Numerical Study on the Air-Cushion Unit for Transportation of Large-Sized Glass Plate

Hyun Joo Jun*, Kwang Sun Kim and Ik Tae Im†**

*R&D Center, AVACO

**Dept. Mechatronics, Korea University of Technology and Education

†Dept. Automotive Engineering, Iksan National College, 194-5 Ma-dong Iksan 570-752

ABSTRACT

Non-contact transportation of a large-sized glass plate using air cushion for the vertical sputtering system of liquid crystal display (LCD) panel was considered. The objective of the study was to design an air pad unit which was composed of multiple injection and exhaust holes and mass flow supplying pipe. The gas was injected through multiple small holes to maintain the force for levitating glass plate. After hitting the plate, the air was vented through exhaust holes. Complex flow field and resulting pressure distribution on the glass surface were numerically studied to design the air injection pad. The exhaust hole size was varied to obtain evenly distributed pressure distribution at fixed diameter of the injection hole. Considering the force for levitating glass plate, the diameter of the exhaust hole of 30 to 40 times of the gas injection hole was recommended.

Key Words : Liquid Crystal Display (LCD), Air-Cushion, Non-contact Transportation, Computational Fluid Dynamics

1. INTRODUCTION

Sputtering is widely used to fabricate electrodes or dielectric films on a glass surface in manufacturing process of highly integrated liquid crystal display (LCD) panels. A glass transportation unit plays an important role to guarantee the dust-free large-sized glass plates. Several techniques to move glass plates have been devised and applied in the manufacturing process. Non-contact transportation technique, instead of the conventional system using vacuum chuck or carrier, has been focused due to the enlarged glass size, high-precision and clean environmental manufacturing process. Utilizing chuck fixing on the end-effector of robot arm give a pretty deflection on the glass base-plate and resulting scratch on the surface or even breakdown during transportation[1]. Contamination by dust particles is another problem. Vibration of the plates is one of the common problems in a carrier type transportation unit.

Air bearing using injected gas [1, 2], electrostatic or magnetic force [1] and acoustic levitation [3] are easily found techniques as non-contact transportation methods. Using air cushion has advantage in overall weight of the sputtering equipment because it requires no supplementary apparatus such as large carrier. Moreover, it does not have effects on the coating process like magnetic or electric fields. The size of glass plates in a manufacturing process becomes very large to cope with the large-sized LCD products such as television and high throughput of production. Therefore the size of the process equipment becomes huge. This also implies the importance of the reducing weight and space for facilities installations.

This study is on the design of an air pad for the levitation and non-contact transportation of glass plates using compressed gas injection. The air pad unit will be installed in a vertical type sputtering system of a very large glass plates for the LCD panels. Gas flow under the plates and resulting pressure field on the glass surface were analyzed to obtain conditions for the stable floating and transportation. Design parame-

†E-mail : itim@iksan.ac.kr

ters were determined based on the analysis results. Fig. 1 illustrates the air cushion concept for the levitation of glass plates using injected gas through holes. Properly arranged exhaust holes are also important to obtain evenly distributed pressure which is inevitable to maintain the glass plates stable without deflection or wavy oscillation. Data for designing the air pad such as hole size were proposed through the flow analysis using computational fluid dynamics.

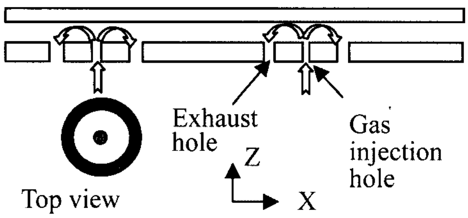


Fig. 1. Schematic illustration of an air-cushion levitation system for non-contact transportation of large-sized glass plates.

2. AIR PAD CONFIGURATION

In the previous report [2] on the non-contact transportation of glass plates, we have shown an air pad in which the gas injection holes and exhaust slots were periodically arranged. The proposed pad shape, however, was for the transportation of the 5th generation glass plates. Simple scale-up of it for the 7th generation glass plates is easily predictable to have several problems. Necessary gas flow rate, one of the production costs, increases very rapidly according to the enlarged exhaust slot area.

