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Substrate Transport for Production at Variable Process Speeds

Thomas Oberle[1], Christoph Ziegler[1], Robert Thieme[1], Martin Porschen[1,2]; [1]GT+W GmbH; Rödermark, Germany: industry; [2]Technische Universität Darmstadt; [2]Darmstadt, Germany: academic.

Abstract

Printing for fabrication of functionalities requires diverse materials and techniques. Unlike graphic products functional devices are produced in a large sequence of production steps that differ in techniques as well as in materials. Moreover, their process parameters can vary over magnitudes. Just for the reason of different manufacturing speeds, press layouts like 6 colour + lacquer will not be feasible.

How can different techniques and processes be integrated into one substrate transport concept? The present talk discusses this question focusing on technological and economic parameters. Especially drying, curing and sintering processes are significant for production of functional layers. They are time consuming to be completed. Gravure printing on the other hand requires high printing speeds to achieve high quality. Once implemented, a substrate transport system with variable speeds offers opportunities for the process definition and eliminates the need of wide-stretched assemblies.

Our approach to meet those conflicting objectives is a substrate transport concept named sheet-on-shuttle. We discuss the characteristics of our lab scale substrate transport system, the measures taken to design a system suitable for fabrication and current challenges.

Motivation

Printing in general

Printing stands for a variety of production techniques for graphic products. For the last decades researchers strived to utilise these techniques to make functional devices. The main challenge is, that "the requirements on the printing quality are much higher for electronic devices than for graphical applications, while the materials are much more difficult to handle." [1]

An established systematic description of a printing process is the following sequence of steps: conditioning, fluid acquisition, predosing, dosing, transfer, relaxation and drying. [1, 2]

A major challenge for the fabrication of printed electronics is the combination of different process speeds. This will be depicted by a printed conductive layer utilising gravure printing. The master in gravure printing is a printing form with engraved cells on its surface. The printing form is flooded with conditioned fluid. Thereby the cells are filled. During dosing excessive fluid is removed from the cylinder surface using a doctor blade. The surface with its filled cells is then pressed against the substrate thus fluid is transferred. One important requirement for gravure printing is a minimum speed to reduce the duration from the moment of dosing to the moment of transfer. There are numerous interferences compromising the defined process and its print result. These interferences can be minimised or supressed by shortening the time for developing through increased printing speed. [1, 3]

The drying step of printing can be done to different levels. First level, solvents and other possible substances used for the conditioning of the fluids are removed. This level is sufficient in the production of graphic products. Second level, chemical and physical processes are initiated and facilitated which are necessary to get a functional layer. This level is called curing. If inorganic particles are processed, a desired third level is to sinter these particles. There are contradicting requirements regarding drying, curing and sintering. The processes in the transferred material need a large amount of energy which needs to be applied without destroying the already processed layers and the substrate. This results in process times which can reach several minutes as opposed to process times of the gravure printing of at most a few seconds.

In graphic gravure printing presses each printing unit comes with an extensive drying unit which can dry to a decent level at web speed. This is suitable since the products to be printed do not require parameters which vary over magnitudes. Though, gravure printing presses are most suitable for large printing jobs which are feasible to be done at web speeds over 15 m/s.

Such a machine design is not feasible for fundamental research, application development or the fabrication of small batches. GT+W has developed the Superproofer 220 to offer a press design which allows the parameter space of high quality printing at minimum consumption of materials.

Superproofer 220 and Superproducer

The Superproofer 220 is a single sheet printing press for the purpose of printing highly accurate multilayer stacks in gravure or flexographic printing. The press offers a stable, reproducible printing process for a single sheet of substrate with an extensive range of process parameters and subsequent in-line drying. It resembles the equilibrium fluid transfer process combined with single sheet substrate transport and very economic fluid consumption.

The Superproofer 220 has a sheet-on-shuttle substrate transport system depicted in Figure 1. The substrate (5) is attached to a shuttle (4) which is driven by a dedicated linear drive with closed loop control (not depicted in the figure). The printing form cylinder (2) is driven by another independent drive in closed loop control. This set-up allows the substrate to be synchronised to the steadily running printing unit. Thus, the printing unit can be operated at an optimal parameter set. The substrate is then driven through the nip between printing form cylinder and impression roller (3) synchronized to the position of the printing form. The required travel for acceleration and deceleration depends on the given printing speed (v_{DF}) and possible acceleration rate.

