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AN OPTICAL CALIBRATION METHOD FOR A DOUBLE-SLIT INTERFEROMETER CAPABLE OF INSPECTING THICKNESS VARIATION OF MOVING GLASS PANELS

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Abstract – A double-slit interferometer capable of inspecting thickness variation of a moving glass panel with nanometric resolution, and its calibration method using a partly electrode-coated nematic liquid crystal cell are presented.

Keywords: double-slit, interferometer, thickness variation, calibration, liquid crystal

1. INTRODUCTION

Thickness uniformity of glass panels is an important issue in the flat panel display (FPD) industry. In the production lines, it is desired to inspect the thickness variation of glass panels while they are moving so that inspection time could be saved. However, large and thin (typically about 0.7 mm) glass panels tend to sway while moving in the production line, and thus various existing measurement techniques cannot be the solution. Recently we proposed a new measurement technique based on double-slit interferometry, which is capable of measuring thickness variation of glass panels in harsh environment [1]. In this paper, we propose an optical method to calibrate the measurement system.

2. THE DOUBLE-SLIT INTERFEROMETER

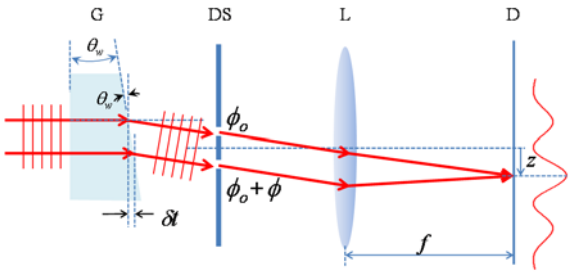

Fig. 1. Schematic diagram of the double-slit interferometer. G: glass panel; DS: double-slit; L: lens; D: detector plane

Figure 1 shows the schematic diagram of the double-slit interferometer, and shows the principle of measuring local thickness difference of a glass plate. If a glass panel whose refractive index is n is located in front of a double-slit, the glass panel can be modeled as a series of infinitesimal optical wedges whose wedge angle, θ_w, varies with position. If we focus on a local area, the glass panel can be thought of as an optical wedge as shown in Fig. 1. The collimated incident beam passing the glass panel will be refracted and enter the double-slit inclined so that there will be an initial phase difference between the electric fields entering the slits (ϕ in Fig. 1). This causes a shift to the central peak of the double-slit interference pattern.

The local thickness difference, δt, between the two neighboring points (P_1 and P_2 in Fig. 1) can be obtained as

$$\delta t = \frac{a\gamma}{(n-1)f} P \equiv CP \cdot \qquad (1)$$

where a denotes the center-to-center separation of the slits, γ is the size of a unit pixel of the camera, f is the focal length of the imaging lens, and P is the relative pixel position of the central peak of the interference pattern at the detector plane. P is set to zero when there is no glass plate in the measurement system. The constant C is the calibration constant. Thus, the differential thickness profile of the glass panel can be measured by monitoring the peak intensity position of the central interference fringe on the detector plane while the glass panel is translated. Then the thickness profile of the glass panel is obtained by integrating the measured differential profile.

3. CALIBRATION OF THE MEASUREMENT SYSTEM USING A LIQUID CRYSTAL CELL

In principle, once the pixel position of the central peak of the interference pattern at the detector plane (P) is known, the thickness difference (δt) is determined through Eq. (1). In

practice where we use a broadband light source, however, the focal length (f) of the imaging lens is not certain not only due to the uncertainty of the focal length itself, but also due to the positioning uncertainty of the camera. Thus a new method of calibrating the system which does not require exact values of the slit separation, focal length of the lens, and pixel size of the detector, is needed to obtain higher accuracy. We propose a method to calibrate the double-slit interferometer system by using a liquid crystal (LC) cell. This method can directly map the central peak position of the interference pattern to the local thickness difference of the glass plate.

