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Production of electronics and photovoltaics using a reel-to-reel process

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Abstract

Reel to reel manufacturing is a mature technology that involves the passing of a flexible substrate or web continuously through one or more processes. The web is typically much longer than it is wide, and the width in turn is much greater than its thickness. It is a continuous process that results in high output at a low unit cost when compared with other production methods. Historically this has included newspaper printing and textile manufacture, but more recent research is being conducted in developing printed electronics, such as solar cells (Organic Photo-Voltaic or OPV), and wearable tech and flexible screens (Polymer LEDs or PLEDs). These devices consist of up to five layers, with a separate printing or coating process needed for each. Greater accuracy is necessary than for traditional industries and advances are required in three areas: control of the web; measurement and registration of the printed web; and flexible semi-conductor materials. In this paper we present a new methodology to improve printing accuracy by combining an advanced metrology system with an innovative process design.

Web tension control, Web lateral control, R2R, Roll-to-roll manufacturing, Organic photovoltaics, Polymer LEDs

1. Introduction

The US Department of Energy describes reel-to-reel processing as "a family of manufacturing techniques involving continuous processing of a flexible substrate as it is transferred between two moving rolls of material" [1]. The cost of setting up a R2R production line can be large, but high throughput and lower production costs can be achieved. These low costs can only be exploited in large scale production at or near full capacity and a limited range of products can be manufactured due to the fixed sequence of steps. Printing techniques include deposition, gravure, flatbed and rotary screen printing, laser ablation, offset printing, and inkjet printing.

More recently, research has been conducted in adapting the production of Organic Printed Electronics (OPE) and Organic Photovoltaics (OPV) to reel-to-reel processing in order to take advantage of its lower production costs. These devices consist of up to 5 layers and require a separate printing or coating process for each. The location of the features on the previous layer must be determined and the position of either the web or the printer adjusted before a new layer is added. As the R2R process is continuous, the control system must be able to continuously measure the previous printed layer and then carry out any adjustments required. In order to achieve this, advances are required in three areas:

a) Control of the web;
b) Measurement and registration of the printed web; and
c) Flexible, semi-conductor materials.

The research will initially control and measure the accuracy of the process during a single print run. Once this has been achieved, a second layer will be printed. Successful completion of this stage will enable further research into the measurement and control of multiple webs in a lamination process.

This paper is organised as follows. In Section 2, we present the design of the reel-to-reel plant. In Section 3, we present the requirements for control of the web.

2. Cranfield R2R development platform

The Cranfield Reel-to-Reel development platform consists of an Unwind Roller, a Coating Drum, a Gravure drum and a Rewind Roller. The Unwind Roller carries the web prior to processing while the Rewind Roller collects the web after processing has been completed. A lacquer is applied to the web as it travels around the Coating Drum. The Gravure Drum is an engraved cylinder that carries the pattern which is to be imprinted in the lacquer. Other rollers are included where necessary to guide the web between processes. The Unwind Roller, Rewind Roller and the Gravure Drum are driven by electric motors.

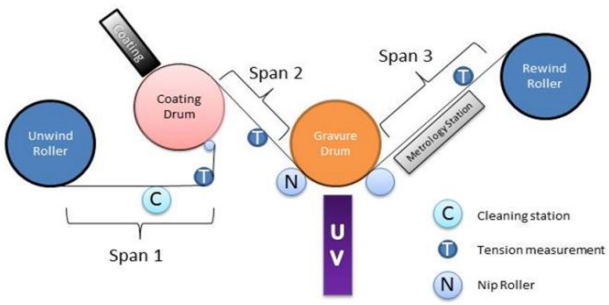

Figure 1. Cranfield R2R test plant.

The web is divided into three spans. Span 1 lies between the Unwind Roller and the Coating Drum and includes a cleaning station to prepare the web for the coating process. Tension in this span is controlled by varying the speed of the Unwind Roller.

