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Dynamic analysis of a PDP exhaust hole processing equipment considering glass substrate interaction †

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Abstract

Exhaust hole drilling is one of the PDP (Plasma Display Panel) manufacturing processes to make about 1mm diameter holes for sucking out air in order to generate vacuum between two PDP glass substrates. In the drilling process, big-sized glasses about the size of a queen size bed are loaded, aligned, drilled, and unloaded, during which the dynamic interactions between glass and the handling equipment are very significant. To analyze exhaust hole drilling equipment dynamics, interaction with glass substrates that have somewhat different material properties from general glasses should be considered. The Young's modulus and Poisson ratios of the substrates have been determined experimentally and verified via computation that simulates a well-known three-point bending test. Dynamic interaction of the glass with the handling equipment is modeled using a flexible glass and rigid body handling equipment models. The velocity profile by which the glasses are driven and the material properties of the handling equipment components contacting with the glasses are evaluated in view of the structural integrity of the glass and the operational efficiency of the equipment. The dynamic model is demonstrated to be an effective design tool for an exhaust hole drilling machine.

Keywords: PDP glass substrate; Exhaust hole drilling; Multibody; Flexible body; Glass handling mechanism

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1. Introduction

The exhaust hole drilling on a PDP glass substrate has been mainly performed by mechanical drilling. However, this causes vibration and results in residual stresses and coarse surfaces that may cause serious damages to the glass. To circumvent these problems, laser drilling has recently been widely used. The efficiency of the exhaust hole drilling process depends on two factors; one is how to control laser power and exposure time, and the other is how to handle such big-sized glass substrates accurately and safely. The exhaust hole drilling machine, as shown in Fig. 1, loads a big-sized glass, and the glass is aligned to be drilled. It is then unloaded by the glass handling mechanism. During this process, PDP glass contacts with various components of the equipment and experiences abrupt start and stopping motion that may cause structural damage. Thus, in the design of the glass handling mechanism, the dynamic interaction between glass and the machine should be taken into consideration.

Since the exhaust hole drilling process is performed at a high speed, large defection, vibration, and collision between glass and the handling mechanism are inevitable [1]. Thus, dynamic analysis that considers the interaction between glass and the equipment is necessary for equipment design. However, since the characteristics of PDP glass and general glass are quite different, and glass is generally very brittle, it is not appropriate to model PDP glass based on the linear elasticity theory [2].

Tak et al. [3] developed a dynamic interaction model between LCD glass and its handling robot in an

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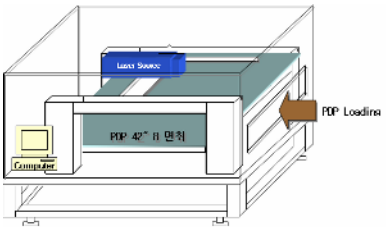

Fig. 1. Exhaust hole drilling machine.

attempt to reduce vibration which is so severe that it may break the glass. The material properties of glass are estimated through the three-point bending and O-ring tests, and glass is modeled using triangular shell elements. Chung et al. [4, 5] reduced vibration during high-speed handling of LCD glass by optimizing the acceleration profile. Lee and Lee [6] performed analysis on a glass handling system that has an air floating device and driving mechanisms such as roller and timing belt to reduce vibration.

This research proposes a method for experiment-based modeling and performing dynamic analysis of a PDP glass handling equipment that interacts with a large-sized flexible glass.

2. Glass modeling

To estimate the material properties of glass, a three-point bending test is performed. As shown in Fig. 2, load is applied to the 20 80×25×2.8(mm)-sized specimens until failure with a maximum loading velocity of 0.01mm/mm. Fig. 3 shows the force-deflection curve. From the test results, the stress and Young's modulus can be calculated as follows:

$$\sigma_u = \frac{3PL}{2bh^2}, E = \frac{PL^3}{4bh^3\delta_{\max}} \tag{1}$$

where σ_u represents strain, P is the maximum load, L is the distance between two supports of specimen, b and h are the width and thickness, respectively, E is Young's modulus, and $\delta_{\max}$ is the maximum deflection, respectively.

