POROUS AIR BEARING TECHNIQUES FOR CONTACTLESS HANDLING, FLATTENING AND STABILIZATION OF WEBS

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ABSTRACT

In roll-to-roll processes for printed electronics, avoiding web contact is critical to reduce damage and contamination. Experiments on newly developed cylindrical air bearings demonstrate that a stiff < 0.1 mm air layer can be realized to support webs, proving the feasibility of contactless handling without losing web control. Air bearings are also introduced as a novel way of generating a very flat web (<5 µm deviation over 55 mm in machine direction) which is critical for printing, drying and inspection processes.

Keywords: Contactless web handling, Roll-to-roll, Flexible electronics, Porous Air Bearings, Metrology

INTRODUCTION

In thin-film electronics produced on flexible substrates by roll-to-roll (R2R) processing, scratches and particles in the active or barrier layer decrease the quality and lifetime of the product. Defects in the active layers may cause local inactive areas or electrical short-circuits, while defects in the protective barrier layer may introduce local susceptibility to moisture. The importance of preventing defects and contamination is recognized in the EU FP7 funded research program Clean4Yield, where equipment developers, research institutes and R2R end users cooperate to realize clean R2R processing for thin-film electronics [1].

Since contact between the web and R2R web handling equipment – e.g. transport rollers – is a major source of scratches and particle contamination, developing contactless web handling equipment is essential for achieving clean R2R processing. This paper presents contactless transport and handling of webs using porous-media air bearings. The relevant technology, measurements, possible applications and future work are discussed.

TECHNOLOGY DESCRIPTION

Air bearings are widely used in numerous applications where precision motion is involved. Air bearings provide non-contact guided movement between two components by creating a pressurized air film between two surfaces.

The air film is created by supplying a flow of air through a restrictor in the bearing surface. This can be achieved by using orifices or a porous media surface. Orifice-type air bearings are most commonly used, however porous-media air bearings are rapidly emerging due to robustness and performance [2]. For R2R applications, the major advantage of porous bearings is the pressure profile which is evenly spread across the surface, which enhances global and local stiffness and reduces local deformations and the risk of contact.

The cross-section of a typical porous air bearing is shown in Figure 1.

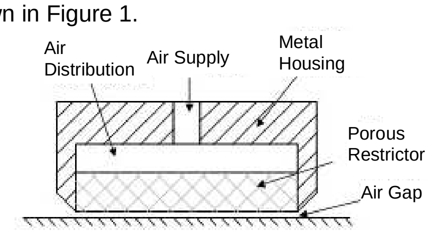

Figure 1: Cross-section of typical porous air bearing

Air bearings exist in various forms and sizes. Two specific types of air bearings are proposed here for use in R2R applications. The first is a cylindrical porous-media air bearing, or air turn, developed by New Way Air Bearings. The air turn can be used as replacement of idler rollers, non-driving contact rollers, for web transportation. A web can be wrapped over the air turn, in the same way as with a roller. The air layer between the non-rotating cylindrical air turn surface and the web allows close to frictionless motion as there is no physical contact. Existing air turns are typically orifice-type cylindrical air bearings [3].

The second type of air bearing that has been assessed for use in R2R processing is a New Way conveyor air bearing, here called air table. These are normally used for contactless transport of rigid substrates such as glass sheets in the flat panel display industry. A concept drawing is shown in Figure 2. The air table contains vacuum grooves to pull the supported substrate towards the air bearings improving stiffness and stability at a given fly height. In R2R lines, this will especially be useful at processes where web stability or flatness is critical, such as printing, drying or inspection steps.

