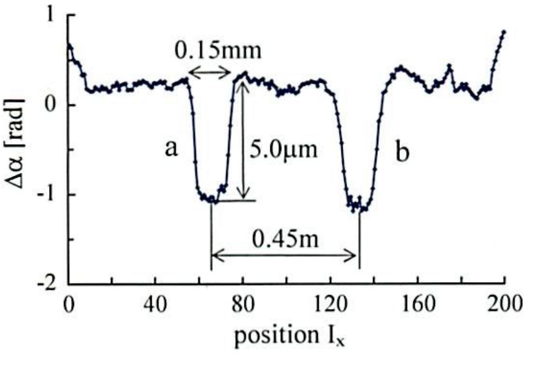


**Fig.7** Distribution of Δα obtained from the results of $\alpha_1$ and $\alpha_2$ in Figs.5 and 6, respectively.

## 5. CONCLUSIONS

A collimated line beam was incident at the oblique incident angle of 0.61 rad into the inner surface of the hydrodynamic bearing whose inner diameter and length were 3 mm and 3.5 mm, respectively. Lights reflected from the inner surface were filtered by the 200 microns slit with 1 mm length on the focal plane of the lens with 50mm focal length. The optical field along a line of 3 μm width on the inner surface was formed from the filtered light on the CCD image sensor. Phase distribution of the formed optical field was proportional to the inner surface profile along the line. This optical field interferes with the reference wave in a two-wavelength interferometer using the tunable external cavity laser diode. The two wavelengths were 785 nm and 762 nm to produce an equivalent wavelengh of 22.7 μm at the oblique incidence. Shapes of grooves with depth of about 5 μm and width of about 0.15 mm could be measured with an error less than 0.3 μm.

## REFERENCES


1. Albertazzi GA. JR, Viotti M.R., and Dal Pont A., "A white light interferometer for inner cylindrical surfaces," Appl. Opt. 39, 4589-4592 (2000).
2. M.R. Viotti, A. Albertazzi, A.V. Fantin, and A. Dal Pont, "Comparison between a white-light interferometer and a tactile formtester for the measurement of long inner cylindrical surfaces," Proceedings of SPIE vol. 6293, 62930F.1-8 (2006).
3. O.Sasaki and H.Okazaki, "Sinusoidal phase modulating interferometry for surface profile measurement," Appl. Opt. 25, 3137-3140 (1986).