New air bearing technologies for roll-to-roll printing applications

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Rolling element bearings developed in the last century were a revolutionary improvement over the plain bearings that had been pushed to their limits in applications like electric motors and automobile wheels. Air bearings can likewise be seen to represent the next logical step in bearing design. These may be exploited by mechanical engineers to extend their design capabilities for precision manufacturing systems.

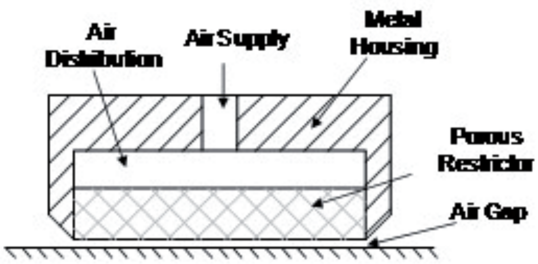

Fig. 1: Cross-section of typical porous air bearing

Air bearings use a thin film of pressurized gas to provide a low friction, load-bearing interface between surfaces. As the two surfaces do not touch, the traditional bearing-related problems of friction, wear, particulates, and lubricant handling can be avoided. The use of air bearings in certain precision systems is well established due to the distinct advantages they offer in precision positioning, such as zero backlash and constant static/dynamic coefficients of friction, so no stick-slip. Thus, they have been exploited in applications such as ultra-precision lithography machines and CMMs (Co-ordinate Measuring Machines). Low friction also means less heat generation, so less thermal disturbance, and minimal power loss for high-speed applications, such as high-speed precision spindles. While any heat generation is of course not zero, relative surface speeds of the order of 30 m/s must be reached before significant heat can be measured.

In recent years, IBS Precision Engineering has been championing the use of air bearings in the area of roll-to-roll where non-contact, almost zero friction, and no static build-up can also be of great benefit to production processes.

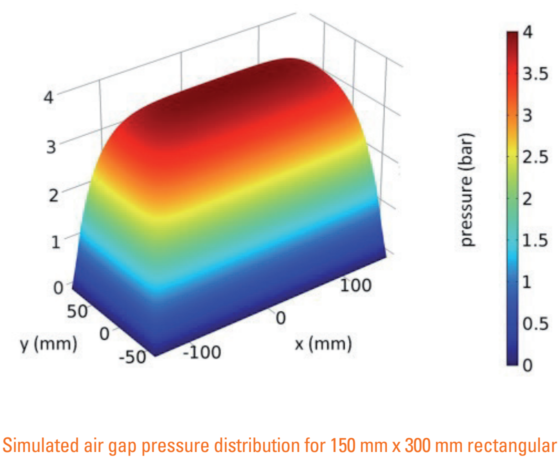

Fig. 2: Simulated air gap pressure distribution for 150 mm x 300 mm rectangular porous air bearing.

SEMI-FLEXIBLE SUBSTRATE HANDLING OR PROCESSING. The typical fly heights for loads (or films) on porous air bearings are of the order of 10s to 100s of µm. In some applications, vertical positioning and stiffness in the z-direction are critical. The Flat Panel Display (FPD) manufacturing industry, for example, has stringent requirements for the handling, processing, and inspection of the glass; where glass can be considered a semi-flexible substrate. Precision, non-contact handling of the glass is required for both optical inspection and for LCD printing (Fig. 3). Here, air bearings with so-called vacuum pre-loading are used to control the vertical height within ±5 µm. In such air bearings, regions of sub-atmospheric pressure ('vacuum holes or grooves') are distributed within the bearing region and used to reduce the levitation height and improve the out-of-plane stiffness [1]. The vacuum channels act as the equivalent of a preload, reducing the sensitivity to variation in the transported substrate, with zero additional mass. Similar techniques are also used in photovoltaic Solar Panel processing.

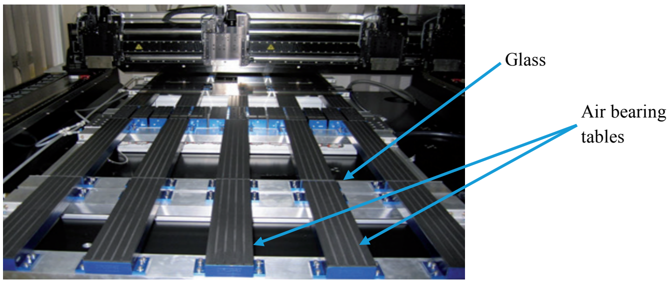

Fig. 3 Flat-panel display glass processing unit showing air bearing tables for glass transport.

