Development of a noncontact optical sensor for measuring the shape of a surface and thickness of transparent objects

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Abstract. This paper deals with a noncontact optical sensor to measure the shape and the thickness of transparent plates such as glass panels of liquid crystal displays. The conventional methods to obtain the shape or thickness of transparent plates depend on contact-type sensors such as linear variable differential transformers. Due to the contact between the tip of the sensor and the surface of objects, the tip is abraded. In addition the casting of glass at high temperature increases the size of the sensor body. The accuracy of the sensor is degraded for these reasons. To overcome these problems, we proposed a low-cost and simple noncontact optical sensor that is composed of a hologram laser unit (of the type used for optical pickup in CD players) and a plastic lens. To evaluate the performance of the proposed optical sensor, a series of experiments were performed for various measurement conditions. The proposed sensor shows excellent performance in measuring the shape of transparent plates. [DOI: 10.1117/1.1355260]

Subject terms: sensors; holograms; fiber lasers; optical pickup; CD pickup.

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1 Introduction

The development of multimedia systems has increased the demand on precise measurements of the shape of cathode-ray tubes and the thickness of LCD glass plates. These components are made of glass in a high-temperature casting process. The conventional methods to obtain the shape of transparent objects involve the use of contact-type sensors such as linear variable differential transformers (LVDTs). For these methods, however, the measurement accuracy is degraded by two factors. The first factor is thermal expansion of the sensor due to high-temperature thermal convection. The second factor is abrasion of the sensor tip due to the contact between it and the hot surface of the glass. To overcome these problems, optical sensing methods have been proposed to obtain the shape of the glass objects. The methods provide high speed, high accuracy, and noncontact measurement.[1]

A simple and low-cost optical sensor to measure the surface and the thickness of the glass simultaneously is described here. It is best to adopt a laser automeasurement system for transparent plate glass such as LCD panel glass. The optical pickup head for a Compact Disc (CD) player[2,3] is available on an autofocusing device. The optical head is used to pick up the binary digital signal on the disc in a CD player with a laser beam. Such an optical head and a motorized linear stage[4] are employed to measure the object. To improve the performance of the sensor, a thermoelectric cooler[5] (TEC) is used to maintain the temperature of the semiconductor laser.

2 The Measurement Principle

2.1 *The Hologram Laser*

In the optical pickup of a CD player, data reading can be carried out by controlling the objective lens via a force voice-coil actuator. The actuator can also be used in the measurement of displacement. It has two degrees of freedom: one for vertical focusing, and the other for tracking. But the tracking motion causes a problem in surface profile measurement.[6] There are some other problems in measuring with a CD pickup module. Firstly, there is no feedback sensor for monitoring the position of the actuator in the vertical direction. Because the position of the surface of the object is estimated from the position of the actuator (or object lens), the position of the actuator is needed. Secondly, the range of motion of the actuator is too short to measure the thickness of glass and the range of depth of a free-form surface. In order to extend the measurement range and to achieve a low-cost optical sensor, some modifications have been made.

Figure 1 shows the beam spot on a signal-detection photodiode (SDP) and a focus-error signal (FES) curve as an example. The SDP is split into five segments. The optical pickup is positioned so each of the three beams strikes a prescribed segment of the photodiode. In Fig. 1, point (a) shows the beam spot when the distance of the object is too far, point (b) at perfect focus, and point (c) too near. Thus, the FES is given by D2 minus D3. To generate a FES, a hologram optical element (HOE)[7] is used to focus onto a SDP. In perfect focus, the focal spot is equally distributedon the two segments (D2, D3) of the SDP. However, if the lens is not in focus, the focal spot on the detector is moved because of the optical properties of the HOE. The unequal distribution of light on the SDP generates a FES. This signal is normalized with respect to the light level to make the signal independent of laser power and disk reflectivity. An example of the FES is shown in Fig. 1. This curve is often called the *S* curve because of its shape. The curve reflects the position of the surface. If a motor controls the optical sensor so that the value of the FES is zero and lies between peak and peak, the controlled positions of the sensor along the surface represent shape of the surface to be measured.

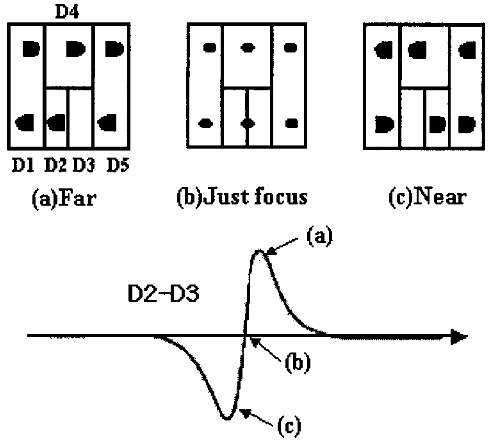


Fig. 1 Beam spot on signal detection photodiode and focus error signal curve.