Span 2 is between the Coating Drum and the Gravure Drum with tension being controlled by the use of an active dancer. A

Nip or Pinch roller is located at the end of Span 2. This ensures that the correct pressure is maintained during the printing process. After printing, the lacquer is cured by passing it over a UV LED. To ensure even curing, the speed of the Gravure Drum must be held constant. This means that, although the Gravure Drum is driven, it cannot be used for tension control.

Span 3 follows the Gravure Drum and contains the Metrology Station. Tension in this span is controlled by varying the Rewind Roller speed.

2.1. The gravure drum test pattern

The gravure drum is machined with three test pattern pairs. Each pair consists of two patterns, one containing grooves cut in the machine direction, the other with grooves cut in the cross direction. Both patterns are 12 mm wide, with each groove having a pitch of 40 µm and a depth of 20 µm. The unpatterned surface area of the drum is machined to a visual mirror finish. A pattern pair is located 150 mm from each edge of the drum measured from the centreline of the cross-directional pattern. The third pair is located in the centre of the drum.

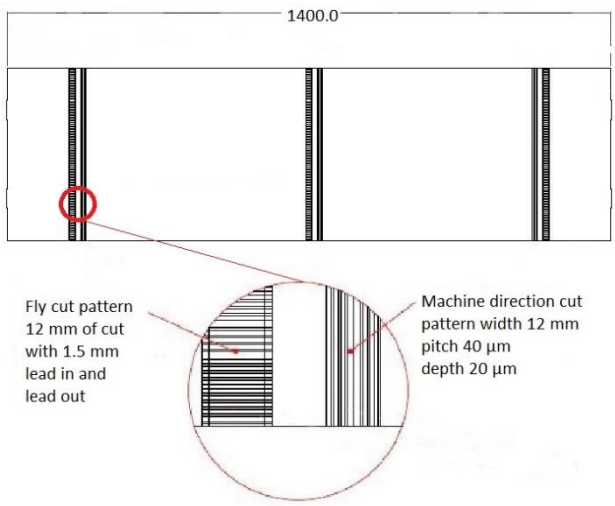

Figure 2. Gravure drum pattern.

3. Control of the web

3.1 Control of the web in the machine direction

There are two principal variables to be controlled in the machine direction, tension and speed. This is carried out via the torque input from the drive motor(s). Control of the tension is crucial as it affects the geometry of the web, prevents the loss of traction, helps to reduce wrinkling, and affects the wound-in shape [2]. High tension may cause the web to break, or may damage the printed layer during rewinding [3]. Tension may be controlled either by varying the length of the web along a span or by altering the angular speed of the driven motors.

The linear speed may affect the accuracy of printing with better results being obtained at low web speeds when using high viscosity inks [4] and faster speeds may result in a thicker film due to the reduction in drying time [5]. Web speed may be controlled by altering the angular speed of the drive motors.

The relationship between the web tension and the linear velocity of the web is

$$L \cdot \frac{dT_2}{dt} \approx E \cdot A \cdot (V_2 - V_1) + T_1 \cdot V_1 - T_2 \cdot V_2$$

Equation 1. Relationship between web velocity and tension [6].

where L is the strained length of the web span, T_1 is the tension in the preceding web span, T_2 is the tension in the measured web span, V_1 is the web velocity in the preceding web span and V_2 is the web velocity in the measured web span.

As the radius of the unwind and rewind rollers roller changes as the web unwinds or rewinds, variable gain control is required to compensate for this. Simulations show that the maximum gain of the of the controller for the unwind controller halves during the unwinding of a 500 m length of web material, leading to an increase in the error between the calculated tension and the target tension

3.2 Control of the web in the cross direction

The dynamics of the web in the cross direction have been modelled as a string [7], an Euler beam [8] and a Timsoshenko beam [9]. A lateral movement in the web can result in cross web tension differences leading to pattern errors [10]. The effect of these will be investigated and active and passive methods of controlling cross-direction tension examined.

4. Summary

We detailed the Cranfield R2R development platform which is currently under instruction. On its completion, we plan to carry out experiments to measure pattern errors caused by tension variations and develop controls to counteract them.

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