Roll-to-Roll web handling system for on-roll patterning maskless lithography process

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Abstract

In the context of roll-to-roll technology for producing next-generation flexible electronic devices, roll-to-roll technology is highlighted as a promising alternative due to its advantages in large-area, low-cost, and high-speed production. However, its application is currently limited to thin-film formation processes such as coating, lamination, and rolling due to precision constraints, including overlay errors for resolution and multilayer formation. For instance, commercially available flexible display products use glass substrates as carriers to utilize existing processes. This presentation focuses on the development of technologies to enhance overlay precision in multilayer formation within roll-to-roll web control systems. The major factor affecting overlay precision in roll-to-roll systems is the sensitivity of the plastic substrate's length to external disturbances, such as variations in tension loads and mechanical, chemical, and thermal processing during the production process. To address this issue, a roll-to-roll maskless lithography system is proposed, which aims to measure film deformation in real-time and adjust the exposure image accordingly to correct the film deformation. Integrating maskless lithography processes onto roll-to-roll films requires significant improvement in six-degree-of-freedom position errors occurring during roll-to-roll film transport, achieving levels comparable to those of conventional flat glass substrates. This presentation will also provide design details and interim experimental results of the roll-to-roll web transport system currently under development.

The maskless exposure process requires not only high-precision sample transport but also control of parasitic motion errors in directions other than the transport direction to within a few micrometers. In contrast, the film transport control accuracy of conventional roll-to-roll processes is significantly lower, typically ranging from tens to hundreds of micrometers. This issue is particularly pronounced due to the mechanical properties of thin plastic films, which are susceptible to vibrations and deformations, with these effects being more severe in free-standing films without support from rollers. As an alternative, this study aims to develop a roll-to-roll system that performs maskless exposure processes on films supported by rollers on-roll, as illustrated in Figure 1. The system intends to achieve precise film transport control through roller transport control, assuming no relative motion between the rollers and the film. Prior to system development, relative motion between the rollers and the film was analyzed based on modeling, and conditions such as roller surface characteristics, friction between the roller and the film, and film transport speed were determined and incorporated into the equipment design. The slip-free transport of on-roll films was verified experimentally with the fabricated equipment. This indicates that precise control of film transport can be achieved through the six-degree-of-freedom precision control of the rollers.

The key specifications for the support rollers used in patterning are as follows. First, the rotational speed error of the roller in the film's rotation direction must be controlled to within 1 micrometer based on the circumferential surface displacement. Additionally, the transverse error of the film during constant speed transport can cause overlay errors in the product, so this must also be controlled to within 1 micrometer. Finally, the focus direction error of the film must be maintained within the depth of focus of the exposure head. To achieve these objectives, an air bearing-based frictionless roller rotation system has been proposed as shown in Figure 2. The air bearing not only serves as a transport guide for the roller but also controls parasitic motion of the roller by regulating the gap height between the pad and the guide surface. A coreless arc-type linear motor has been used for the drive to reduce external disturbances in the drive direction. Additionally, a six-degree-of-freedom measurement technology for the roller is being concurrently researched for precise transport control. To improve the measurement accuracy of the roller's rotational position, a self-calibration method that separates scale graduation errors and scale rotation runout to measure the actual rotation angle of the roller has been applied. The research results analyzing and improving the encoder installation angle error from existing methods will be presented. For parasitic directional motion of the roller, multiple displacement sensors are used to measure the roller surface. However, roller shape errors affect the measurement accuracy of roller transport errors. Therefore, a self-calibration method that separates the cylindrical error of the roller is being studied, and the results will be presented. Basic tests of the roller with these technologies have been partially conducted, achieving a rotational speed error of up to 0.5 micrometers at a transport speed of 10 mm/s and a runout error of 2.2 micrometers peak-to-peak.

