Study on the Roll-to-Roll Ink-Jet Printing System

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Abstract

The performance of the printed devices generally depends on the drop landing accuracy. In a roll-to-roll ink-jet printing system, it is more difficult to control the drop landing accuracy because of the substrate distortion and web handling. Such distortion could arise from exposure to elevated temperatures, mechanical stresses from handling, changes in surface material compositions or moisture absorption. For the web handling, the important factors are the speed, tension and alignment. To study these printing issues, we have constructed a roll-to-roll ink-jet printing system whose web width is 30 cm. In this paper, the system is introduced and the results from experiments are shown and discussed.

Introduction

Manufacturing process on flexible films with roll-to-roll (R2R) system is a new opportunity for inkjet printing technology. For producing flexible displays, accuracy and reliability are most important issues and challenges to the inkjet process in recent years. In a roll-to-roll ink-jet printing system, however, it is more difficult to control the drop landing accuracy because of the substrate distortion [1] and web handling. To overcome these difficulties, some parameters in the R2R web delivery system should be controlled, for example, the web tension force, the web speed stability, the web guiding accuracy [2].

In this study, we have constructed a roll-to-roll ink-jet printing system. The architecture of the system is introduced and the results from experiments are shown and discussed.

Architecture of the R2R IJP System

For the flexible display applications, we developed a continuous R2R ink-jet printing system. It is different from the conventional capillary injection which is a time-consuming process for liquid crystal filling in LCD industry [3]. In the color Ch-LC display application [4], the RGB Ch-LC should be dispensed to the 139um wide channels on the flexible substrate, as shown in Fig 1. To insure the accurate drop landing, the web guiding tolerance and the flexible substrate deformation must be controlled with in the range of ±30 um. In addition, the web tension and the web velocity must be stable for the printing uniformity.

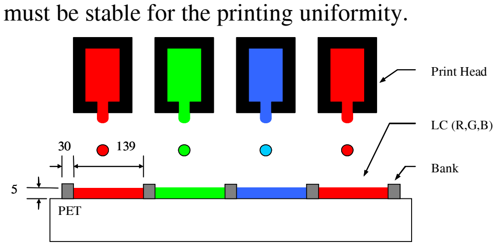


***Figure 1**. The schematic drawing of the Ch-LC ink jet printing*

Figure 2 shows a schematic view of the R2R IJP system which consists of a granite based IJP platform and an accurate web handling system, where the print head module is mounted on the gantry frame.