The proposed method uses an LC cell having partly coated indium tin oxide (ITO) electrode at each surface. The cell is filled with a nematic LC. When voltage is applied to the LC cell, the LC molecules re-align and change the effective refractive index of the LC medium. Firstly, we put the LC cell between crossed linear polarizers with the axis of the LC molecules at 45° with respect to the transmission axes of the polarizers. A beam from a broadband super luminance diode (SLD) is passed through the centre of the coated part of the LC cell and the intensity of the transmitted beam is measured while changing the applied voltage stepwise to the cell. By analysing the transmitted intensity, the relation between the applied voltage and the phase change occurred in the LC cell is obtained. In the next step, we put the LC cell in front of the double-slit (see Fig. 2) and aligned so that one slit is opened to the uncoated part of the LC cell whereas the other slit is opened to the coated part of the cell. While changing the applied voltage to the LC cell stepwise, the pixel corresponding to the central peak of the interference pattern at the detector plane is found using the zero-crossing algorithm. By combining the two measurement results, the functional relation g, between the peak pixel position, P, and the phase difference, ϕ, is found as

$$\phi = g(P). \tag{2}$$

Since the phase difference at the DS can be expressed as

$$\phi = \frac{2\pi}{\lambda} \times (n-1) \times \delta t, \tag{3}$$

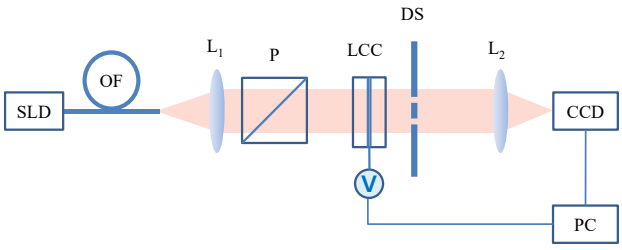

Fig. 2. Schematic diagram of the experimental setup for calibrating the double-slit interferometer system. SLD: super luminance diode; OF: optical fiber; L_1: collimation lens; P: polarizer; LCC: liquid crystal cell; DS: double-slit; L_2: lens; CCD: charge coupled device camera; PC: personal computer; V: voltage source.

the local thickness difference is obtained as

$$\delta t = \frac{\lambda}{2\pi(n-1)} g(P). \tag{4}$$

Figure 3shows the relation between the change in peak position of the interference pattern at the detector plane and the phase difference at the DS.

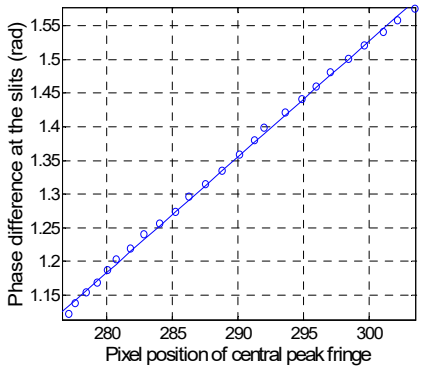

Fig. 3. Measurement results of the relation between the peak position change at the detector and the phase difference at the double slit. The solid line is the least squares fit line of the data.

The slope of the graph shown in Fig. 3 is obtained through a linear least squares fitting as 0.0172 rad/pixel. Inserting the values of $\lambda = 1020$ nm, and $n = 1.5$ to Eq. (4), the local thickness difference was found to simply relate with the peak position as $\delta t = 5.6 \times P$ nm. The calibration constant calculated from Eq. (1) by inserting nominal values of $a = 100$ μm, $\gamma = 7.4$ μm, $n = 1.5$, and $f = 250$ mm is 5.9 nm/pixel. By applying the proposed calibration method, we can enhance the accuracy of the measurement system by approximately 6 %.

4. CONCLUSIONS

An optical method to calibrate the interferometric system which can measure thickness profile or filtered thickness profile of a moving glass plate is proposed. The calibration method makes use of a partly ITO-coated LC cell filled with nematic LC. After measuring the phase retardance of the LC cell as a function of applied voltage, the LC cell was put in front of the DS in the manner that only one slit can see the ITO coat. The voltage applied to the cell generated reference phase difference at the two slits and the change in position of the central peak of the interference pattern was measured as a function of the voltage. In this way, we found out the calibration constant more accurately without knowledge of the slit separation, focal length of the imaging lens and the unit CCD pixel dimension. The proposed calibration method is expected to enhance the measurement accuracy about 6 %.

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