Smoothing the Tension

Optimal web tension control with a dSPACE prototyping system

Fig. 1: The VESTRA paper coating system – the pilot coater at PTS, Munich.

When paper is finished in a coating system, it can be given either a glossy surface or a smooth, matte or closed one. Coated and processed paper meets the highest standards of printing quality. However, the production of coated paper is prone to web breaks, which causes productivity losses. Current coaters either cannot compensate for huge variations in web tension, or do not compensate sufficiently.

Modern coating systems are continuous production plants where the paper webs are processed at different production sections. The paper runs through several processing steps and must endure elastic or plastic deformations. The individual subsystems are coupled with each other by the running paper web itself. This significantly affects web stability throughout the entire coater and can even cause web breaks, resulting in idle times and plant standstills. Fluctuations in web tension arise throughout the system from changes in the physical parameters of the paper web during coating or in speed variations of the plant, from malfunctions or from applying/removing the blade and resulting coupling effects that are transmitted throughout the whole coater by the web. Conventional tension controllers are unable to compensate for these fluctuations sufficiently. If the web tension is not held within certain bounds (especially during coater start-up and shutdown), the attainable production quality may suffer badly or even be useless. Our objective was therefore to develop an improved control system for the web run by stabilizing web tension, taking into account the electrical and mechanical behavior of plant and web.

System Model of the Pilot Coater

To design an optimal controller and implement it on the pilot coater, we needed to acquire a thorough understanding of the entire system's physical and technical properties with regard to the web run to be optimized. We were able to model, simulate, and analyze the entire system using the collected plant data and the known, nonlinear physical system description (fluid mechanics and elasticity theory). We identified the following subsystems, coupled by the paper web, as the most important components of the system:

- Drive system (motor, gear, shaft, and clutch)
- Nip section (guide roller for the web)
- Paper web (textile web)

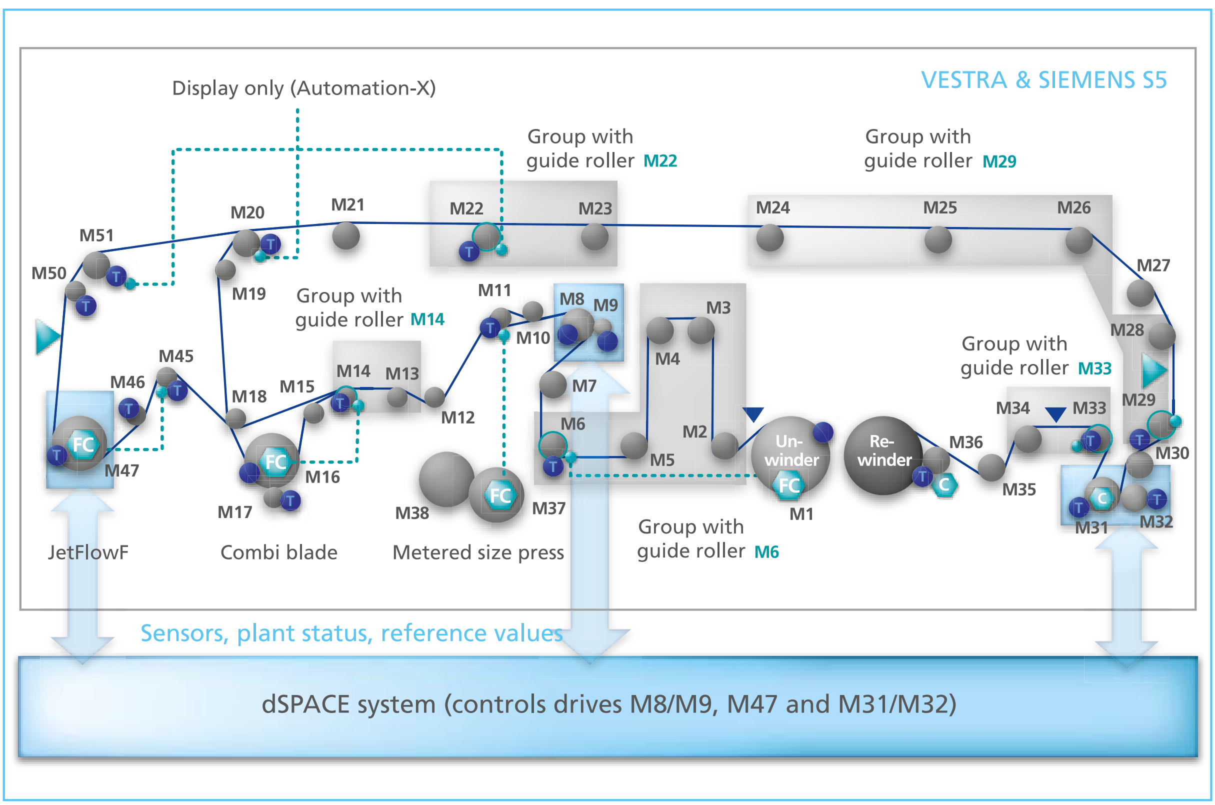

Fig. 2: The VESTRA coater with an interface to the dSPACE system for testing and verifying the new control structures.

