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# Deformation of large liquid crystal display glass sheets across a gap between noncontact transportation devices

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ABSTRACT

In recent years, large mother glass sheets with high resolutions have been used for electric devices, such as television panels, personal computer monitors, and cell phones, particularly to reduce manufacturing costs and improve production efficiencies. Accordingly, high-speed inspection processes for detecting defects in thin-film transistor arrays using charge coupled device (CCD) cameras have become very important, and a noncontact transportation technique for the high-speed inspection section is necessary to avoid damage to the glass sheets during inspection processes. Furthermore, a gap of around 100 mm between transportation devices is needed for the inspection area of the CCD cameras to project an inspection light from underneath the glass sheet. This means that the capability to make a large, thin glass sheet jump over the gap is required for the noncontact transportation device.

In this paper, an air-levitating transportation device that had air-supply pads with orifice restrictors and vacuum ports was proposed to support a 500 mm square, liquid crystal display glass sheet. The deformation of the glass sheet supported by the proposed transportation device was investigated numerically and experimentally when the glass sheet jumped over the gap between the proposed devices. In addition, the optimum combinations of air supply and vacuum pressures and their areas in the proposed device were studied for obtaining the largest jumping distance of the thin glass sheet. It was found that by properly selecting supply and vacuum pressures and their areas, the largest jumping distance supported by the proposed device could reach approximately 75 mm.

## 1. Introduction

In recent years, liquid crystal displays (LCDs) have been applied to various electric devices, such as televisions, personal computer monitors, and smartphones. In particular, the demand for large television panels has been increasing and hence higher resolution and larger sizes of mother glass sheets are required to reduce costs and improve production efficiencies. To handle the increasing resolution and the size of mother glass sheets, high-speed inspection processes for detecting defects in thin film transistor (TFT) arrays using charge coupled device (CCD) cameras has become very important. Therefore, a noncontact transportation technique for high-speed inspection is necessary to avoid damage to the glass sheets during inspection processes. Nowadays, several companies provide noncontact air conveyors for large commercial LCD panels, but only a few studies have reported the behavior of glass sheets supported by air conveyors. Amano et al. [1] numerically and experimentally investigated the deformation of the glass sheet when a porous air-pad transportation device quiescently supported the glass sheet. Lee et al. [2] numerically studied the design of a noncontact air conveyer with simple air slits to minimize the air consumption and measured the deformation of a glass sheet supported by the conveyors. Oiwa et al. [3] investigated the deformation of the glass sheet numerically and experimentally when the glass sheet was quiescently supported by a noncontact aerostatic conveyor with inherent orifice restrictors. Li et al. [4–6] experimentally investigated the levitating height of a glass substrate using vortex-bearing elements. Zhong et al. [7] experimentally investigated the dynamic characteristics of porous-walled air film for a non-contact conveyor system.

In these air conveyers, an inspection area is normally required to detect the TFT defects using the CCD cameras. In addition, the inspection area requires a gap of around 100 mm between the transportation devices to project inspection lights from underneath the glass surface as indicated in Fig. 1. Accordingly, the noncontact transportation device needs to have the capability of making a large glass sheet jump over the gap. In designing such a non-

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## Nomenclature

| | |
|---|---|
| $C_D$ | Discharge coefficient, assumed $C_D = 0.8$ in this study |
| $D$ | Stiffness of the glass sheet, $D = Et^3/\{12(1-\nu^2)\}$ |
| $E$ | Young's modulus of glass sheet |
| $G$ | Weight of the glass sheet |
| $h$ | Levitating gap of glass sheet |
| $n$ | Number of office in the air-supply pad, $n = 6$ |
| $p$ | Pressure |
| $p_a$ | Ambient pressure |
| $p_{sg}$ | Supply pressure |
| $p_{vg}$ | Vacuum pressure |
| $q$ | Load per unit area |
| $q_x$, $q_y$ | Mass flow rates in the $x$ and $y$ directions |
| $q_{in}$ | Mass flow rate flow through an equivalent orifice in the air-supply pad |
| $R$ | Gas constant |
| $T$ | Absolute temperature |
| $t$ | Thickness of glass sheet |
| $w$ | Displacement of the glass sheet |
| $x$, $y$ | Cartesian coordinates |
| $\kappa$ | Ratio of specific heat, $\kappa = 1.4$ |
| $\mu$ | Viscosity of air |
| $\nu$ | Poisson's ratio of glass sheet |
| $\rho$ | Density of air |
| $\rho_g$ | Density of glass sheet |

contact transportation device, the performance evaluation uses an actual large transportation device. It is obvious that using the actual large device for performance evaluation is very time consuming and costly. To design the air conveyor effectively, numerical methods to predict the deformation and levitating height of the glass sheet are required.

