Improved Ink Registration through Advanced Steel Belt Steering

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Abstract

Manufacturing equipment for single-pass digital printing faces an interesting challenge to deal with the growing productivity demand in combination with rising droplet registration accuracy. Although the administration speed of print-heads is still rising, high throughput speeds and/or increased print resolution can only be achieved by using multiple heads in series. Given at least 4 different inks, the distance between the first and last print-head can become more that a meter. When the relative registration accuracy over such a distance must be less than 10 micrometer, an intense fusion of multiple engineering disciplines becomes essential. In order to eliminate the mechanical (e.g. elasticity) properties of the substrate, a steel belt conveyer using vacuum technology for substrate clamping is introduced. Many conventional steel belt conveyors and their steering systems can't meet the previously mentioned accuracy target. By introducing actuated Axially Movable Segments Rolls (AMSR), the 2 surface orientations (X, Rz) of the belt (and therefore the substrate) can be continuously controlled, without deformation of the belt. On both sides of the rolls there are reluctance force actuators for segment manipulation. During rotation, the belt (always) will translate axially with respect to the segments that are in contact due to given limitations in belt and/or roll manufacturing (e.g. accuracy of the weld perpendicularity). The actuated AMSRs compensate this translation, based on the measured belt position. Once per revolution, when the segment is not in contact with the steel-belt, it will be actively positioned back to its 'center' position to minimize disturbances in the system. A demonstrator has been build to validate the actuated AMSR technology.

Introduction

With the continuous improvement of the print-head's jetting accuracy, registration deviations of subsequent droplets from independent heads must also become smaller. CCM is well acquainted with the mechatronic challenges that are encountered during the development of inkjet printing equipment for customers. It became clear that a generic solution for accurate transport of substrates is mandatory to reach the next level of jetting quality.

For applications with a fixed array of print-heads there is a distance between independently generated droplets. In conventional systems the substrate is manipulated directly along the print heads, like illustrated in *Figure 1*.

During transport from the 'first' droplet location to the 'last' adjacent droplet location, the combination of limited substrate stiffness and all kind of forces will introduce lateral and longitudinal (illustrated) disturbances in color registration. In other words, when the substrate can move freely, one should take exceptional precautions regarding substrate steering and driving, in many cases still resulting is unsatisfying results.

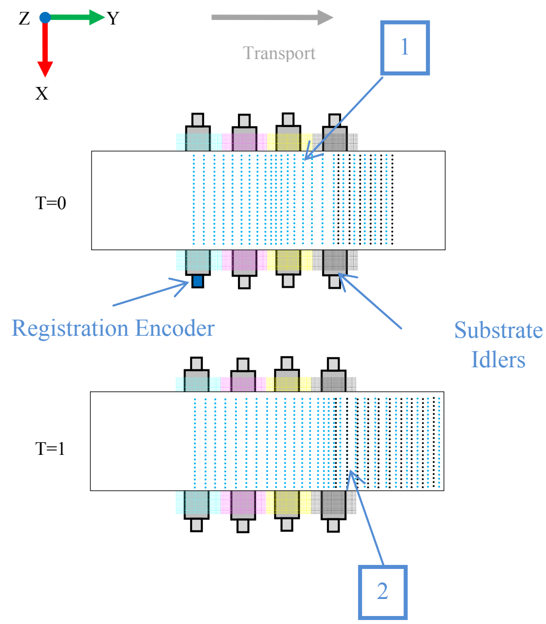

Figure 1: Drop alignment artifacts due to substrate transport; registration error after substrate tension variation [1] results in 'banding' [2]

Approach

Prior to finding an improvement for color registration, different 'target' materials to be printed have been inventoried. One can think of sheet-to-sheet transport of paper, cardboard, plastic, MDF and other semi-rigid material. For roll-to-roll applications paper, plastic and other non-rigid material must be handled.

A commercially available conveyor system with a suction area right below the color engine[1] like illustrated in Figure 2 seems an obvious (cost effective) concept to carry the previously denoted list of substrate types.

Based on CCM experiences and measurements, the motion accuracy of a mandatory transport concept should meet a planar accuracy of less than 10 µm over a length of 1 m at a transport speed up to 2.5 m/s. That is why the high young's modulus properties of enert and easy cleanable stainless-steel were tempting to serve as a carrier.

[1] The color engine represents a subsequent series of color bars, each holding multiple print heads.