SUPPORTING FLEXIBLE SUBSTRATES FOR ROLL-TO-ROLL. The development of flexible devices for use in consumer electronics has recently attracted much interest. In addition, internet-of-things technology requires low-cost ubiquitous and disposable electronic devices. Roll-to-roll manufacturing is a highly productive manufacturing process that can be used to print electronics and resolve issues of cost and flexibility [2]. Three main process parameters are important in roll-to-roll manufacturing: 1) web tension; 2) web position/speed; and 3) printing force. As printed electronics become more sophisticated and more integrated, these parameters require higher accuracy. Furthermore, newly developed functional inks for printed electronics are typically very sensitive; thus, contact with the printed surface should be avoided wherever possible. The application of air bearings in roll-to-roll processes offers improvements in the accuracy of the web positioning and speed. Avoiding web contact also offers reduced damage and contamination of sensitive films.

NON-CONTACT CONVEYING – AIR TABLES. Conveyor air bearings, or air tables, normally used for transport of rigid (or semi-rigid) substrates, may be applied for web transport. In such air tables, vacuum grooves are used to pull the supported web towards the air bearing, improving stiffness and stability at a given fly height. Using a capacitive sensor and a metal-coated film as shown in Fig. 4, fly height and deformation of a flexible film can be investigated. In this instance, a 300 mm, 50 µm film has been assessed.

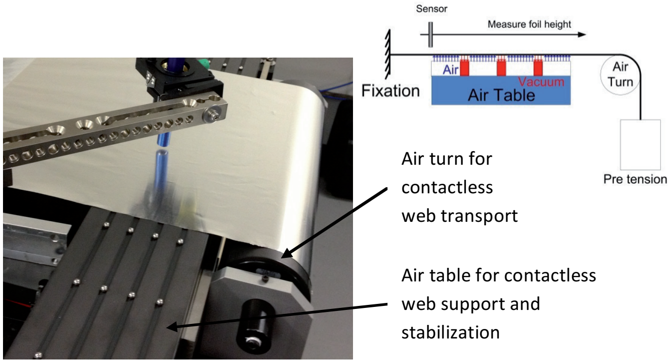

Fig. 4 Air table measurement set up.

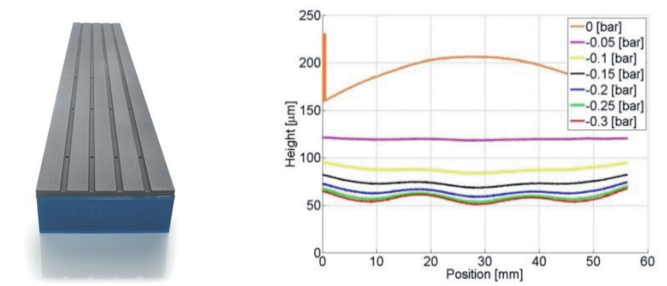

Fig. 5 Air table (left). Film fly height above air table (right) in tension direction using 2 bar air pressure, 0 to -0.3bar vacuum.

Fig. 5 shows the fly height and form in the length (tension) direction of the film, as a function of vacuum pressure with the air bearings pressurised to 2 bar. This data confirms that at optimal vacuum/pressure settings, film height variation < 5 µm over 55 mm can be achieved in the tension direction. The height variation in a lateral direction was less than 15 µm, measured over 200 mm of film width.

To test the capability of the air table to reduce vibrations in a moving film, measurements were completed in cooperation with Eight19 Ltd, Cambridge, UK. Integrated into an R2R line, the film height was measured with a capacitive displacement sensor. Without support by the air table, vibrations of more than 250 µm were seen in the film (Fig. 6). With the air table, these vibrations were reduced to < ±5 µm. The measurement was repeated with 1 and 5 m/min film velocity. No significant difference between these measurements was seen. Such film stabilisation has important advantages for applications such as inkjet printing where film stabilities in the vertical direction below 50 µm are often required.