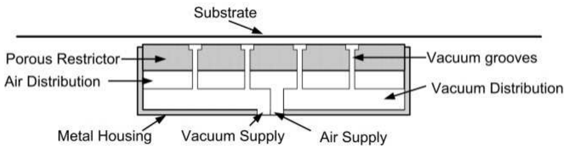

Figure 2: Air table concept drawing

EXPERIMENTAL STUDY

Air turn feasibility tests

In order to demonstrate the feasibility of the air turn concept, determine the thickness and stiffness of the air layer and investigate the risk of contact, a test setup was developed. A flexible foil was placed over two air turns, of which one was used to set a defined preload, as seen in Figure 3. The foil was kept stationary during the measurements. Capacitive displacement sensors with sub-micron resolution (Lion Precision C9.5-2000) were used to determine the fly height and deformation of the foil.

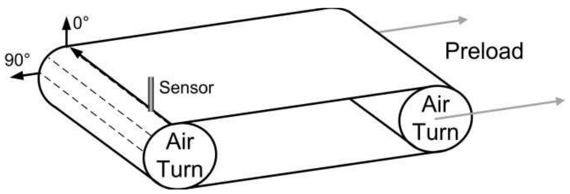

Figure 3: Concept drawing of measurement setup

Measurements were taken both with and without air pressure over the width of the foil directly above one of the air turns. From difference between these measurements the fly height is derived.

The measurements were repeated at several orientations between 0° and 90° around the circumference of the air turn (see Figure 3). A 150 µm thick, 300 mm wide PET foil was used. Figure 4 shows the measured fly height values.

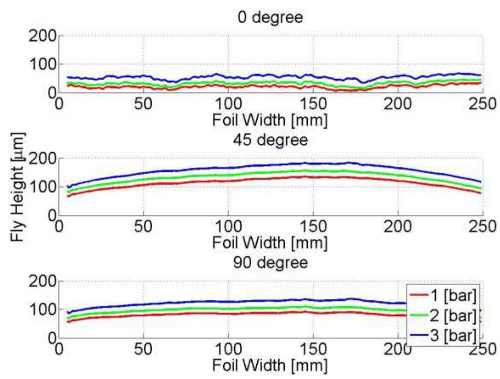

Figure 4: Fly height of PET foil over air turn at several positions and varying supply pressure

In Figure 5 the relation between the fly height of the foil and the applied preload (twice the foil tension) is represented. This measurement was done at the 90° line in the middle of the foil, using a 100 µm thick, 250 mm wide stainless steel belt.

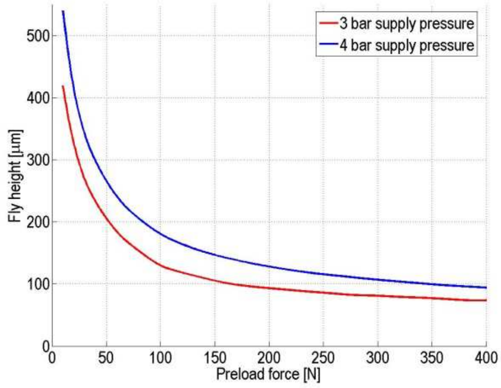

Figure 5: Fly height versus applied preload force for 4 bar and 3 bar supply pressure of foil on an air table

The results in Figure 4 and 5 clearly show that there is no contact between foil and air turn over the entire supported surface, even at foil tension up to 200 N (equal to a preload of 400N). The results in Figure 4 indicate that wrinkles present in the foil (seen in the 0° line) are flattened above the air bearing surface. More measurements are required to show the wrinkling behavior of the foil between two air turns. It is expected that, due to the frictionless character of the air turn, less wrinkles will appear than in a situation where a roller is used.

The displacement of the preloaded air turn was measured in order to calculate effective bearing stiffness of the air film. It was found that the foil is supported with a very high stiffness (about 1e6 N/m at 150 N foil tension and 4 bar supply pressure), giving excellent foil stability.

Air table feasibility tests

A setup was built to demonstrate the concept of supporting a flexible foil with an air table. The setup is graphically represented in Figure 6. The air table is placed such that the vacuum grooves are perpendicular to the tension direction of the foil. As areas of air pressure and vacuum are subsequent of each other, local foil deformations are expected. Therefore, a set of measurements have been done on the deformation of the foil. The foil was kept stationary during the measurements.

