

In-situ Absolute Calibration of Interference Microscopes

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ABSTRACT

In the present study, a new in-situ absolute calibration method for an interference microscope is proposed, and a new calibration system is developed. This method can be used to determine not only the linearity error but also the mean sensitivity on the base of the wavelength. The calibration system combines a compact laser interferometer and the previously developed in-situ calibration system. The laser interferometer is used only to determine the necessary displacement shift quantity with an integer multiple of half wavelengths. Using this known displacement shift quantity, both the mean sensitivity and the linearity error of a microscope can be determined. The feasibility of the proposed method is demonstrated also with experimental results.

1. INTRODUCTION

Interference microscopes (microscopes) have long been used in quantitative characterization of surface structure. With recent phase detecting techniques, microscopes can achieve extremely high vertical resolution[1]. However, the accuracy of microscopes is affected by some inherent systematic errors[2]. In particular the linearity error (deviation from a linear calibration line) of the microscope output is much larger than the resolution level. In addition, because the characteristics of the linearity error are not stationary, but change with measurement circumstances, it is desirable to calibrate microscopes frequently in the circumstance where the microscope is working (in-situ calibration). However, an accurate calibration reference is necessary in the conventional comparison method, and it is difficult to get a reference with enough accuracy in practice. It is also much more difficult to carry out the in-situ calibration.

Authors have proposed an *in-situ* self-calibration method for a microscope[3]. However, the proposed method is based on the premise that the mean sensitivity (inclination of linear calibration line) of the microscope be given beforehand, therefore, only the linearity error can be determined.

In the present study, a new in-situ absolute calibration method for a microscope is proposed, and a calibration system is developed. This new method can be used to determine not only the linearity error but also the mean sensitivity on the base of the wavelength. The new system combines a compact laser interferometer and the previously developed in-situ calibration system[3]. The laser interferometer is used only to determine the necessary displacement shift quantity with an integer multiple of half wavelengths of the laser light source. Using this known displacement shift quantity, both the mean sensitivity and the linearity error of a microscope can be determined.

In the present report, the principle of the proposed in-situ absolute calibration for a microscope and its calibration system are introduced. A microscope[4] has been calibrated successfully to the limit of stability of this microscope which is determined from the signal-noise ratio.

2. ABSOLUTE CALIBRATION PRINCIPLE

Figure 1 shows a schematic diagram of the calibration target, which is a scanning white light interferometer microscope that employs a new spatial frequency domain analysis technique[1]. The test surface shown in Fig. 1 is scanned by moving the objective in the Z-direction using a PZT. Because the sampling position is decided by the scanning PZT, nonlinear motion of the PZT will greatly affect the linearity of the microscope. For example, although this microscope has a vertical resolution of 0.1 nm with a maximum vertical range of 100 μm , the assured accuracy is only 1.5% of the vertical range[4].

Assume the calibration curve of a microscope is described by the function $f(z)$ that can generally be

expressed as the sum of a straight line having a slope of S_0 and the deviation function $g(z)$ from the straight line[3]. The function $f(z)$ is expressed as follows:

$$h = f(z) = S_0 \times z + g(z) \quad (1)$$

Here, S_0 and $g(z)$ represent the mean sensitivity and the linearity error, respectively. Let the displacement output of the microscope at sampling position z_i be m_i , and that at position $z_i + \Delta z$ (Δz is the displacement shift quantity) be m_{i+} . If the inverse function of $f(z)$ is given by :

$$h_i = m_i, \quad f^{-1}(h_i) = h_i / S_0 - b(h_i) \quad (i = 1, 2, \dots, n) \quad (2)$$

where n is the sampling number and $b(h)$ is the inverse function of $g(z)$, the derivative of $b(h)$ at the discrete i -th sampling point can be expressed by

$$b'(h_i) = 1/S_0 - \Delta z / \Delta m_i \quad (\Delta m_i = m_{i+} - m_i) \quad (3)$$

Here, the necessary displacement shift quantity Δz can be determined with an integer multiple of half wavelengths of the laser light source, S_0 can be calculated by

$$S_0 = \{ \sum \Delta m_i / \Delta z \} / n \quad (4)$$

and $b(h)$ can be obtained by integrating $b'(h_i)$.

Figure 2 shows the experimental apparatus for calibrating the output curve of a microscope. The calibration system consists of a calibrated microscope, a compact laser interferometer which is used only to provide the necessary displacement shift quantity Δz with an integer multiple of half wavelengths, and an inclined flat surface as a test surface, which can give a continuous change in the input value z_i over the calibration range from z_1 to z_n , is used as specimen (see Fig. 4). The laser interferometer is fixed to the support stage of the microscope, and the inclined flat surface is fixed to the worktable center of the laser interferometer. The displacement of worktable, that is Δz , is moved by a tube PZT.