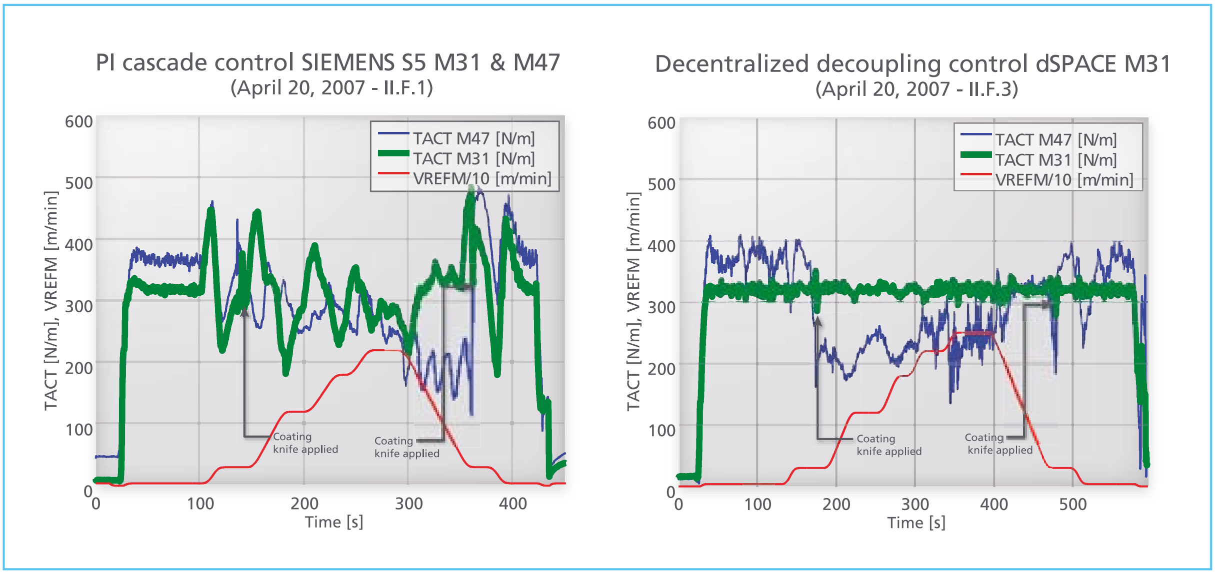

Fig. 3: Comparison between conventional PI cascade control (SIMATIC S5) and Decentralized Decoupling Control (dSPACE) at gripping press M31/M32 at different speeds.

These components describe the behavior of the paper and the web tension as a function of the drive units (motor and guide roller) and the possible load effects from friction or from applying the coating knife at the coating device. Our system model allows us to study coater processes offline and provides an easy way to test and analyze new strategies.

Properties of the Improved Control Structures

In all continuous production processes in which a paper web is conveyed through various subsystems, the overall plant behavior in relation to the paper web is complicated. The individual processing sections and/or nip sections (gripping presses or rollers) are coupled with one another via the paper web. Any undesired variations in web tension first affect the source subsystem and are then passed to succeeding and preceding subsystems. The control structures must therefore have the following properties:

- Good reference tracking (short transient time and small overshoot) and disturbance rejection of the control loop
- Robustness (for handling parameter uncertainties or variations)
- Good decoupling of the subsystems (optimal suppression of coupling effects)

To facilitate the implementation of the new control structures on the VESTRA coater, we decided to use rapid control prototyping with a dSPACE system. The dSPACE system was connected to the VESTRA via a specially developed electronic interface (see fig. 2) and allowed direct control of drives M8/M9 (gripping press 1), M47 (applicator device JetFlow-F) and M31/M32 (gripping press 2).

Decentralized Decoupling Control

Our first approach to stabilizing the web run is Decentralized Decoupling Control. Simulations allowed us to efficiently study and compare conventional PI cascade control (the control structure in the SIMATIC S5) and Decentralized Decoupling Control with respect to control performance, robustness and decoupling properties. The simulated plant behavior with PI cascade control reflected the qualitative and almost the quantitative behavior of real plant if delays due to slow cycle times and communication delays (due to the ProfiBus) are taken into account. First the standard PI cascade control was tested with the Siemens SIMATIC S5 and with the dSPACE system. Both had an identical controller structure and design. However, the dSPACE system provided clearly improved control performance simply because of its fast cycle time (the time the microprocessor takes to execute the programmed algorithms) and its negligible communication delays (unlike the SIMATIC S5, the dSPACE system is connected to the inverters directly).

On the other hand, the coupling effects due to the paper web are approximately the same for both systems. The Decentralized Decoupling Control at gripping press M31/M32 implemented on the dSPACE system reacts noticeably faster and more effectively to events such as the propagation of tension fluctuations arising from applied or removed coating blades or from changing reference machine speeds (VREFM). The web tension TACT M31 at gripping press M31/M32 is considerably smoother (see fig. 3).