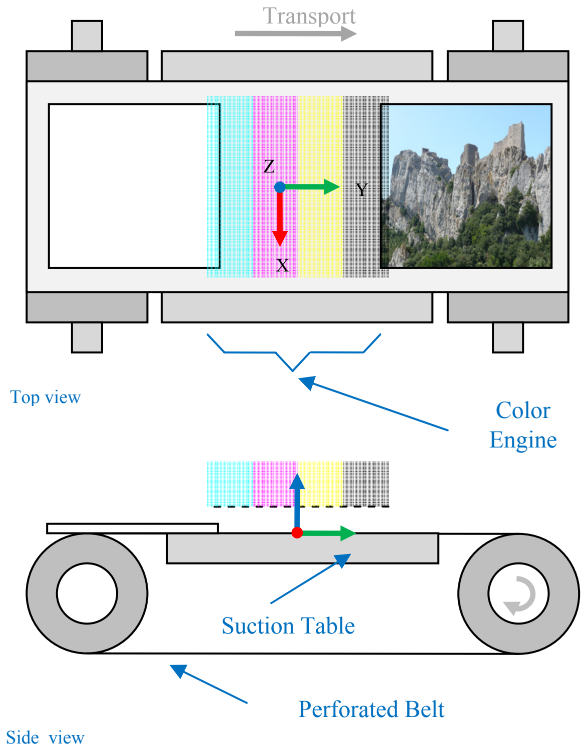

Figure 2: Conveyer belt transport concept, also showing applicable coordinate system

Conventional conveyor systems

Due to the high material stiffness, steel belt conveyors have excellent motion accuracy properties in the transport-direction (Y). However, achieving high motion accuracy in the lateral direction (X) proved to be the greatest challenge in steel belt transport. CCM already has done research in belt steering systems [1] prior to getting involved in inkjet equipment development. This research shows that geometric imperfections of a belt or its rollers cause internal stresses in a conveyor belt. Partly due to these internal stresses the belt will move in the lateral direction when transported. Eventually it will run off its transport rolls. Therefore a steering mechanism is mandatory. Currently available steering systems introduce lateral translation in the printing area, like illustrated in Figure 3. Furthermore conventional steering concepts introduce stresses in the belt that cause longitudinal deviations.

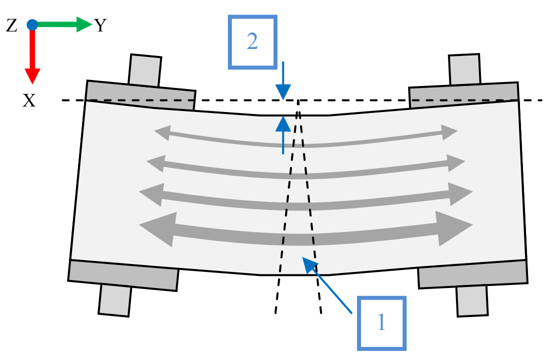

Figure 3: Conventional steering mechanisms introduces both stretch of the belt [1] and deflection in the printing area [2]

Axially Movable Segmented Roll (AMSR)

In [1] is explained that an infinite belt motion will introduce infinite (lateral) belt translation. In order to compensate for this effect, the rolls in *Figure 4* are deliberately cut into segments. Each segment can move independently in lateral (X) direction by means of mechanical guides. By introducing these axial movable segments (AMS) the existing infinite lateral motion will be chopped into steps per active[2] segment. In *Figure 4* this principle is visualized in 4 steps of rotation, starting with an inactive roll.

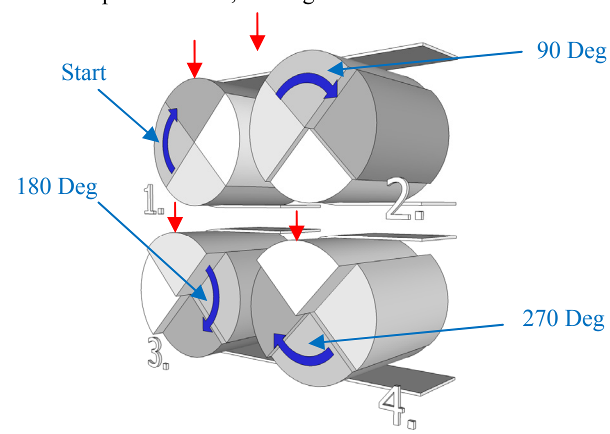

Figure 4: Axially movable segments during rotation

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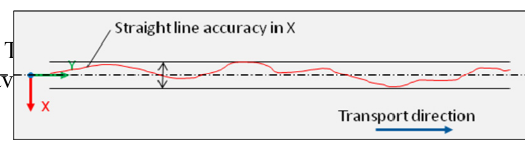

Figure 5. The guide for the axial motion of the segment has a relevant stiffness. During the active part of the rotation, this spring is tensioned because of the segment movement.
At the red arrow marked location in Figure 4, this tension disappears almost instantaneously when the segments becomes inactive.