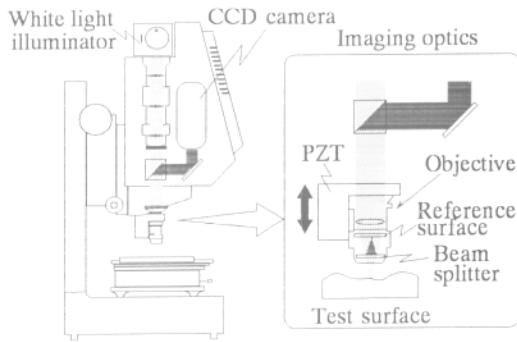


Fig. 1 Schematic of microscope

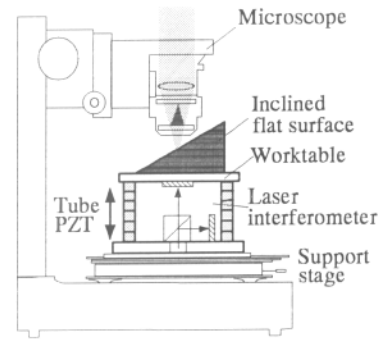


Fig. 2 Calibration system

Figure 3 shows the construction and optics system of the developed laser interferometer. The incident light from a laser light source system (LDS) is split into two beams by a cube beam splitter (BS) inside the tube PZT. One beam is reflected by moving mirror fixed on the bottom of the worktable, and the other beam is reflected by a fixed mirror. The two beams are then reflected back to the BS, producing an interference fringe, which is received by a 2-dividing photo-diode (2-PD) after passing through a bi-concave lens. When the worktable is moved by the tube PZT, the fringe moves according to the light distance change between the two reflected beams. The outputs at two points of phase difference π of the fringe are detected by the 2-PD. If x_1 and x_2 are the outputs of the 2-PD, and Y is the output of the laser interferometer, then Y is defined by the following equation:

$$Y = \frac{x_1 - x_2}{x_1 + x_2} \quad (5)$$

The differential detection method can be used to effectively eliminate intensity variations in the LDS of the laser interferometer. Furthermore, because the optical pitch difference between two interference beams be

as small as possible so that the stability of the fringes is good. However, wavelength variations of the LDS due to thermal drift cannot be eliminated by the differential detection method. Thus, in order to improve the stability of the wavelength and thereby achieve higher accuracy, a thermal controller was added to the LDS. The LDS shown in Fig. 3(b) consists of a laser diode (LD), a thermal sensor and a Peltier-element. The Peltier-element is used to regulate the detected temperature of the LD in order to suppress thermal drift in the LD. The output of the laser interferometer is a sinusoidal voltage signal of zero-line symmetry.

Figure 4 is a diagram of the signal processing system used to calibrate the microscope. The outputs of the calibrated microscope are detected and stored by the CCD camera shown in Fig. 1. The first, the calibration data m_i ($i=1,2, \dots, n$) of the output curve of the microscope are detected and stored. The second, the calibration data m_{i+} ($i=1,2, \dots, n$) corresponding to m_i are detected and stored after the tube PZT is moved by increasing offset voltage. The moved displacement quantity Δz of the tube PZT is an integer multiple of sinusoidal voltage signal period from the laser interferometer. This period is $\lambda/2$ (λ is the wavelength of the laser light source). This sinusoidal voltage signal is produced by the outputs of the 2-PD, which are converted by I-V converters and calculation circuits (addition, subtraction and division). In addition, in order to keep the Δz be constant during this period for detecting data m_{i+} and thereby achieve higher accuracy, a feedback control circuit shown in Fig. 4 was used after the tube PZT is moved. The proposed system provides an extremely simple mechanical structure, and is not effected by the hysteresis and creep of the tube PZT.