We propose an air-levitating transportation device using the combination of air-supply pads and vacuum holes, which were placed alternately. The deformation behavior of a 500-mm-square glass sheet under the stationary condition was investigated numerically and experimentally to obtain the optimum combinations of air supply and vacuum pressures and their areas when the glass sheet jumped over the gap. In the numerical calculations, the Reynolds equation and the equation of elasticity for the glass sheet were solved simultaneously using the finite difference method. In addition, the numerical results were compared with the experimental results to verify the validity of the numerical predictions. It was found that the proposed transportation device could make a glass sheet with a thickness of 0.7 mm jump over a gap of 75 mm.

**Table 1**
Physical properties of the glass sheet.

| | |
|---|---|
| Young's modulus, $E$ [GPa] | 70 |
| Poisson's ratio, $\nu$ | 0.2 |
| Density, $\rho_g$ [kg/m$^3$] | 2500 |
| Thickness, $t$ [mm] | 0.7 |

## 2. The proposed noncontact transportation device

Fig. 2 shows the geometrical configuration of the proposed noncontact transportation device. In this figure, the principal dimensions of the proposed device are indicated. A glass sheet was supported by three flat plates with a width of 150 mm and a length of 500 mm set in parallel each other. As shown in Fig. 2, each plate had 38 air-supply pads to levitate a glass sheet by feeding the pressurized air and 37 vacuum holes to reduce the levitating height and increase the stiffness of the air film. The air-supply pads and vacuum holes were placed alternately. The proposed device was divided into four regions in the $x$ direction to control the supply and vacuum pressures at each region individually. The glass sheet was transported in the $x$ direction as indicated in Fig. 2.

Fig. 3(a) and (b) shows the cross-sectional and top views of the air-supply pads. Each supply part, with a diameter of 18 mm, had six orifice restrictors with a diameter of 0.2 mm at the position of a diameter of 10 mm and embedded at the plate surface with a depth of 0.1 mm. The diameter of the vacuum holes was 1 mm.

Fig. 4 shows the structure of the tubing of the proposed device. An air compressor was connected to the air-supply pads and a vacuum ejector was connected to the vacuum holes. Pressure gauges at the positions seen in Fig. 4 measured the supply and vacuum pressures. Table 1 shows the principal physical properties of the glass sheet (Nippon Electric Glass OA-10) used in the calculations and experiments.

## 3. Numerical calculation method

In this paper, the deformation and the levitating height of the glass sheet supported by the proposed device were obtained numerically by solving the Reynolds equation and the equation of elasticity for a thin plate simultaneously.

### 3.1. Calculation method for pressure distribution

The pressure distribution in the levitating gap between the glass sheet and the device was obtained by solving the Reynolds equation. The mass flow rates in the levitating gap in the $x$ and $y$ directions through the width of $dy$ or $dx$ were given as follows:

$$q_x = -\rho \frac{h^3}{12\mu} \frac{\partial p}{\partial x} dy \tag{1}$$

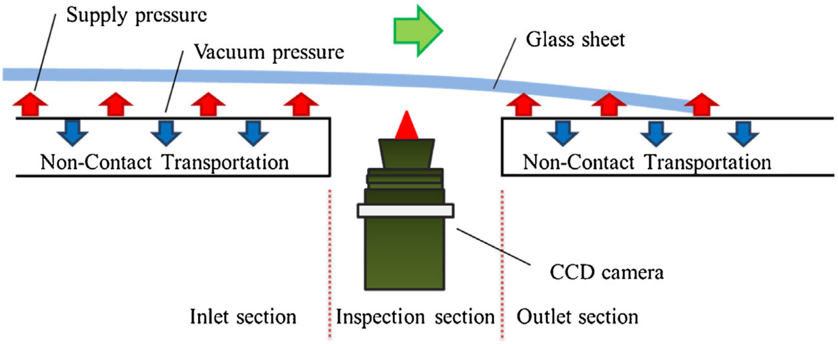

**Fig. 1.** Noncontact transportation device for inspection process.