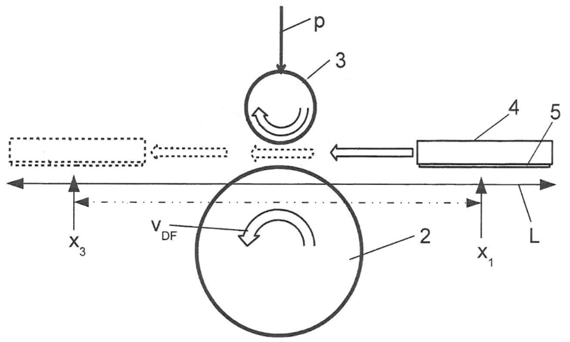

__Figure 1:__ Sheet-on-shuttle concept of Superproofer 220: (2) printing form cylinder, (3) impression roller, (4) shuttle, (5) substrate, (L) required space,(x_1-x_3) required travel, (v_{DF}) printing speed, (p) impression. Fig. excerpt from [4].

The Superproofer 220 can print on a 150 mm long substrate at 5 m/s despite its compact size of 1.2 m length. A drying unit is integrated into the press subsequent to the printing unit. The shuttle is stopped after the printing process and can then be moved along the dryer unit. Thus, a simple sequence of the two processes printing and drying can be implemented with total variability of the parameter spaces of both processes.

The substrate can be safely transferred to another process unit on its shuttle, if it is fitted to the shuttle concept. Hence, the Superproofer 220 is a neat solution for a process step within a discrete fabrication sequence.

For fabrication a sequence of in-line processes is demanded. Currently GT+W is adapting the single sheet-on-shuttle concept to a modular press concept which offers the desired flexibility regarding process parameters and their order in a sequence. This project is referred to as the Superproducer.

Experimental

The linear motion of the Superproofer 220 is established as system for conventional printing technologies and processes with low requirements as drying processes. It has to be investigated if it is also suitable for NIP processes. Furthermore, it has to be investigated if the linear drive concept can be adapted to the comprehensive concept for a fabrication line.

Superproofer – linear motion

It has to be stressed that a unique feature of the Superproofer 220 is the drive concept in which the motion of each single substrate is synchronised to the motion of the single process [4]. In the Superproofer 220 this is the printing form cylinder movement. Hence, the high-quality continuous printing process can be resembled in a single sample printing process. A single print is initiated by the printing unit which is run at constant speed. The shuttle with attached substrate is then launched from its rest position into the nip guided by a cam register. Depending on the set printing speed the cam calls for the required acceleration.

The substrate shuttle of the Superproofer 220 is run through an ordinary printing unit with printing form cylinder and impression roller. This design calls for a flexible suspension of the shuttle in vertical direction and around the axis parallel to substrate motion. In order to transmit the force of the linear drive directly the suspension of the shuttle has to be very stiff around the vertical axis to the substrate plane and to shear forces due to the inertia of the mass of the shuttle. The system has a rail guide. In regards to a preferably precise guidance of the linear motion, the system is initially loaded to provide the necessary stiffness. This results in a friction of the same magnitude as for the required acceleration. The linear measurement system is integrated to the rail of the linear guide. This measurement is utilised by the drive controller.

Both, the moving part of the linear motor and the moving part of the linear measurement system are cable-bound. This limits the expandability of the design of the Superproofer 220.

Superproducer – linear motion

In a production system this drive system needs to be adapted to a greater variety of processes. Additionally, these processes have to be arranged in sequence to use the label in-line-production. GT+W aims to develop a modular fabrication system based on the sheet-on-shuttle-concept applied in Superproofer 220. The prime objective is to design a cable-free shuttle. The necessary two development steps are switching to a linear motor that moves a cable-free part with fixed coils and choosing a suitable measurement system for control. We investigated the use of the Bosch Rexroth's FTS system.

The Superproducer system will be discussed according to Figure 2.