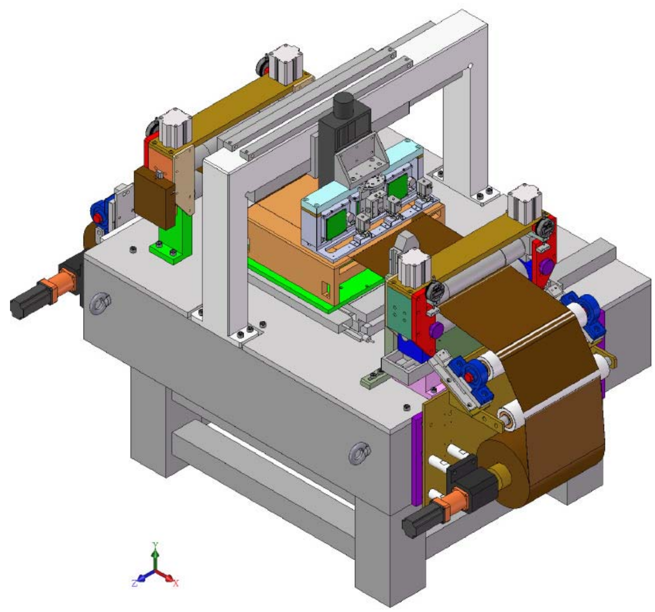


***Figure 2**. The roll to roll ink jet printing system*

The web handling system consists of an unwinding module, a rewinding module, a traction module and a web guiding module. The unwinding, rewinding and traction module which are driven by three separated AC servo motors are coupled with appropriate gear ratio to coordinate the web delivery rate and the web tension. The mechanical design of web handling system follows the Normal Entry Law (NEL), the parallelism error between two separated, 30 centimeter span rollers are less than 10 um. Figure 3 shows the web guiding mechanism. If the optical EPC (edge position control) sensor detects any web edge position error, the web guiding controller drives the guiding roller and unwind roller synchronously to compensate the web position error. To prevent the contact between the printing area and the rollers, a caterpillar like layout of rollers has been used to keep one-side contact.

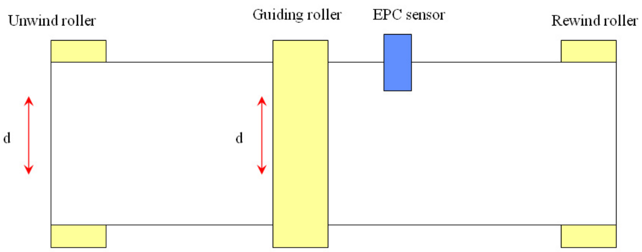


***Figure 3**. The schematic drawing of the web guiding system*

The web handling controller consists of a well tuned tension regulator, a velocity regulator and a web guiding controller. The block diagram of the web control flow is shown in Figure 4. The traction roller drags the web forward in a stable speed and the tension regulator coordinates the speed of the unwinding and the rewinding rollers to keep the web tension T1, T2 in a specific value.

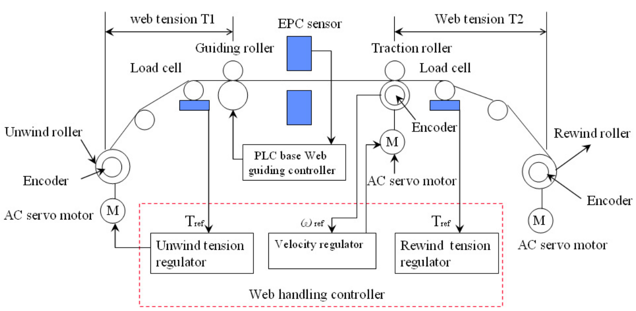


***Figure 4**. The block diagram of the web control flow*

The continuous R2R ink-jet printing system has been tested. The results show that the web tension could be kept in the range of ±2% steady state error and the web guiding accuracy is ±10um at a web speed of 1 m/min. Figure 5 and Figure 6 demonstrate the web guiding and tension control ability of the web handing system at the web speed of 1 and 3 m/min. It is worthy to notice that the web position error increases as the web speed increases. This could result from the insufficient response speed of the web guiding mechanism.