Based on the experiences on the 5th generation air pad, we devised a new one for the 7th generation glass plates. The position and shape of the exhaust holes are the most differentiable from the 5th generation pad. Slots for gas exhaust in the previous pad design were located between gas supplying holes. They are located around the inlet holes in the new design. Saving gas consumption is one thing to the change of the holes arrangement. Fig. 1 shows the schematic concept of the new air pad. Once the mass flow supplying pipe was filled, gas is injected through small holes acting as nozzles. Gas flow direction is changed when it hits the glass surface and flows out through the exhaust holes. Mass flow supplying pipe makes the velocities from the inlet holes are almost the same along the pipe. Injection and exhaust holes were arranged with uniform distance in both directions and the pitch of 150~200 mm was used according to the previous research results [2]. The pad was installed at over 80 degree from the horizon in the sputter.

3. ANALYSIS

Computational fluid dynamics was used to analyze the flow characteristic of gas between the glass plate and the pad. Gas is injected from inlet holes and flows to outlet after impinging against the glass plate. We assumed that the glass plate was suspended at 2mm by the gas and symmetry for the sake of simple analysis because it was located in the center of a pad. It was also considered completely flat without deflection. The incompressible gas with neglecting temperature variation was assumed. Inlet velocities at all holes were considered to be uniform.

Because the Reynolds number based on the inlet velocity and radius was more than 3500, the flow was treated as a steady state turbulent flow. Standard k-ε model was used. Thus the flow could be described by mass conservation equation, time averaged momentum equations and k-epsilon model equations.

Boundary conditions for the solution of governing equations were as follows. At the inlet holes, gas flow velocity was prescribed as Vin. At the exhaust region near inlet holes and four sides along the glass plate edge, constant pressure boundary condition was used. At the solid surfaces of pad and glass plate, no-slip condition was applied. To solve the governing equations, the commercial CFD software FLUENT [4] was used.

Fig. 2 shows an example of the grid system with the lines for checking the pressure profile on a glass plate. Near holes with high inlet velocity, fine grid was used because the gradient of pressure and velocity was expected to be large. To find appropriate grid system, the pressure distribution on the glass plate is checked at fixed grid number of X and Y directions and varying grid points of Z-direction, perpendicular

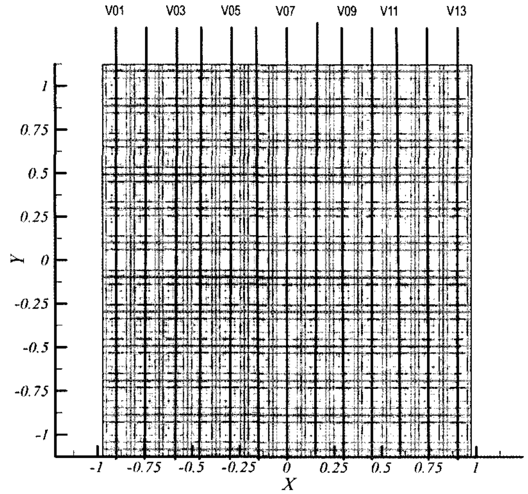


Fig. 2. An example of the grid system with the lines for checking pressure profile on a glass plate.