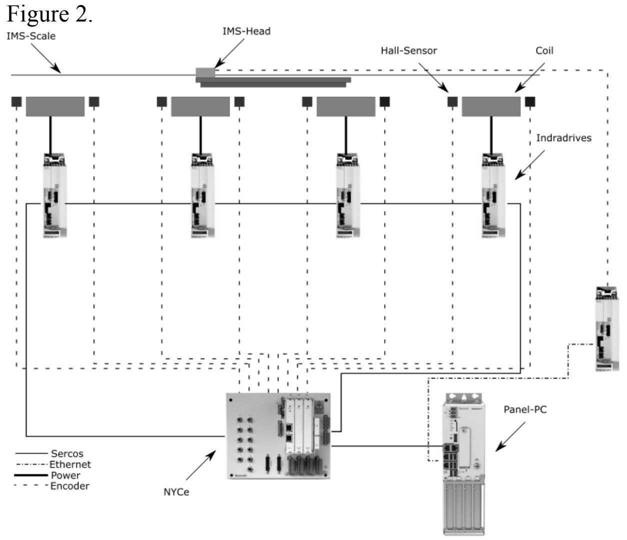

__Figure 2:__ Schematic setup of the Superproducer's motion control system

The system to be investigated consists of one industrial PC, one NYCe, four coils, four converters IndraDrive Cs, eight hall sensors, a package of magnets and one linear guide. The target of the hall sensors is the magnet packs mounted to the shuttle. This setup is sufficient to move the shuttle in a controlled manner. The fifth IndraDrive Cs and the Integrated Measurement System IMS are used as independent measurement system for analysing the internal hall sensor measurements.

With this setup we executed a set of motion experiments controlled by the internal hall sensors, the NYCe and the PC. We programmed motion profiles which were uploaded to the PC. The motion sequences were performed by the system under investigation. We will present the data recorded by the IMS. We stress that the IMS is not used for motion control. We used it to validate position and speed control of the drive.

The control layout depicted in Figure 2 offers limited possibilities compared to the control of the Superproofer 220. Each IndraDrive Cs is treated as an independent drive. The NYCe is the control unit for the IndraDrive Cs and toggles between them. The configuration of the track is designed in such a way that the magnets cover always a constant area of coils. At the transition between two coils the shuttle with its mounted magnets is moved by both coils. The position is determined by the hall sensors which transmit two shifted sinusoidal signals to the NYCe induced by the passing magnets. The magnet package is 576 mm in length and has 24 magnetic pole pairs. The pole pitch is 24 mm.

Superproofer – test set up

The shuttle of the Superproofer is positioned in the press by a locating pin. Supplementary, we developed a camera-based positioning unit in order to print multiple layers with high accuracy on top of each other [5]. This external unit has the same mount as the press. The position of printed registration marks can be measured to the reference of the mount. The determined position of the substrate can be synchronized to the known position of the printing form. Utilising this device, we have investigated the accuracy of the Superproofer 220 in respect to the control feedback. As a measure of the accuracy we determined the overall alignment accuracy of 30 single prints in printing direction. These measurements comprise the errors of the mounts in press and measuring device on top of the actual printing errors. In comparison, we recorded the actual position, the speed and the lag using the provided functionality of the converter IndraDrive Cs. The measurements were taken for runs at 1 m/s and 5 m/s. Additionally the tests were conducted in impact printing configuration (referred to as nip configuration) and non-impact printing configuration (referred to as NIP configuration).

For a good alignment of each layer the overall accuracy of the position is not as important as the reproducibility of the position. Thus, we consider the deviation between all single test runs to be more important than the errors of a single test run. Of interest was a possible correlation between the results of the test prints and the recorded control feedback.

Superproducer – test set up

The new drive concept presented above has to be validated. Cable-free shuttles are necessary for the flexible modular fabrication system in order to be theoretically of indefinite length. Compared to cable-bound shuttles, the task to control cable-free shuttles is more complicated. This is because of the need to control and synchronize multiple coils. In order to meet the same requirements as in the cable-bound case but handling the more difficult cable-free case, the complexity of the control needs to be managed sufficiently.