A finite element model for the three-point bending test as shown in Fig. 4 is set up using ABAQUS. The purpose of this process is to validate the FEM model of the specimen, thus checking the accuracy of Young's modulus and fine-tuning the Poisson's ratio. Fig. 5 shows the force-deflection curves as a function of Poisson's ratio. For the Poisson ratio range of 0.2-0.26, the force-deflection curves show very little change. Thus, the nominal value of 0.23 for Poisson's ratio is adopted.

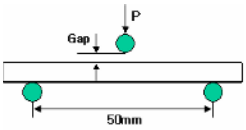

Fig. 2. 3-Point bending test.

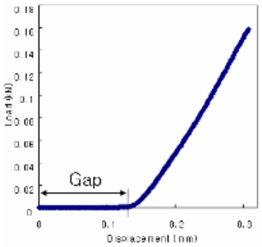

Fig. 3. Force-deflection curve.

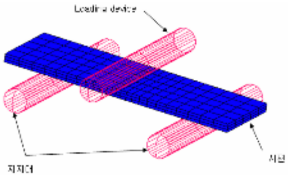

Fig. 4. Finite element model of the three-point bending test.

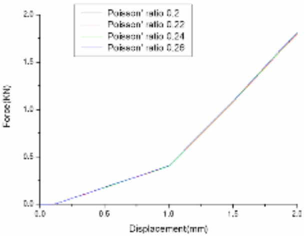

Fig. 5. Force deflection as a function of Poisson's ratio.

The calculation of fracture stress is important because glass may be broken during the handling process. For the estimation of fracture stress, three-point bending test results are analyzed using the Weibull distribution function. Cumulative failure distribution at stress level x is computed as

$$F(x) = 1 - \exp\left[-\left(\frac{x}{0.05044855}\right)^{2.742831}\right] \tag{2}$$

The plot of F(x) is shown in Fig. 6. For a load above 0.26KN, all specimens fail with a stress of 0.0867 GPa, which is relatively a larger value than the general glass failure stress of 0.065 GPa. During glass handling, the maximum stress should not exceed the failure stress.

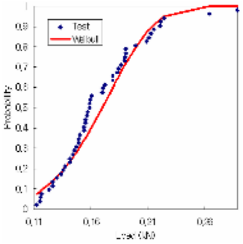

Fig. 6. Probability-Load Diagram.

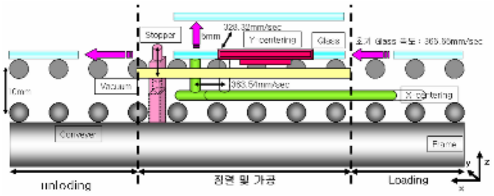

Fig. 7. Loading, aligning, and unloading.

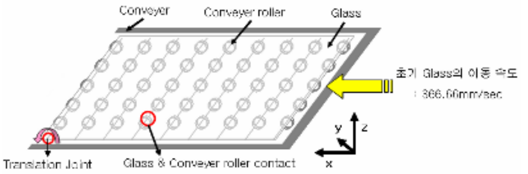

Fig. 8. The glass loading process.

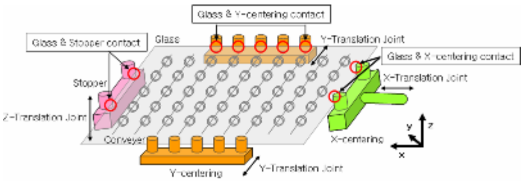

Fig. 9. The alignment process.

3. Modeling of the glass handling mechanism

During exhaust hole processing, a glass is loaded, aligned, and unloaded as shown in Fig. 7. Fig. 8 shows the loading process where a conveyor roller moves vertically (z-direction) and contacts with the glass underneath, and then by rotation of the roller, the glass is driven with a velocity of 366.6mm/sec. Fig. 9 shows the aligning process where glass is driven laterally (x-direction) and stopped by a rubber stopper. Once glass is stopped, it is floated by the air pressure underneath, and then the x- and y-directional aligning devices move the glass to the center position by laterally pushing the glass.