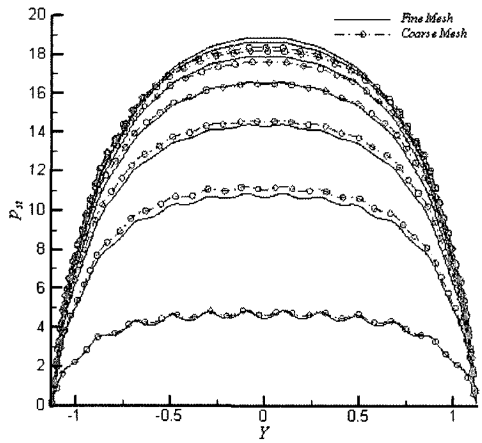
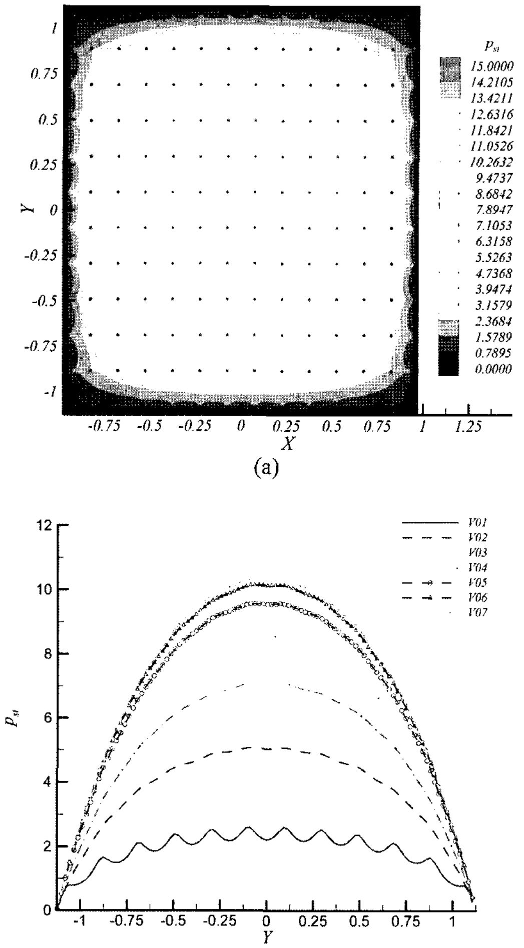


Fig. 3. Pressure profiles along the vertical lines for the two different grid systems.



(a)

(b)

Fig. 4. Simulation results when the diameter of the exhaust holes is 4 Di, (a) pressure contour map on the surface of the glass, (b) pressure profiles along the vertical lines.

to a glass plate. Fig. 3 shows pressure profiles at two grid systems, coarse mesh system having 12 grid points and fine mesh system having 20 grid points along the Z-direction. There is a difference, but not very large, at pressure near the center of the glass plate where pressure is the highest. The present study used the fine mesh system having 20 grid points. Additional fine grid systems were not tested because the computing power was limited.

The lift force of the glass plate owing to gas injection can be obtained by integrating the pressure over the area,

$$F_l = \int_A p \, dA \, . \quad (1)$$

4. EFFECT OF EXHAUST HOLE

The most important point in the pad design is to transport a levitated glass plate at a stable state. For the stable transportation, we have known from the experimental experiences that a pressure distribution of a glass plate has to be as uniform as possible [5]. To obtain enough levitation force and an equal pressure distribution on the glass surface, the size and position of inlet and outlet should be appropriate. As the first step to get design parameters, we focused on the effect of the size of the exhaust holes to the pressure distribution. As a fixed diameter of inlet holes, Di, diameter of outlet holes was increased from 4 times to 80 times of D_i.

Fig. 4 shows the analysis results when the exhaust hole diameter is $4D_i$. The pressure at the center of the plate is high and becomes lower to the edge. This is because insufficient gas exhaust due to the small size of the exhaust holes. Unstable transportation is easily predictable at this pressure distribution because the glass plate is waving when it moves. Floating height of the glass of the center of the plate is higher than the boundary area so the plate shape becomes like a mountain in actual situation. Fig. 5 shows the analysis result at a diameter of exhaust hole of $36D_i$. Pressure is remained uniform except the edge part of the glass.

Return flow after the gas hits the glass surface flows directly toward the exhaust holes and this makes the pressure distribution uniform. We can see the difference in flows from the velocity vectors and pathlines plots shown in Fig. 6(a) and Fig. 6(b).