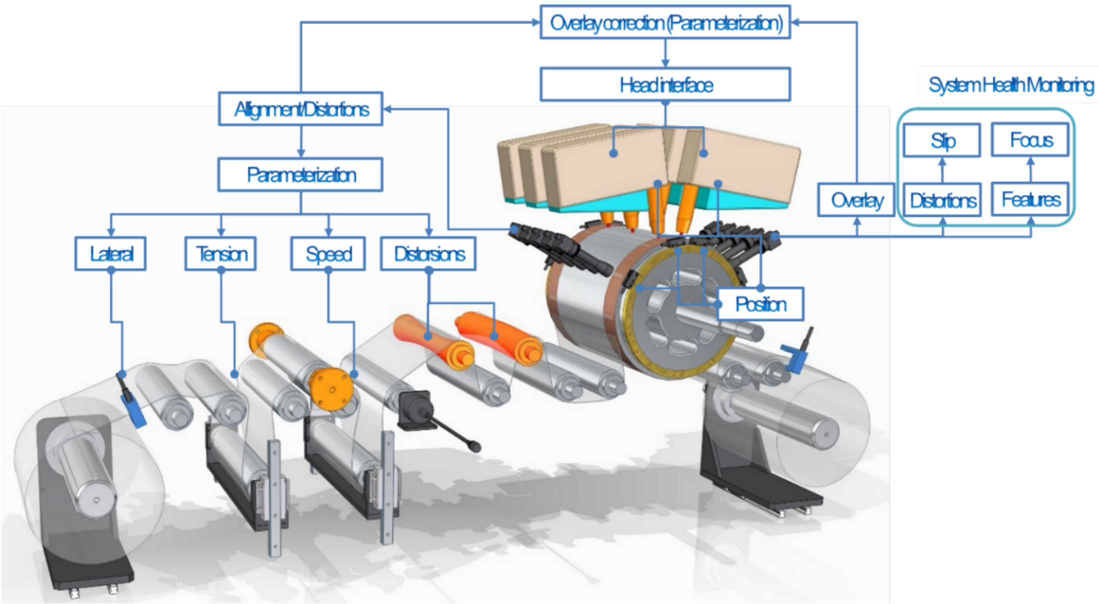

Figure 1: Concept of roll-to-roll maskless lithography system

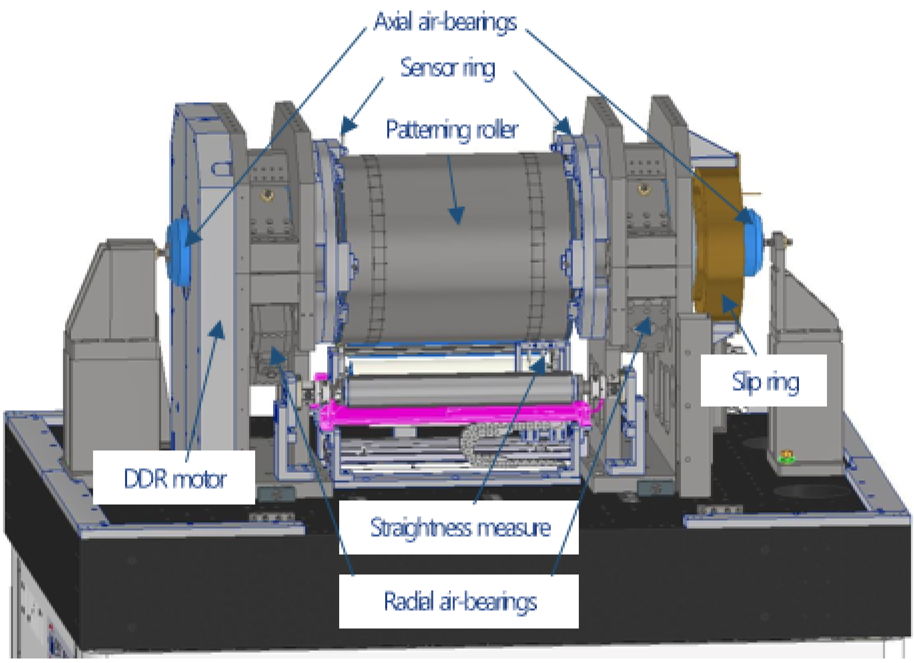

Figure 2: 6 DOF Control and measurement system of roller