2.2 *Thickness Measurement*

To measure the thickness of the glass, the conventional methods have to measure two points on the opposite surface along the same normal direction. In this case, the relative mounting position error of two sensors will cause thickness measurement error. The proposed sensor system, however, can measure the thickness from a FES that is detected by a single sensor movement. Figure 2 shows the FES as the sensor moves toward the glass. The two focal points *A* and *B* (i.e., the two zero-crossing points) are generated at the surface. The sensing distance *t* from *A* to *B* is proportional to the real thickness *T*, but it is not equal to it. This is because of the refraction of the light in the glass. Considering the refraction ratio, the real thickness can be obtained as $T=t\times n_g/n_0$, where n_g and n_0 are the refractive indices of the glass and air, *T* is the thickness of the target object, and *t* is the sensing distance.

3 Experimental Results on the Proposed Optical Sensor

As shown in Fig. 3, the optical sensor is composed of a sensor module, driver, and computer. In the sensor module, there are a hologram laser, an objective lens, an automatic power control (APC) circuit to assure constant power of the laser, and a photodiode signal amplifier. An analog-to-digital converter for the FES signal, a laser power control (LPC) for adjusting the laser power to various reflectivities of target surfaces, and a thermoelectric cooler (TEC) control for maintaining temperature are components of the sensor driver. The computer can be used for data acquisition and processing to calculate the shape and thickness of objects. The optical module is mounted on the stage, which is driven by a step motor. The outputs of the sensor signal are connected to a computer through a driver. The range of motion of the stage is 5 mm. Its resolution 0.5 μm.

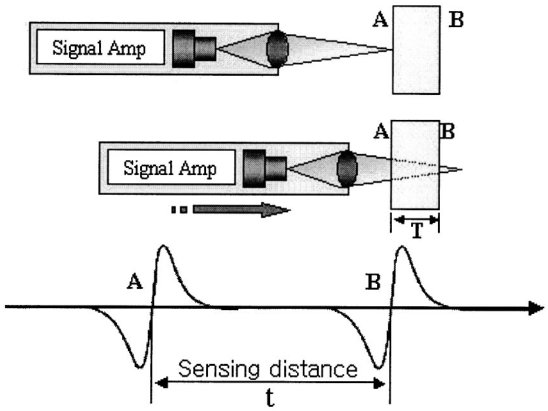


Fig. 2 Focus error signal for measuring thickness.

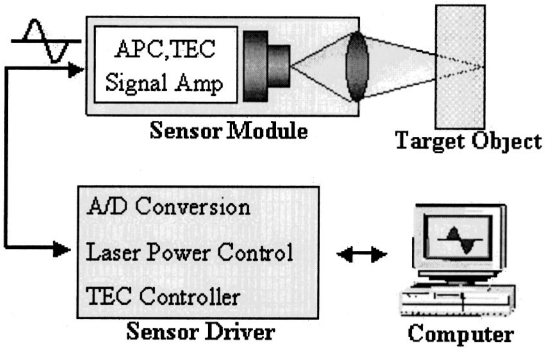
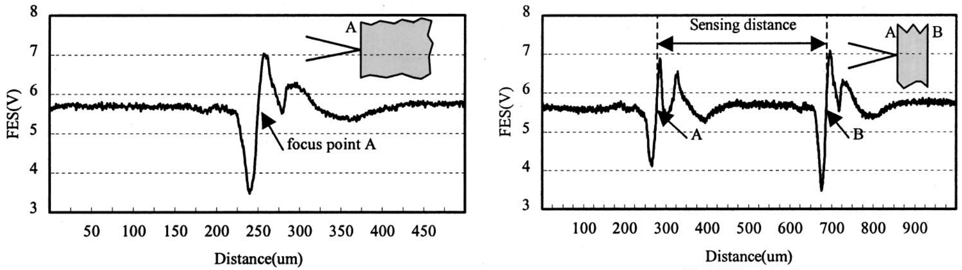


Fig. 3 Configuration of the sensor system.

To evaluate the performance of the proposed optical sensor, a series of experiments were performed for various conditions. The experimental results for the transparent glass plate are shown in Fig. 4. Figure 4(a) shows the *S* curve. The zero-focus point *A* represents the position of the object. Figure 4(b) shows two *S* curves for a thickness of the thin glass plate equal to 650 μm. In Fig. 4(b), the sensing distance is 409 μm and the reflection ratio is 1.585. Therefore, the real thickness of the glass plate can be calculated as described above. The result is 648.3 μm, and the error is 1.7 μm. From the experimental results we see that the actual sensor system yields excellent results in measuring the glass thickness in an industrial setting.