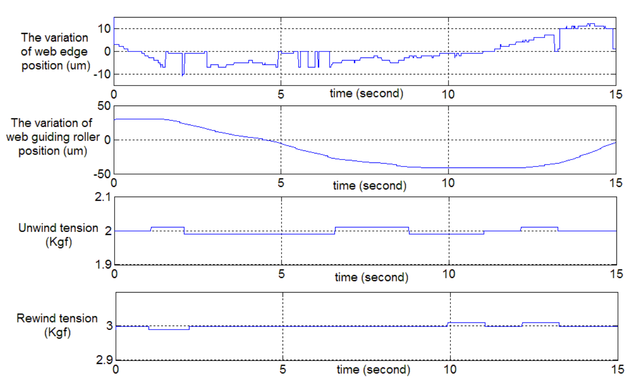


***Figure 5**. Web guiding and tension variation at the web speed of 1 m/min*

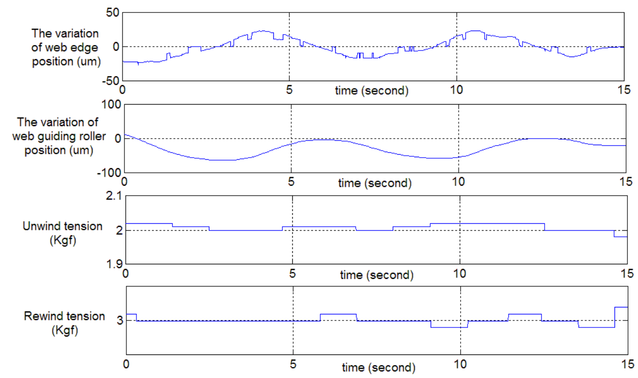
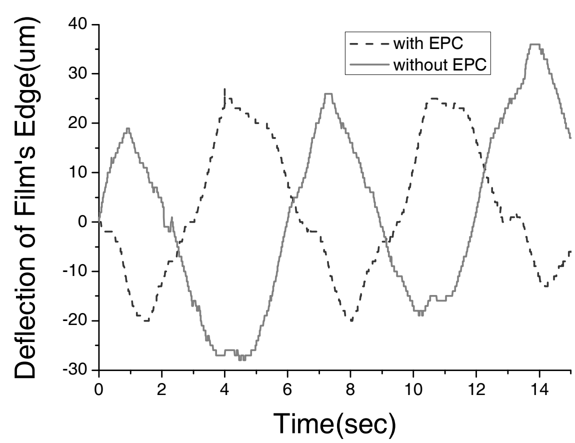


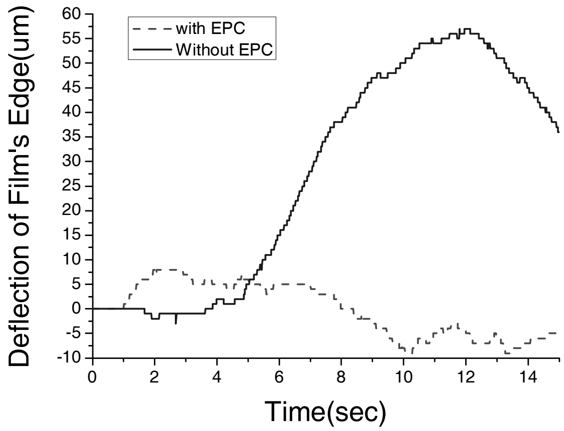
***Figure 6**. Web guiding and tension variation at the web speed of 3 m/min*

Web Guiding

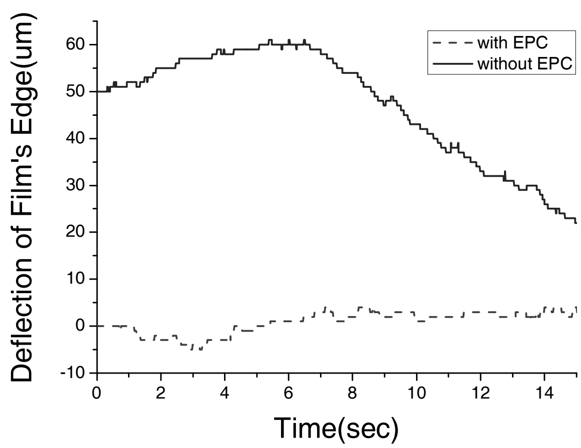
The web guiding system (edge position control, EPC) can reduce the web position deflection (lateral position error) of a moving PET film in the roll-to-roll system described above. Figure 7 shows the effectiveness of the EPC system which is able to reduce about 70% edge position error for the PET film transportation speed from V=0.5 m/min to V=1 m/min. However, as the web speed raises up to 3m/min， the web guiding performance degrades. This could result from the insufficient response speed of the web guiding mechanism as mentioned above.