In this paper we test the cable-free system by examining the even speed of the Superproducer in non-impact configuration. The measurements were taken for runs at 0.8 m/s using the additional measurement system IMS. Thus, we recorded the position and the speed of the shuttle.

Data and Analysis

Superproofer 220

For a series of 30 prints the reachable overall alignment accuracy in printing direction of the Superproofer 220 was examined. The results shown in Figure 3 comprise the errors of the measurement device, the mount in press and measuring device, additionally to the actual printing accuracy. It shows that 50 % of the prints were in a range of ±5 µm and 76 % in a range of ±10 µm. The test runs were done at a printing speed of 1 m/s.

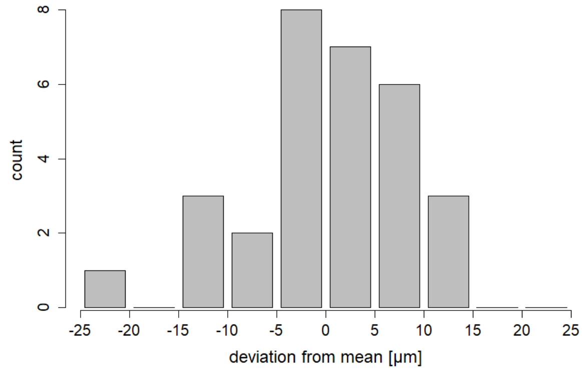

Figure 3: *Experimental investigation of accuracy of single print runs. Count of samples within a range of deviation from mean. Class width of 5 µm. Total count of 30.*

In Figure 4 the recorded speed and the standard deviation of the lag are plotted against the actual position of ten test runs at a printing speed of 1 m/s in nip configuration. At the position 250 mm the shuttle enters the nip and oscillates with a high frequency until it leaves the nip at the position 460 mm. Even though the shuttle oscillates, the standard deviation of the lag over the ten test runs remains lower than 5 µm. Together with the results presented in Figure 3 this shows that the printing process is reproducible.

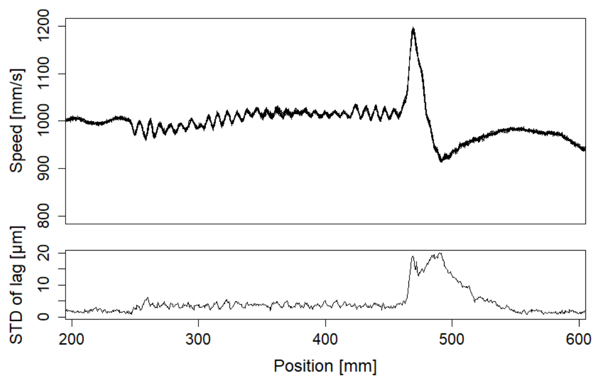

Figure 4: *Recorded speed and standard deviation of lag plotted against recorded actual position; printing speed: 1 m/s, nip configuration.*

In contrast to Figure 4, Figure 5 shows the same experiment in NIP configuration. Therefore, the interference between the linear and the printing unit is eliminated. The recorded measures for ten print runs at 1 m/s plotted against the measured absolute position show only slight oscillating with low frequency. Furthermore, the standard deviation of the lag is nearly constant, it averages 1.5 µm. This shows that the linear unit is also suitable for NIP processes.

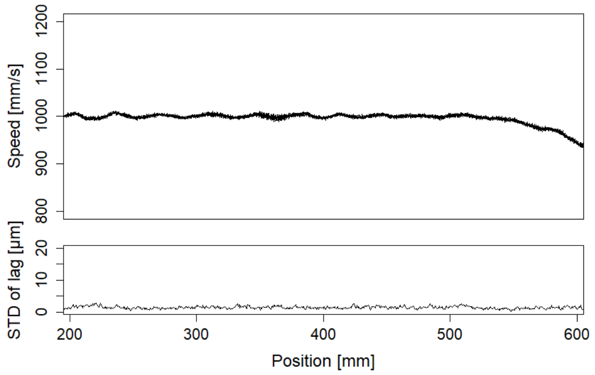

Figure 5: *Recorded speed and standard deviation of lag plotted against recorded actual position; printing speed: 1 m/s, NIP configuration*

Figure 6 displays the recorded speed and the standard deviation of the lag plotted against the actual position of the ten test runs at printing speed of 5 m/s in nip configuration. Because of the higher speed, the standard deviation of the lag increases to a mean of 5.0 µm. This shows the complexity of the motion control. Even speeds at low set speeds call for other characteristics of the controller as opposed to the high accelerations required for high printing speeds. Both operations work well in the Superproofer 220.