In order to show the sensor performance for various positions of the glass plate, we performed the experiment for two adjacent glass plates where one is tilted as shown in Fig. 5. The sensor is moved a distance Δx in the *x* direction to measure the position of the surface and sequentially scanned through a distance Δy in the *y* direction to measure the next position of the plate. As shown in Fig. 6 the thicknesses of two plates are denoted by T1 and T2; the gap between plates and the tilt angle are denoted by T_g and θ, respectively. The experimental result for the one position of plates is shown in Fig. 7 as an example. In Fig. 7, the four focal points denoted by *A*, *B*, *C*, and *D* can be easily extracted. The method for extraction of the focal point from the *S* curve is mentioned in Ref. 6. The sensing distances T1, T2 and gap T_g can be calculated by the difference of the four points. In Fig. 8 the experimental results show the position and thickness of the plates where T1, T2, θ, and the reflection ratio were 650 μm, 650 μm, 0.65 deg, and 1.585, respectively. The values of Δx, Δy, and the scanned distance in the *y* direction were 0.5 μm, 10 μm, and 10 mm, respectively. The curves denoted by A', B', C', and D' are the outputs of the four focal points. The curves A' and B' are the boundary of G1. The curves C' and D' are



(a) FES for thick glass
(b) FES for thin glass

Fig. 4 FES for measuring shape and thickness of the glass.

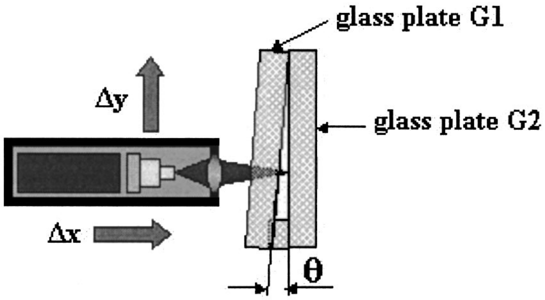


Fig. 5 Experimental setup for shape measurement.

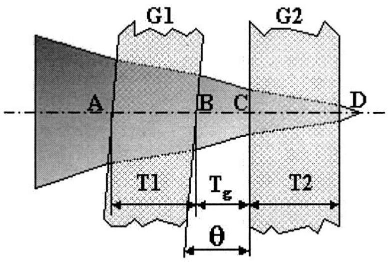


Fig. 6 Notation for the two glass plates.

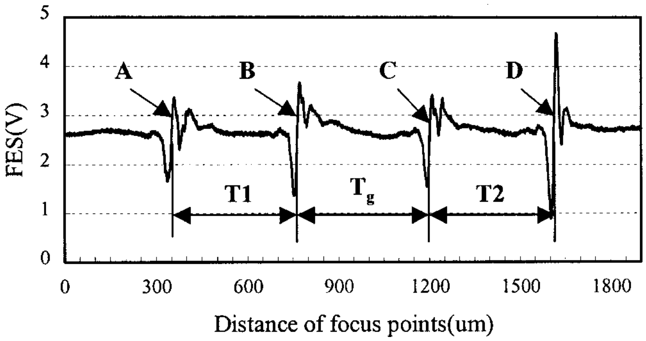


Fig. 7 FES for the two glass plates.

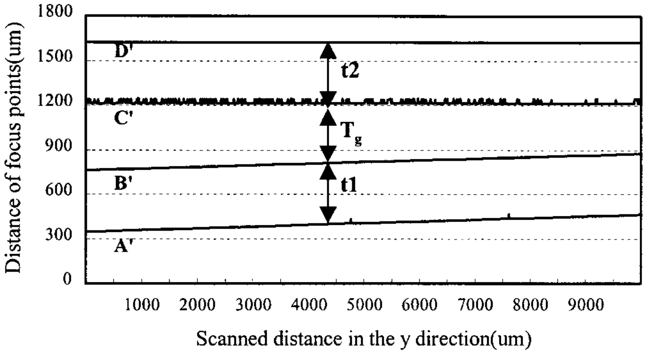


Fig. 8 Experimental results of the shape measurement.

the boundary of G2. From the results, the slant angle θ is calculated from the curve B'. The positions of the inner boundary of G1 are varied from 763.5 to 876.5 μm along the scanned distance of 10 mm. Therefore, the tilt angle was measured as 0.647 deg. The measurement results on the thickness can be calculated from the average value of t1 and t2. The measured thicknesses. T1 and T2 are 653.02 and 649.85 μm.

4 Conclusions

In this letter, we have introduced a noncontact optical sensor for measuring the shape and the thickness of transparent objects such as glass plates. Experiments were performed for transparent plate glass used in LCD panel display devices. The following conclusions can be drawn from the experimental results.

Firstly, we developed a low-cost and simple noncontact optical sensor composed of a hologram laser unit from a CD player to measure the surface and the thickness of the glass simultaneously. Secondly, to overcome the wavelength variation due to temperature change a TEC was employed, which improves the sensor performance in the real world where the ambient temperature varies. The sensor will be used in an optical system for measuring the thickness of LCD plates at Samsung Corning Company.

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