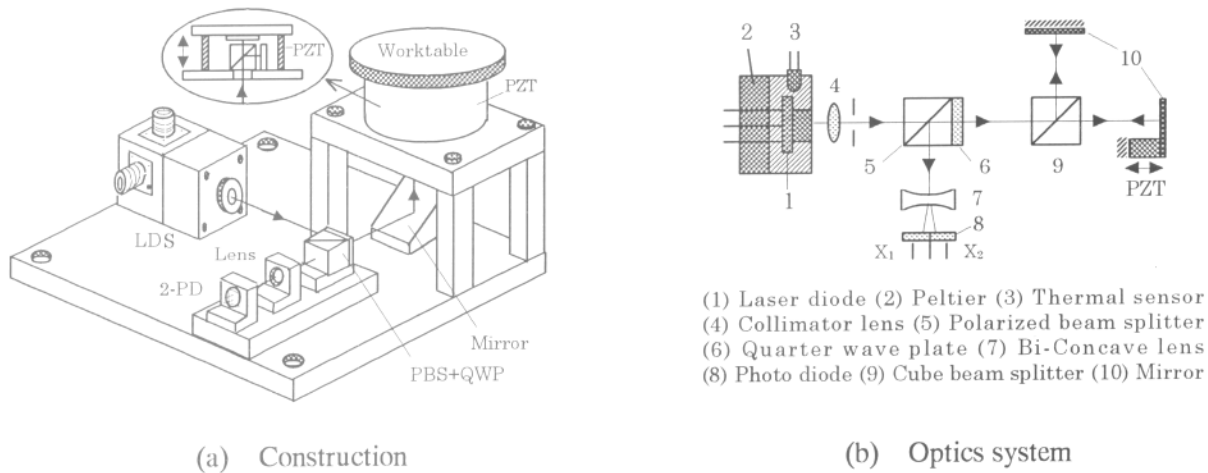


Fig. 3 Laser interferometer

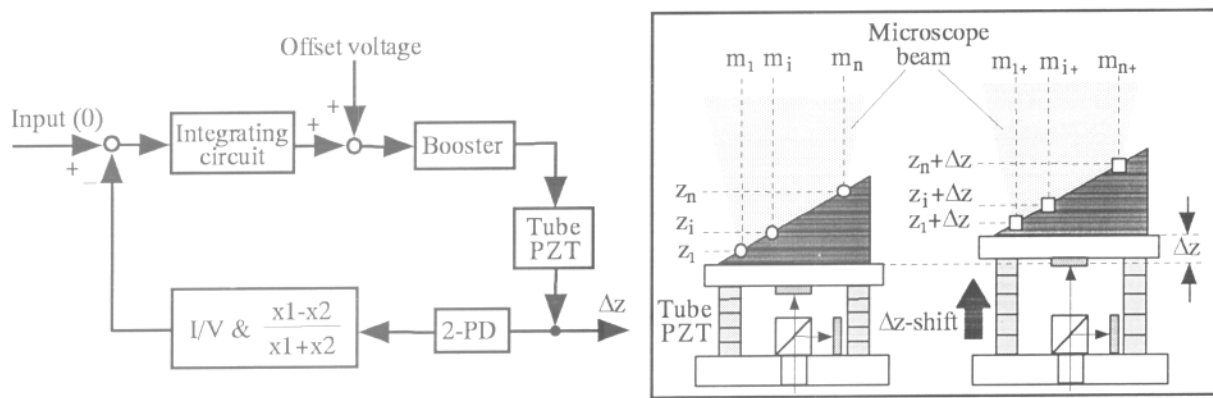


Fig. 4 Diagram of signal processing system

3. EXPERIMENTAL RESULTS

The nominal value of mean sensitivity of a calibrated microscope[4] as reported by the manufacturer is 1. The wavelength λ of the laser light is 784.73 nm as measured by an HP70950 optical spectrum analyzer. The necessary displacement shift quantity Δz for in-situ absolute calibration is $2 \times \lambda / 2$.

Figure 5 shows the mean sensitivities of the calibrated microscope. The abscissa represents the position of the specimen in the Z-direction, which is calculated from the output of the microscope. The dotted line is the nominal value, the other lines are the obtained value of three repeated calibrations, which are approximately 10% less than nominal value.

Figure 6 shows the linearity errors of three repeated calibrations of the calibrated microscope. The maximum linearity error was approximately 40 nm, which is approximately 0.2% of the calibration range of 20 μm . The maximum repeatability error of the three calibration results was approximately ± 2 nm, which is approximately $\pm 0.01\%$ of the calibration range of 20 μm .

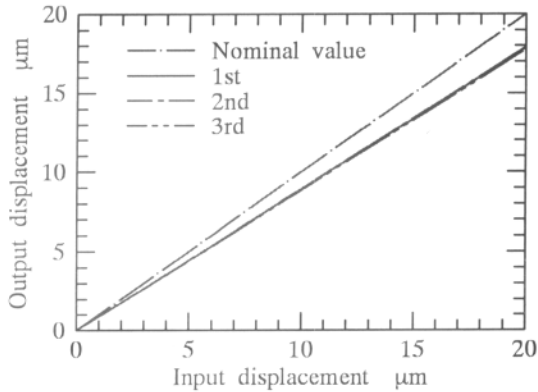


Fig. 5 Results of the mean sensitivity

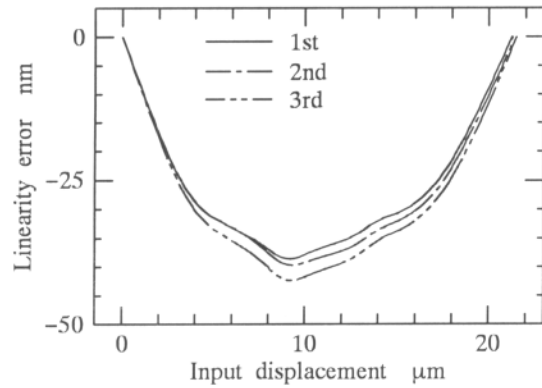


Fig. 6 Results of the linearity error

4. CONCLUSIONS

The results of the present research can be summarized as follows:

- 1) A new in-situ absolute calibration method is proposed for calibrating the output curve of an interference microscope. The effectiveness of the method was confirmed experimentally.
- 2) Accuracy of the method depends only on the stability of the calibrated microscope itself and that of the wavelength of the laser light source.
- 3) A microscope was calibrated successfully, and the maximum repeatability error of the calibration curve was approximately $\pm 0.01\%$ of the calibration range of the microscope.

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