Fig. 7 shows the pressure profiles according to the size of exhaust holes along the Y direction at X=0. The pressure shows increasing tendency at first but decreasing after a certain exhaust-hole diameter. It is thought to be related to the vortex that forms around the inlet holes as shown in Fig. 8. If the size of outlet hole is small, the strong vortex appears near the inlet holes as shown in Fig. 6. This causes a rising flow around inlet hole and acts as a vacuum pump. In this case, air is inflowed though the outlet holes due to the suction effect. In accordance with the increasing size of exhaust holes, flow rate is increased and resulting pressure becomes high. When exhaust hole becomes bigger than a certain value, here $20D_i$ case, the pressure is decreasing because the return flow is

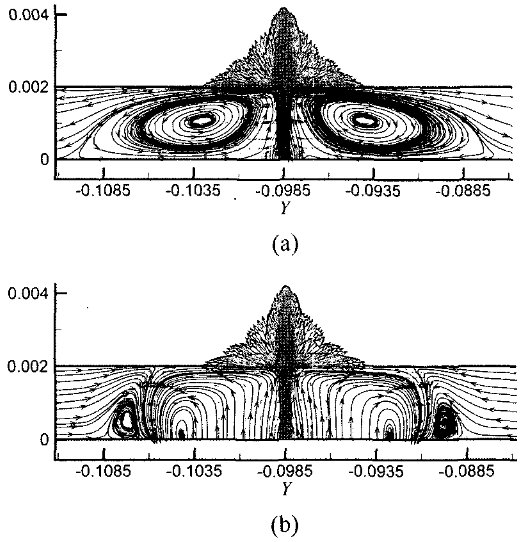


Fig. 6. Velocity vectors and the pathlines at (a) $4D_i$ and (b) $36D_i$ exhaust holes

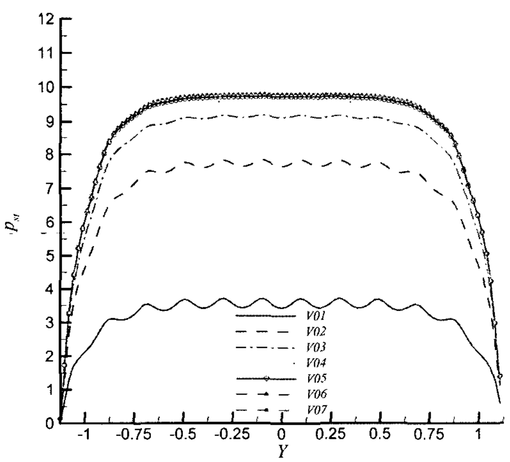


Fig. 5. Profiles of the pressure distribution along the vertical lines at the exhaust hole diameter of $36D_i$.

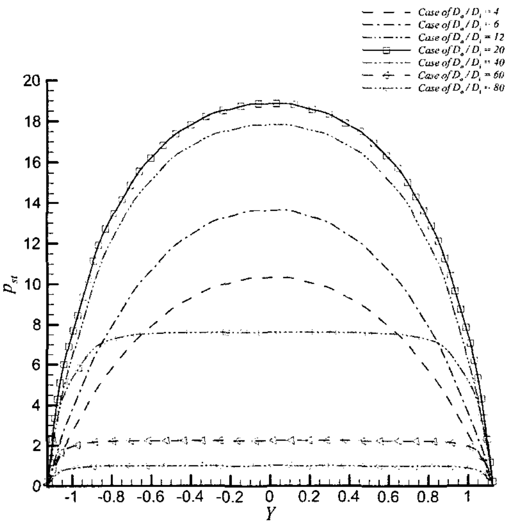


Fig. 7. Profiles of the pressure at X=0 according to the variation of the diameter of the exhaust holes.