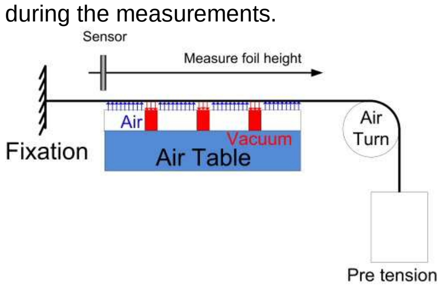

Figure 6: Concept drawing of air table measurement setup.

To measure the fly height and deformation of the foil, the sensor signal when only using the vacuum (assuming the foil is then clamped to the air table) is used as zero measurement. All other measurements are relative to this measurement. A 300 mm wide, 150 µm thick PET foil is used.

By varying the air pressure, an overview of foil fly height was generated while doing a scanning measurement in the tension direction of the foil. The results are depicted in Figure 7. At non-optimal conditions, the influence of the air and vacuum transitions in the air table can be seen. Further it can be seen that at optimal pressure values, which might be different for each application, the foil height variation is < 5 µm over 55 mm in tension direction.

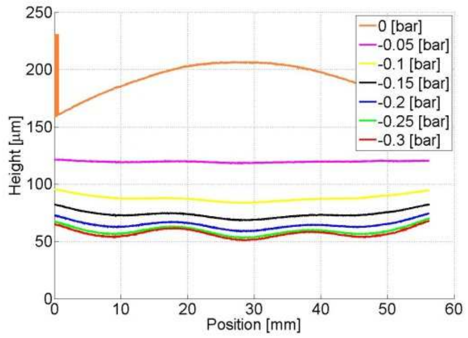

Figure 7: Foil flying height variation directly above air table in tension direction using 2 bar air pressure

In a similar experiment, the height variation in lateral direction is measured. Here, a different PET foil of 50 µm thickness is used. Results of these measurements are shown in Figure 8. Less than 15 µm height variation over 200 mm foil width was realized, while without use of the air table this was more than 75 µm. Locally the flatness of the foil is found to be < 5 µm over 20 mm. The peaks on both sides of the scan represent curvature of the edges caused by the tension in the foil.

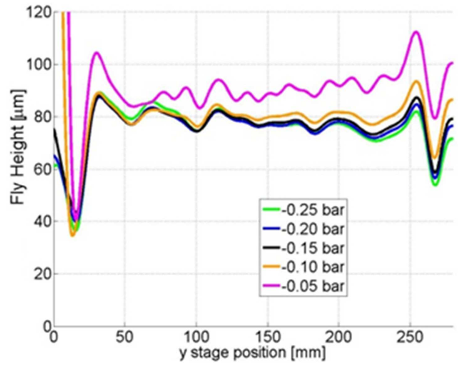

Figure 8: Measurement results on air table measurement over length of air table using 2 bar air pressure

In order to test the capability of the air table to reduce vibrations in a moving foil, measurements were done on a moving foil above an air table in cooperation with Eight19 Ltd., Cambridge, UK. To realize this, the air table was integrated in a R2R line. The foil height was measured with a capacitive displacement sensor in the same way as before. In this case the foil was moved with a constant velocity while the sensor was at a fixed position in the middle of the supported area. Figure 9 shows the obtained results.

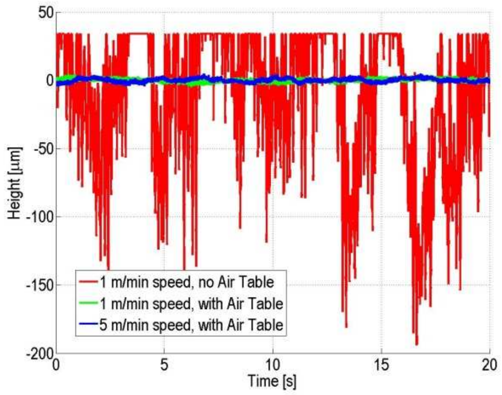

Figure 9: Foil height over time with and without air table support

Without support by the air table, vibrations of more than 250 µm were seen in the foil. With the air table, these vibrations were reduced to < 9 µm peak to peak. The measurement was repeated with 1 and 5 m/min foil velocity. No significant difference between these measurements was seen.