(a) V=3 (m/min)



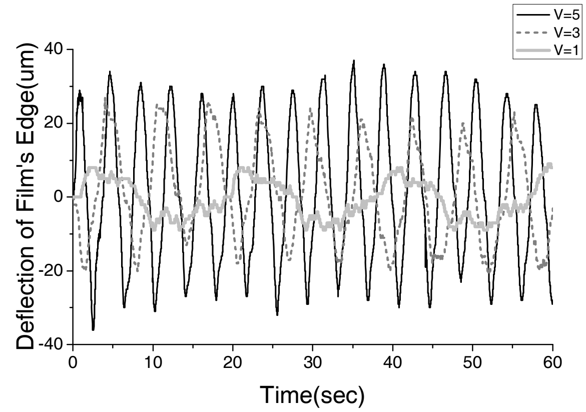
(b) V=1 (m/min)



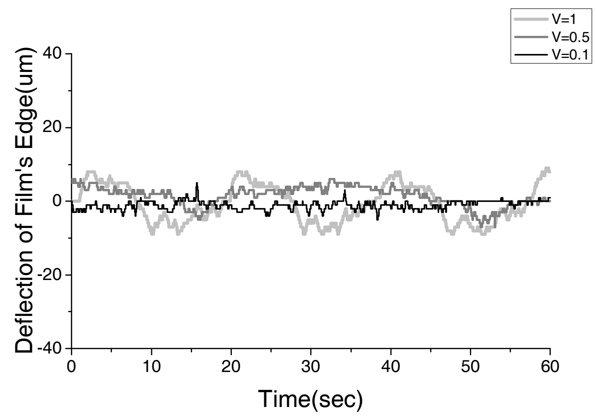
(c) V=0.5 (m/min)

Figure 7*. The deflections of the PET film's edge position at different speeds, in two conditions (with and without EPC).*

With EPC system, the relationships between the deflection of a PET film and the web moving speed in X-axis, that is, the axis parallel to the PET film transportation direction, are shown in Figure 8. It's easily found that the lower the transporting speed is, the fewer the deflection of edge position is. As the web moving speed varies from 0.1m/min to 5 m/min, the ranges of deflection vary from ±10um to ±40um.



(a) V=5, V=3, and V=1 (m/min)



(b) V=1, V=0.5, and V=0.1 (m/min)

Figure 8*. Deflections of the edge position with EPC for web speed V=0.1~5m/min*

If we redraw the edge deflection of V=5(m/min) curve with EPC again, and compare it with the curve in the same speed but without EPC feedback, as shown in Figure 9, something interesting happened. We can find that when the moving speed is higher than 5m/min, the edge deflection of the PET film isn't reduced obviously compared with the no EPC curve. It is because of the slow feedback response of EPC, the feedback EPC amendment plays a damper role in control system theory, and cause a frequency shift in edge position curve.

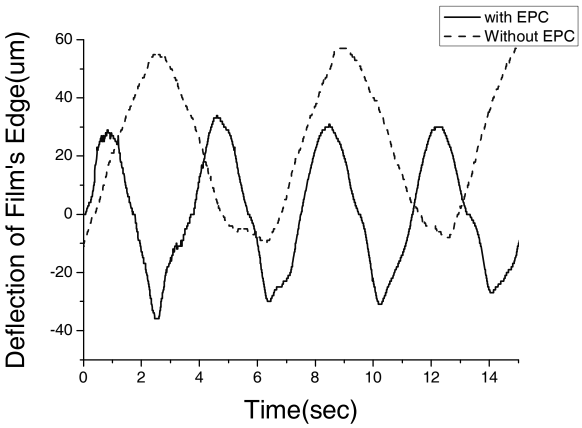


***Figure 9**. Deflection of edge position would not be reduced obviously when the speed was higher than 5 m/min.*

Deflection of Edge Position near Print Head

The position of the EPC sensor is not very close to the print head, and there might be a little difference of the web edge deflection between EPC and the point near the print head. In Figure 10, the web edge deflection near the print head is recorded and reveals a curve with a variation about ±30um while the speed is 1 (m/min). Comparing with Figure 7(b), it is larger than that at the point of the EPC sensor which is only ±10um.