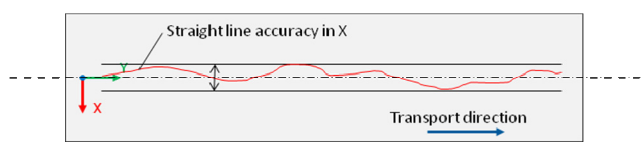

Figure 5: Definition of straight-line accuracy

The energy stored in the spring is suddenly released. Integral axial stiffness of the remaining active segments will be preloaded at once, thus introducing undesired lateral vibrations.

[2] Active means that the segment is physically in contact with steel belt

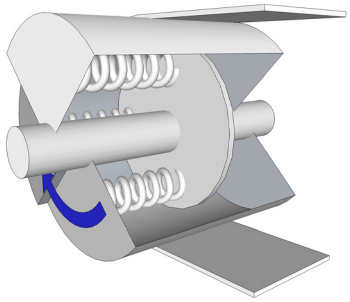

Figure 6: Visualization of AMS guiding stiffness

Actuated AMSR

Like other motion control systems, direct measurement and actuation of the belt edge in the printing area is preferred since it allows continuous control of the belt position, and subsequently the substrate position. *Figure 7* illustrates how relevant degrees of freedom can be controlled without indirect relations with transport velocity.

When an actuator system for the ‘set’ (green) segment is introduced, accurate control of the belt position is possible. An additional actuator for the ‘reset’ (red) segment can be used to control for the release of stored energy in the guides, described in the previous paragraph.

A comparison of Lorentz and reluctance type of actuators showed that the latter offered the best integral compromise of non-recurring costs and performance. It must be mentioned that the nonlinear properties of a reluctance actuator, has required extend research.

Motion control

In *Figure 8* an overview of actuators, sensors and the controller is given. The SAXCS[3] inspired control architecture consists of mainly 2 parts. The first part controls the force mechanism of *Figure 4*. The lateral motion of the segments is measured by gap sensors which are required for the force control loop of the reluctance actuators. This information, combined with the known stiffness of the segment guiding, can be used to predict the lateral force at any moment.

Through biasing of that segment which will almost become free from the belt, an undesirable step force is avoided.

This partly model based approach cannot cope with variations in mechanical properties of the segment guiding or force constant of the actuator. Therefore an additional repetitive control algorithm was added.

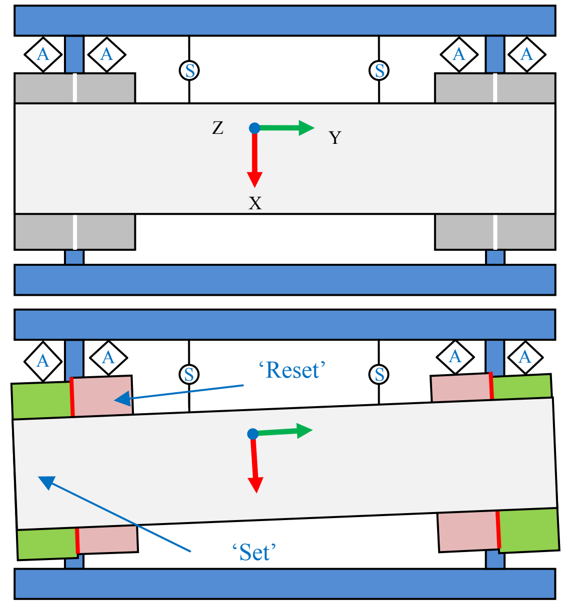

Figure 7: Preferred actuation concept, using actuators [A] the belt can be controlled in Rz and X. Measurement through [S]

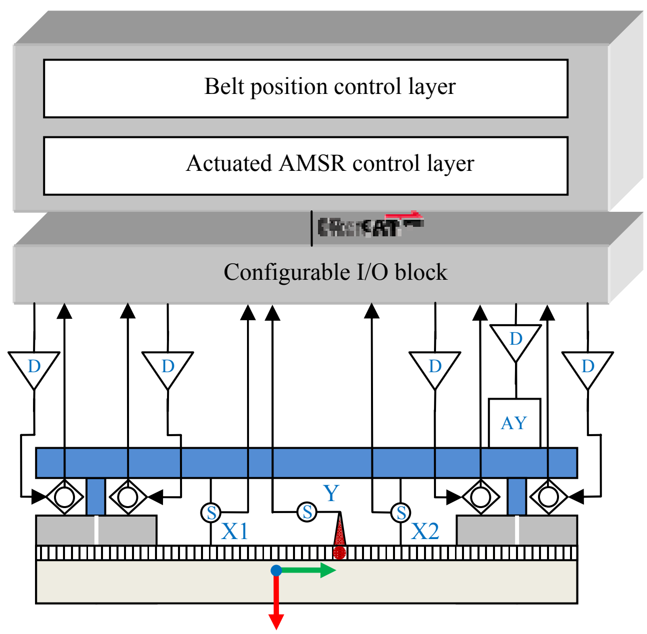

Figure 8: Control architecture, visualizes drives [D], the Y actuator [AY] and different layers

During every revolution of the roll it gradually ‘learns’ model mismatches and compensates for it via slightly adjusted force feed forward.