Cleanliness of air bearings

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 m^3 of exhausted air. This was better than the supplied air, as the sub-micron pores act as an air filter.

For the air turn, an experiment was designed to verify the absence of particle migration to the foil. Initial tests indicated that there is no statistically significant particle increase on the foil after transportation over an air turn. More tests are planned to get more statistical results.

APPLICATION EXAMPLES

Since the experiments show encouraging results, air turns and vacuum-preloaded air tables will be integrated in several applications. Below is an overview of application examples where the described air bearing equipment might be beneficial.

Since the air turn allows clean and damage-free web support, replacing idler rollers by air turns is most beneficial where the web needs to be supported at the side where a sensitive layer is deposited. Air turns may also be used to change the web path direction as shown in Figure 10, providing significantly more flexibility in the layout of R2R lines. Using a contact roller for this application would lead to damage due to slip in the contact area.

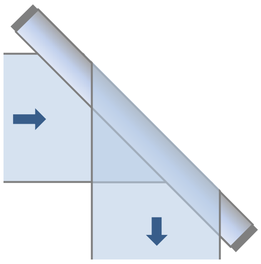

Figure 10: Air turn used for changing web path direction

Another useful application for the air turn is in systems where a dancer roller is used for regulation of the substrate speed or tension as seen in Figure 11. Here, the use of a roller introduces inertia forces on the web, caused by fast acceleration and deceleration of the roller. This makes accurate control of the web tension and velocity complicated. Using an air turn eliminates this problem since it does not rotate.

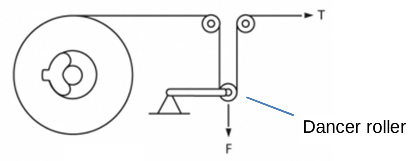

Figure 11: Dancer roller to control web tension or velocity

From the experiments on the air table it can be concluded that the air table is capable of supporting flexible substrates and significantly improves the local flatness and stability of a web. This provides significant advantages for on-line metrology.
Air tables might also be a major improvement for web support in R2R drying ovens. Using rollers is difficult here: since the web should be kept (almost) horizontal because of the coating liquid, only a very small wrap angle is possible. On the other hand, a completely unsupported web over the length of the oven is not good for web stability. The air table provides an excellent solution: very stable web support at a flat, horizontal section. On top of that, feeding the air table with pre-heated air to heat the back side of the substrate may even increase the drying performance.

CONCLUSION AND OUTLOOK

Conclusion
Research is done to contactless web handling in R2R production of flexible electronic devices, in order to reduce device failure caused by scratches and particle contamination. Two porous media air bearing products are presented: the air turn, a cylindrical air bearing, can be used to replace idler rollers. A vacuum preloaded air table is able to support and stabilize the web within 5 µm at web speeds of 5 m/min. Flatness of the foil is found to be < 5 µm over a 20 x 20 mm area. Experiments demonstrate that contactless, clean and stable web transport can indeed be realized with these products. Additionally, the advantage of the air turn over rollers is the absence of contact friction, inertia forces and mechanical vibrations, which improves web control in terms of velocity and web tension.

Outlook
In addition to the presented experiments, the air bearing equipment will be integrated and tested in full-scale R2R lines. This is already done at several different locations, where initial tests show promising results.

So far, all experiments were done using plastic or metal substrates. Initial tests using an air turn in paper industry have been setup.

More testing will be done to get a better understanding of the advantages of using the air bearing products for contactless web handling.
Specific areas for further investigation and applications are:

- Wrinkling behavior
- Web stabilization for optical inspection
- Web support in oven environments

ACKNOWLEDGEMENT
The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 281027.

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