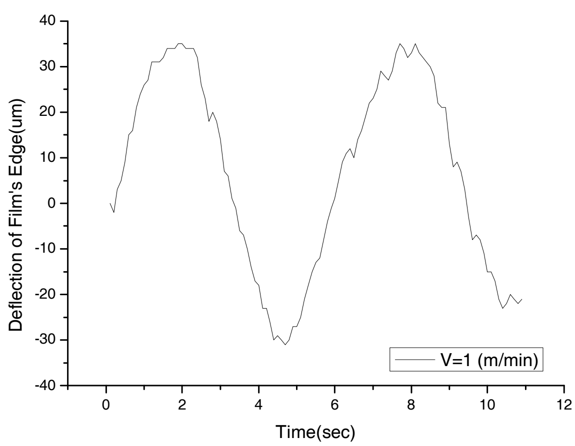
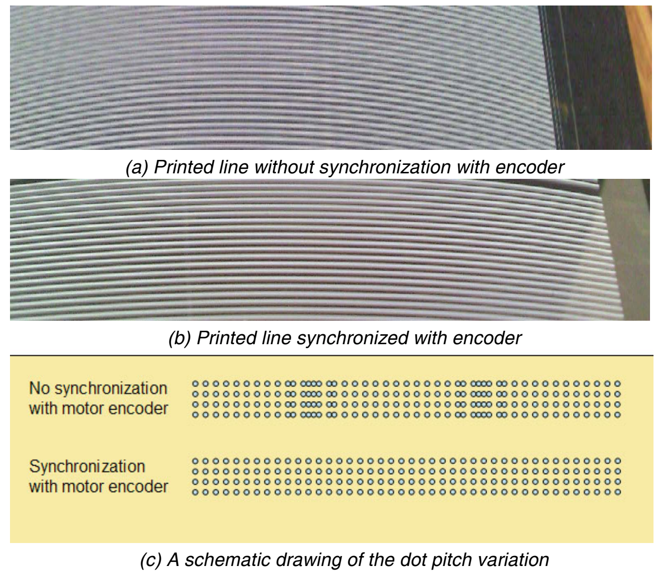


***Figure 10**. The web edge deflection near the print head*

Inkjet Print Test

Generally speaking, there are two ways to dispense drops to the target positions. One is to eject drops during every appointed period of time. The other is to trigger the inkjet by the pulse generated from the encoder mounted on the roller. The main difference between these two ways is the synchronization of inkjet and web movement which is usually not steady enough. The unsteadiness of the web movement may come from the limited motor speed accuracy (typically above 1%) or web vibration. The results of printing a straight line on a flexible PET film with and without the synchronization with the encoder are shown in Figure 11. The lines printed without encoder synchronization are not uniform due to the unsteadiness of the web movement which changes the dot pitch during printing.



(a) Printed line without synchronization with encoder

(b) Printed line synchronized with encoder

(c) A schematic drawing of the dot pitch variation

***Figure 11**. The influence of the pringing methods on the printing quality*

Dot Matrix

In order to compare the accuracy of the drop position in Y direction (perpendicular to the web moving direction) with the influences of EPC system, we designed an experiment to print a 128×1024 dot matrix which is parallel to the edge of PET film, as shown in Figure 12. The distances between two neighbor drops are 508um in X direction and Y direction.

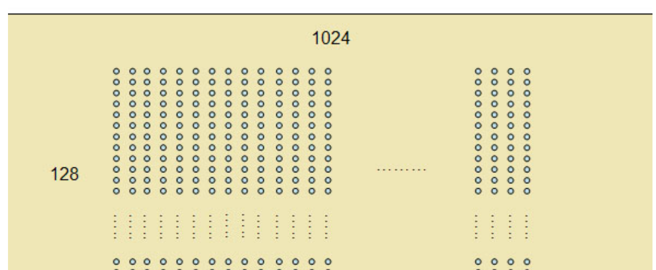


***Figure 12**. Printed 128×1024 dot matrix to verify the relationship between drop landing position on PET film and the EPC system.*

The drop position and the corresponding PET edge position are precisely measured. The deflections of drop position and substrate edge under different web moving speed without EPC feedback are shown in Figure 13.