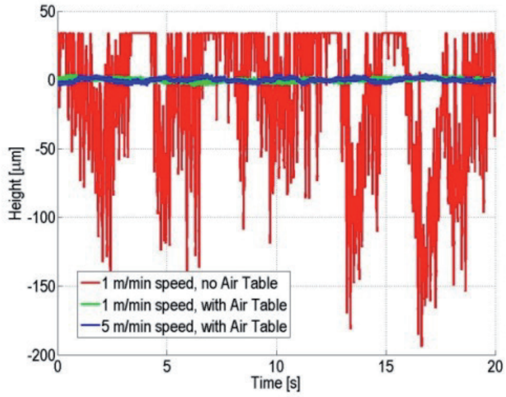

Fig. 6: Film height over time with and without air table support.

Porous media air bearings are often used in cleanroom applications. Results of tests done by the manufacturer indicate that the porous air bearings produce less than one thousand particles >0.1 µm per m3 of exhausted air.

CONTACTLESS ROLLERS – AIR TURNS. Cylindrical porous-media air bearings, or air turns, can be used as replacement idler rollers i.e. non-driving contact rollers, for web transport, as shown in Fig. 7. A web can be wrapped over the air turn, in the same way as with a roller. In this case, the air layer not only supports the film without contact but also serves to flatten out any wrinkles as seen in Fig. 8. For traditional rollers, films such as PET can become charged by the order of 5 keV as they pass over an individual roller. Such static build-up has to be compensated to prevent disruption to processes. For such air turns, as the film does not touch the roller, no charging occurs (see the following section). This removes the need for static discharge bars to be applied before printing actions that can be sensitive to a charged film, such as inkjet printing.

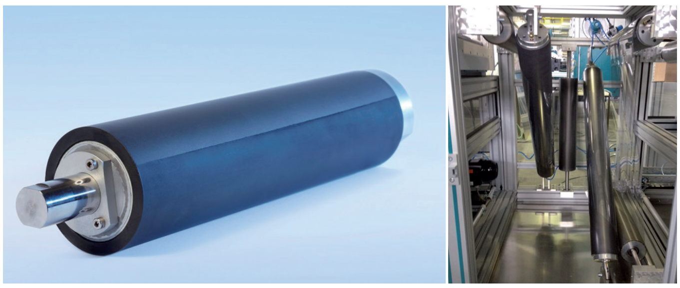

Fig. 7: Cylindrical air turn (left) installed in roll-to-roll line (right)

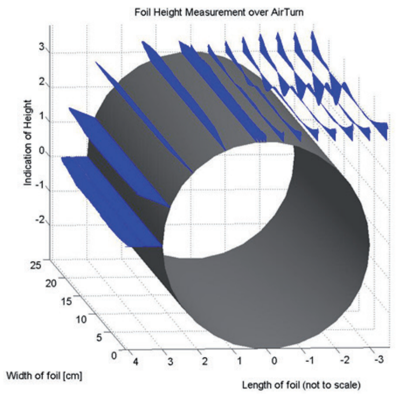

Fig. 8: Film fly height as a function of position over 300 mm diameter air turn.

Detailed investigation of the form of the film as it moves over the air turn has allowed for simulation models to be developed. From these models, the optimum configuration of the air bearings has been identified for in-line use, including air turns with dual zones (Figure 9).

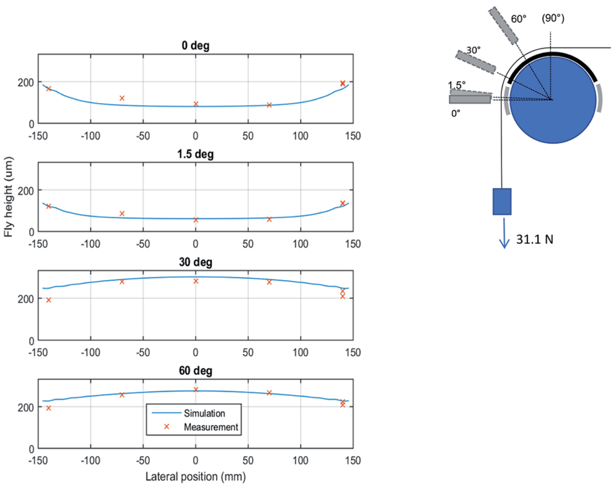

Fig. 9: Measurement of film shape as a function of position on a dual-zone air turn.

Not only plastic films can be supported by air turns. Transport of paper is also possible. Here, the permeability of the paper should be considered. Higher permeability leads to a higher percentage of air loss through the paper, which will, in turn, reduce the fly height and stiffness. Thus, the paper tension when contact occurs is directly linked to the permeability. However, papers have been found to be supported at tensions of 50 N for a range of papers (tested to 52 gsm), with speeds up to 60 m/min achieved.