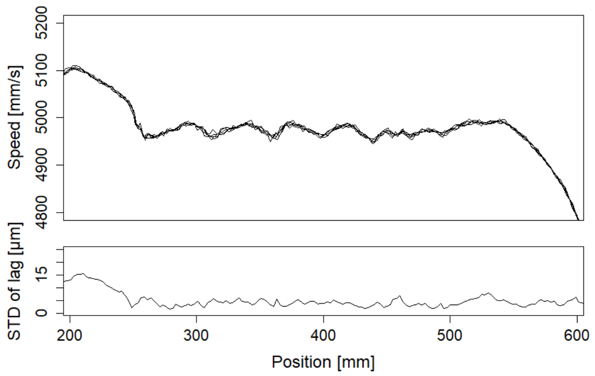

Figure 6: *Recorded speed and standard deviation of lag plotted against recorded actual position; printing speed: 5 m/s, nip configuration.*

Superproducer

In order to investigate the even speed of the Superproducer, we recorded five test runs over a distance of 2000 mm. Figure 7 shows speed, lag and standard deviation of lag plotted against the actual position of the five test runs at a set speed of 800 mm/s. The speed oscillates around the set target speed. Furthermore, there are three peaks in speed and lag during the transition of the shuttle between two coils. These peaks have two causes: cogging forces when leaving or entering a single coil and the mismatching of the two separate motion controls. The lag spikes at 3.1 mm, between two peaks the lag averages out at 108 µm. The mean of the standard deviation is 30 µm.

The motion control with four independent converters is complex. The transition between two coils has to be harmonised in order to achieve a steady movement. This multiplies the complexity to offer the parameter space printed electronics call for.

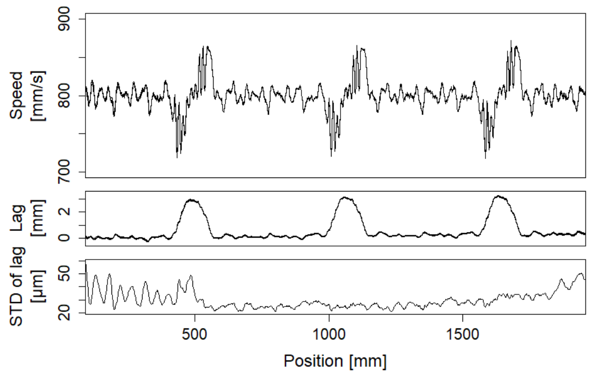

Figure 7: *Recorded speed, lag and STD of lag plotted against recorded actual position; printing speed: 0.8 m/s, NIP configuration.*

Conclusion

In this paper we have introduced our approach to handle different process speeds in the process of functional printing. The principle of the single sheet-on-shuttle substrate transport system in the Superproofer 220 is already well established in the market and fulfils the given requirements. We have analysed the printing accuracy and even speeds in nip and NIP configuration. Furthermore, we built a first test setup for the currently developed Superproducer and examined the even speed in NIP configuration. Considering the increased complexity of the motion control the reached quality of the movement is sufficient. We are working on compensating the spikes of the lag and reducing the deviation between the single test runs. Overall, we consider the results promising. The cable-free shuttle utilising the presented concept can be adapted to printing processes with nip and NIP processes. Though, for highest quality the motion control needs to be improved. Next steps are to offer the same parameter range as in the Superproofer 220 and to design the modular concept for process integration in the fabrication system Superproducer.

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Author Biography

Thomas Oberle graduated in mechanical and process engineering from Technische Universität Darmstadt in 2013. He focused on design in general and printing technologies in particular. For his Master's Thesis he worked at Xaar's Advanced Application Technology Group in Stockholm, Sweden. Since then he is part of the R&D department of GT+W in Rödermark, Germany. There he works on the development of printing technology for printed electronics towards fabrication systems.