***Figure 13**. The drop position and the corresponding substrate edge position of PET film in Y-axis without EPC.*

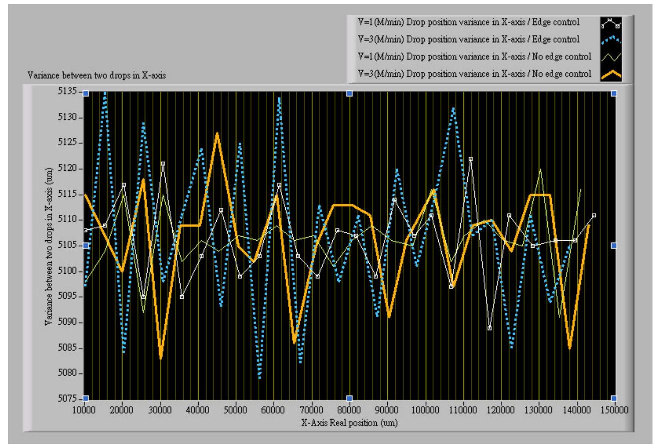


***Figure 15**. The drop position and the corresponding substrate edge position of PET film in X-axis.*

Figure 13 shows that, without EPC feedback system, the drop position in Y direction is independent of the edge variance. The maximum absolute value of drop position variance in Y-axis is less than 8um. For the purpose to show more information in the same figure, the two substrate edge position curves are vertically shifted to zero in Y-axis. Thus, it showed that the distance variation between drops and the substrate edge are larger than ±35um. In other words, if there is a thin film bank structure already made on the flexible substrate, and it's oriented right parallel to the substrate edge by previous manufacturing process, the drops dispensed by inkjet system couldn't land precisely in the bank without EPC system.

With EPC, the relation between the drop position and the web edge is changed, as shown in Figure 14 where there is accordance between drop position and substrate edge curves.

***Figure 14**. The drop position and the corresponding substrate edge position of PET film in Y-axis with EPC.*

Besides the variance in Y-axis, there is also position variance between two neighbor drops in X-axis. The relative X-axis positions are drawn under different web moving speeds in two conditions (with and without EPC), as shown in Figure 15.

Because the printed drop matrix is of an interval of 510um±10 um, and the data is acquired every ten drops, the average distance between per ten drops is about 5105um in Figure 15. It is obvious that an inkjet printing system with EPC feedback could has worse stability in X-axis.

The variance of drop position in X-axis with EPC isn't as optimistic as it in Y-axis. The variances of drop position in X-axis are up to ±20um. This phenomenon might be caused by the drag force in Y-axis of EPC.

Whenever the drop is dispensed from the nozzle of print head, the substrate is at that time drawn by EPC along Y-axis to follow the edge detection and then caused a little deformation not only in Y-axis but also in X-axis. Since the interval between drops in X-axis is determined by the rotational encoder, any substrate deformation could result in the drop landing position error.

Conclusion

The printing test results show that the effect of EPC could causes opposite effects on the inkjet printing accuracy in two axes. The EPC could improve the drop landing accuracy in the Y direction but degrade it in the X direction (web moving direction). In addition, EPC performs better at slower web speeds. However, a slower web speed results in a smaller manufacturing throughput. Hence an adaptive web guiding control algorithm could be adopted to optimize the response of web guiding for different web speeds.

References

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Author Biography

Chen-Chu Tsai received his Ph.D. in mechanical engineering from Chiao Tung University in 2004. Since then he has worked in the Display Process Integration Technology Division, Display Technology Center of Industrial Technology Research Institute in Taiwan. His work has focused on the development of ink-jet printing platforms.

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