NO STATIC CHARGE! To validate whether any electrostatic charge is added to the film by an air turn, the charge levels on the film surface have been measured before and after transport over air turns in the IBS roll-to-roll line. A 300 mm PET film was used for the experiment. A Simco electrostatic field meter was used to measure the charge levels.

The electrostatic charge on the film surface was measured before and after transport over the air turn. Before moving over the air turn, the film was typically charged with approx. 5 kV, caused by unwinding. No decrease or increase in charge could be measured after the film was moved over the air turn. This is as expected since no contact occurs between the air turn and substrate surface. From experience in the field, it is known that traditional contact rollers in roll-to-roll processes add a charge to the film up to 5 kV per roller. Static charges on the film lead to attraction of particles and decrease the quality of coatings; it can also limit print quality, for example, where inkjet processes are employed. Therefore, the fact that the air turn does not add charge to the film is a further major advantage of using air turns instead of rollers.

CONTACTLESS WEB STEERING. Steering units are commonly used in roll-to-roll lines to maintain the lateral position, orthogonal to the travel direction. Such units are typically composed of four rollers, where the front side of the web is made to come in contact with two of the rollers (see Fig. 10). The central rollers in the steering frame can be replaced by air turns to avoid front side contact. Using an edge sensor, the lateral position of the web can be tracked. Trials have been carried out by IBS where the web response to 5 mm stepwise changes in sensor position have been applied. The web was shown to be stable within the required ± 0.2 mm. 5-mm steps in reference position were clearly visible in the roll after winding as visible in Fig. 11. In addition, the steering range was seen to be increased from approx. 3 to 20 mm. The steering response to a step in reference position, as measured by the edge sensor, was seen to be significantly faster.

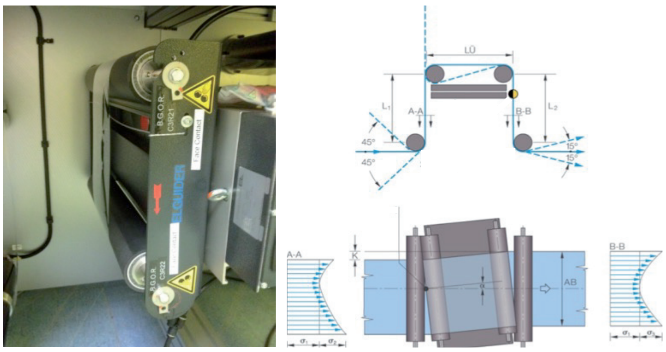

Fig. 10: Typical steering roller configuration (right upper and lower image). Air turns retrofitted to standard steering frame (left).

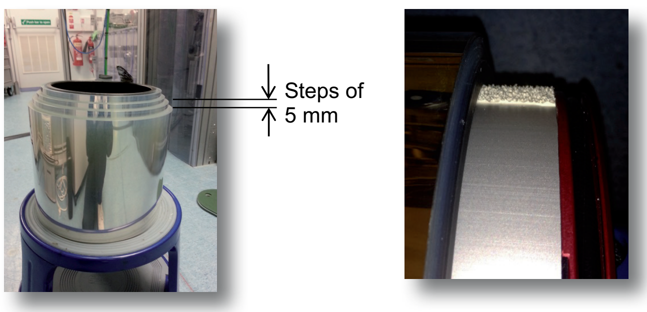

Fig. 11: 5 mm steps can be clearly seen in film wound using steering frame retrofitted with air turns (left). Sharp edge of wound film shows effective steering control (right).

CONCLUSIONS. Whilst well established in the precision engineering field, porous media air bearings offer a surprising range of new avenues for exploitation. Following from their history in the FPD industry, they provide a unique technology for the delivery of roll-to-roll processes for industrial manufacturing.

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[1] Devitt A.J., Non-contact porous air bearing and glass flattening device. U.S. Patent 7,908,885, 2011.
[2] R. R. Søndergaard, M. Hösel, and F. C. Krebs, «Roll-to-roll fabrication of large area functional organic materials,» J. Polym. Sci. B, Polym. Phys., vol. 51, no. 1, pp. 16 –34, Jan. 2013.
[3] Courtesy of Erhardt+Leimer. www.erhardt-leimer.com

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