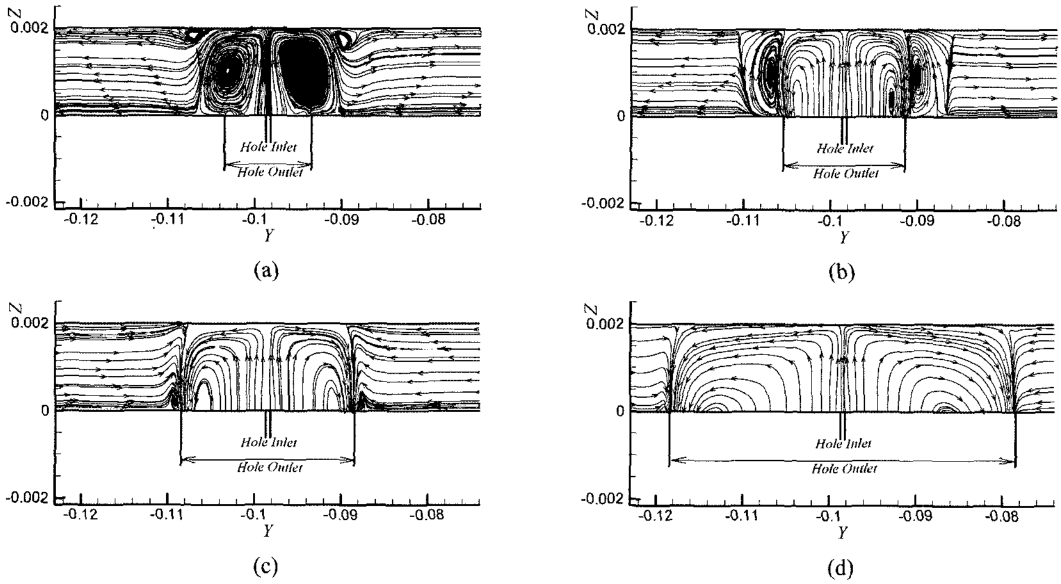


Fig. 8. Flow patterns around the inlet and exhaust holes according to the variation of the exhaust-hole size, (a) $20D_i$, (b) $28D_i$, (c) $40D_i$ and (d) $80D_i$.

exhausted directly and no vortex forms. For uniform pressure distribution, large exhaust hole is required, but too wide hole can not give a sufficient lift force for a ultra-large glass plate. In gas consumption aspect, the pressure distribution and levitation force are the pros and cons since we try to get enough levitation force with small flow rates. Considering the uniformity of pressure and levitation force, it can be said that 30Di to 40Di is a appropriate exhaust-hole size though the solutions are not from the systematic optimization.

Fig. 8 shows the flow patterns around the holes according to the increasing of the diameter of the exhaust-holes. Diameter of the inlet holes was fixed. When the diameter of the exhaust-hole was small strong recirculation flow was made. Recirculation flow was vanished and resulting lifting force was decreased as the diameter of the exhaust-hole was increased.

5. CONCLUSION

According to the increasing size of LCD products, it is very important to develop highly productive sputtering device using very large glass plates for the priority in LCD market shares. In this study, we considered air pad designs as a fundamental step to develop the non-contact glass transportation unit for high throughput vertical sputtering equipment for LCD panels. Flow phenomena between the air pad and glass surface were numerically analyzed to obtain pressure distribution on the glass surface according to the size of the exhaust holes. As a result, the maximum pressure decreases after showing increasing tendency according to the increasing exhaust-hole diameter. To get levitation force without pressure concentration, the diameter of the exhaust-hole is proposed at 30 times to 40 times of inflow-hole diameter.

ACKNOWLEDGEMENTS

This work was supported by grant from the Ministry of Commerce, Industry and Energy.

REFERENCES

1. F. Poh, T. Higuchi, K. Yoshida, K. Oka, "Non-contact transportation system for thin glass plate utilizing combination of air bearing and electrostatic force", SCIE'99, 212, B-2, pp. 1053-1058, 1999.

2. Ik-Tae Im, Hyun Joo Jun, Kwang Sun Kim, "Numerical study on the air-cushion glass transportation unit for LCD panels", Journal of the Semiconductor and Display Equipment Technology, Vol. 5 No. 1, pp.27-31, 2006.
3. T. Amano, Y. K. Nakamura, S. Ueha, Y. Hashimoto, "A multi transducer near field acoustic levitation system for non-contact transportation of large-sized planar objects", Jpn. J. Appl. Phys. Vol.39, part I No.5B, pp. 2982-2985, 2000.
4. FLUENT is a product of Fluent Inc., 10 Cavendish Court, Centerra Resource Park, Lebanon, NH 03766, USA.
5. AVACO Co., LG Phillips LCD Co., "A study on the development of the next generation sputtering equipment for LCD manufacturing - 1st year report", 2006, The Ministry of Commerce, Industry and Energy, Korea.