The second part controls the X,Y and Rz positions of the belt. The X and Rz positions are both calculated from the combined output of two belt edge sensors X1 and X2. A transformation matrix is used to derive X and Rz. Due to the manufacturing process of the belt; the belt edge contains reproducible artifacts

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[3] Smart And fleXible Control Solutions: www.saxcs.nl

with amplitudes beyond the accuracy budget. An identification sequence is performed for each new belt to determine the relation between longitudinal and lateral belt information. The resulting lookup table is then used to compensate for all belt edge artifacts.

The Y controller can use either position information directly measured at the belt (marked Y in *Figure 8*) or it can use position information derived from the rotational encoder which is part of the driving roll. Sensor Y is optical and interprets a laser engraved bar-pattern on the steel belt.

Demonstrator results

In order to test the feasibility and expected accuracy of the proposed solution with actuated AMSR rolls, the Generic Substrate Carrier (GSC) demonstrator was built and is shown in the figure below.

Figure 9: Generic Substrate Carrier demonstrator

To determine the lateral accuracy, the position difference of the belt edge was measured over the work area of 900 mm. By using the output of both belt edge sensors, shifted over the work area length, a power spectral density analysis (PSD) is performed to visualize the 3σ value of the lateral accuracy.

First the accuracy of the actuated AMSR control was measured without compensating for the previously described "reset" segment vibrations. Next, the measurement was repeated with the proposed spring stiffness compensation and learning controller activated. *Figure 10* shows the PSD analysis results for both situations. As can be seen in the figure, the accuracy has improved drastically by using a these compensation techniques. With it, a lateral accuracy of almost 15 µm was achieved with this first demonstration prototype. In longitudinal direction accuracy far below 5 µm has been measured! Also, print tests have been performed with a full-color inkjet module installed onto the GSC. The results of the output prints are significantly better than conventional systems, even with speeds up to 2.5 m/s.

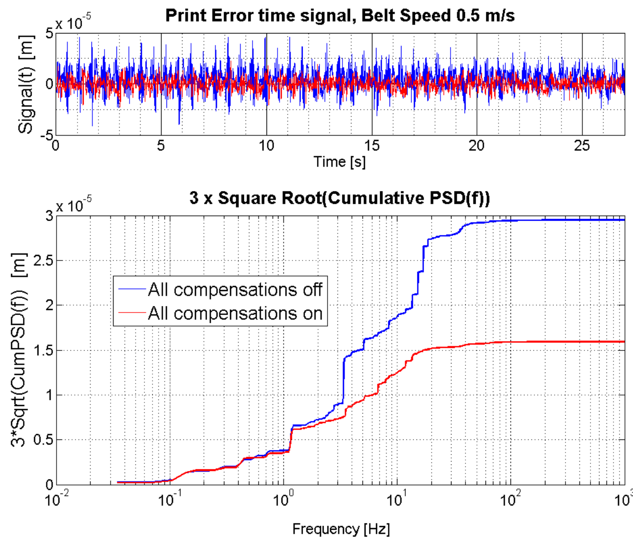

Figure 10: 3σ cumulative PSD of lateral accuracy

Together with DJM[4] the demonstrator was exhibited during the Drupa 2012 fair in Dusseldorf. Motivated by the enthusiasm of interested parties, CCM is now designing a Generic Substrate Carrier for series production. With the lessons learned from the demonstrator, the successor will be able to meet lateral accuracy below 10 µm. In parallel CCM will deploy a roll-to-roll application to serve single-pass substrate printing.

Conclusions

Substrate tension variation and external disturbances become a major problem due to the limited stiffness of the substrates. To overcome this problem a steel-belt conveyor is introduced on which the substrate is fixated with vacuum clamping during the complete print process. An advanced belt steering concept has been developed based on actuated Axially Movable Segmented Rolls (AMSR). The demonstrator of this technology has been successfully exhibited on the Drupa fair 2012. A series product is designed now.

References

[1] Harry P.M. Clerx. "Conveyor Belts, existing systems and new developments" ISBN 90-808282-1-1

Author Biography

In 1994 mr. Beltman graduated for Control Engineering in the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente. At Philips-CFT he got acquainted with lumped mass modeling techniques for machine dynamics. It allows early performance validation for mechatronic designs. At CCM he started off as a system designer and subsequently became project leader. Presently he is mechatronic system architect. Additionally he manages CCMs mechatronics department in combination with CTO activities.

[4]DJM is a company specialized in research and development of industrial inkjet printing solutions