To analyze the motion of the glass handling mechanism, flexible glass and rigid body handling mechanism are modeled using ADAMS.

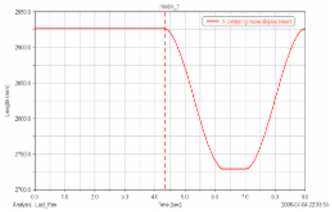

Fig. 10. The displacement during x-centering.

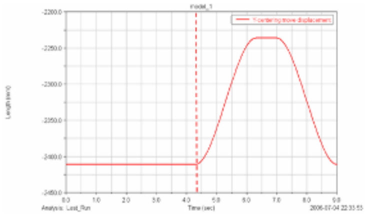

Fig. 11. The displacement during y-centering.

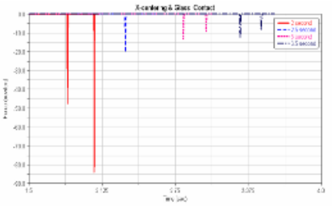

Fig. 12. Impact force as a function of x-centering time.

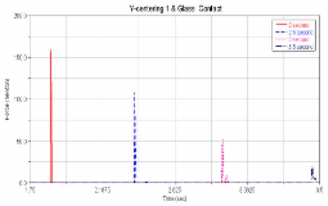

Fig. 13. Impact force as a function of y-centering time.

The displacements of the x- and y-directional aligning devices are given in Fig. 10 and 11, respectively; 4.3 seconds after loading, glass is stopped, and the x- and y-directional aligning processes are performed with 174.6 mm displacement for 2 seconds.

4. Parameter study

The glass handling device should be less sensitive to the variation of design parameters. The velocity profile is aligned, and the spring stiffness of the stopper is adjusted to reduce the impact to the glass.

Fig. 12 shows the impact force of glass as a function time during the x-directional aligning process. As the alignment time increases from 2 seconds to 3.5

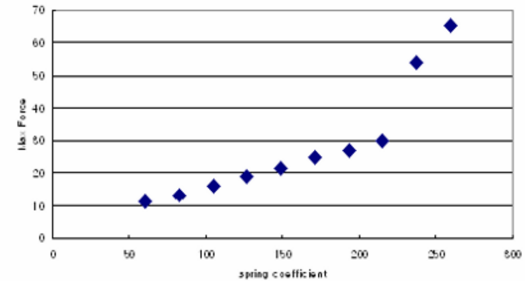

Fig. 14. Impact force as functionof X-centering roller spring stiffness.

seconds, the contact force at the glass is reduced from 84.01N to 12.99N. This result could be easily anticipated, however this could be used as the guidelines for the maximum values on impact force and aligning time. Moreover, the y-directional alignment as shown in Fig. 13 shows similar result to the x-directional alignment.

The contact forces during the x and y-directional alignment process are to be calculated. Initially, there is a distance of 445.2mm between the x-directional aligning roller and the glass. A spring is attached to the roller to reduce the impact force during alignment. The x-directional alignment is performed for 3.5 seconds. Fig. 14 shows the calculated contact force as a function of spring stiffness, where impact force increases as the stiffness increases.

5. Conclusion

To estimate PDP glass's material properties, three-point bending tests are performed. Young's modulus, and Poisson's ratio are obtained through experiment and simulation of the three-point bending test. Furthermore, the facture stress of the PDP glasses is predicted using Weibull distribution function. The flexible models for the glass using ADAMS and ABAQUS showed good agreement with the experiments, thus demonstrating the validity of the flexible glass model.

Three stages of glass handling during the drilling process, loading, aligning, and unloading are simulated considering the dynamic interaction between glass and the handling mechanism. Glass, conveyor, roller, stopper, and the x- and y-directional roller are modeled using a multibody approach.

The velocity profile by which the glasses are driven and the material properties of the handling equipment components contacting with the glasses are evaluated in view of the structural integrity of glass and the operational efficiency of the equipment. The dynamic model for the glass handling equipment is demonstrated to be an effective design tool for the exhaust hole drilling machine.

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