In comparison with conventional PI cascade control, Decentralized Decoupling Control achieves high to very high control performance quality: good reference tracking, good disturbance rejection and broad robustness under varying production conditions.

Feedforward Torque Control of Applicator Roller

One of the most critical situations during paper coating arises when the coating knife (blade) is applied to wipe off excess coating color. The blade imposes a load on the coating device's impression roller and generates a load torque $M^*_{L,i}$ with pulse-shaped behavior at the time of blade application. Adding the coating color results in a change in paper properties (Young's modulus $\Delta E_{i-1,i}$) and in a certain amount of "lubrication" between blade and paper. This reduces the effective torque to an approximately constant value that the impression roller drive has to compensate for continuously during the coating action in order to maintain the desired speed and/or tensile force (web tension). Without feedforward torque control of the applicator roller, this dynamic load torque on the impression roller causes a noticeable drop in speed, which inevitably leads to decreasing web tension at the nip section and to increasing web tension at the succeeding subsystem. These tremendous tensile force fluctuations in TACT M47 may lead to undesired and dangerous web breaks. Our second approach is therefore a feedforward torque control that can be implemented modularly at the specified applicator roller and independently of any preset control algorithm used at the coating device. If the respective moments at which the blade is applied or removed, (i.e., the start and end of coating) are known, the feedforward torque control we have developed provides almost complete compensation of the load torque. It does this by means of the feedforward torque MFFC_Blade, whose characteristics can be determined,

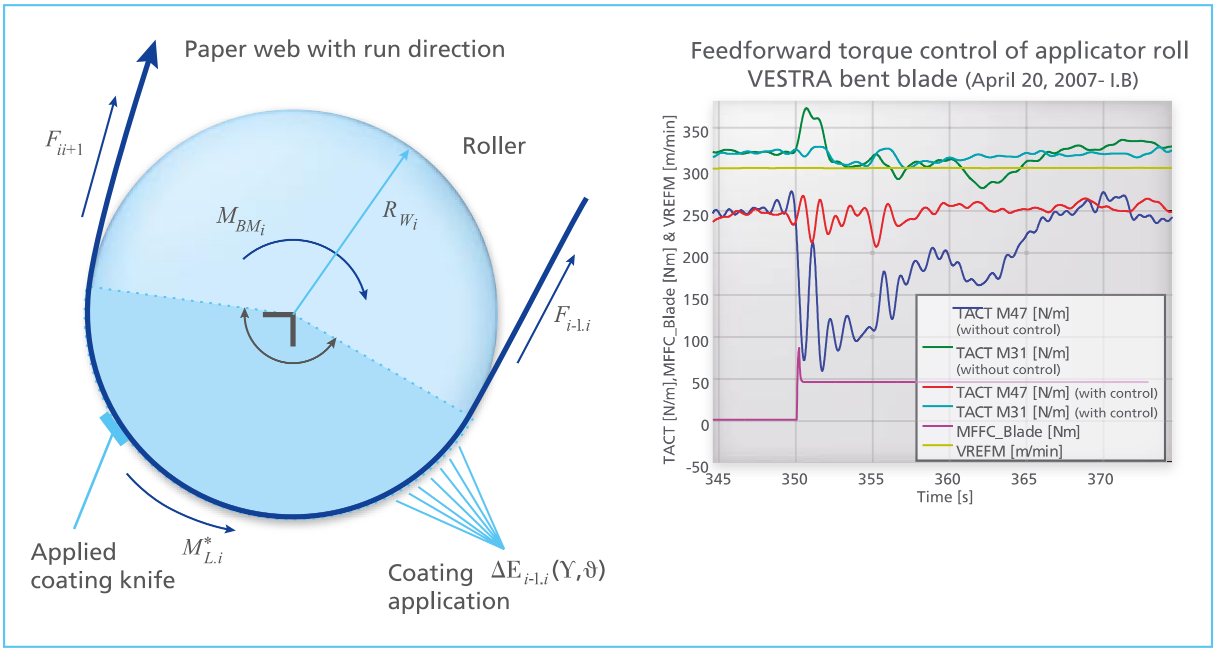

Fig. 4: Coating device M47 (JetFlow F) with coating knife (here: bent blade) – Comparison with and without feedforward torque control of applicator roller.

Glossary

Cascade control –
Nested control loops. The overall plant is divided into smaller controlled systems to simplify controller design and implementation for each.

Decentralized decoupling –
Specially designed state space control that minimizes the coupling effects of the remaining system on a specific subsystem.

Nip section –
According to an idealized model, each subsystem at which the web does not slip through or is subject to lateral offset.

> "The fast cycle times of the dSPACE system alone resulted in considerably improved control performance."
>
> *Christoph Hackl, Technische Universität München*

e.g. empirically, and stored in look-up tables. The feedforward torque control of the applicator roller was implemented and its applicability was verified at the VESTRA by simulation and experiment. Almost precise compensation was achieved (see fig. 4).

Result

We developed a simulation toolbox consisting of several modules for individual nip sections (drive, roller and paper web) and for the entire VESTRA. This toolbox facilitated the efficient testing and offline verification of both new control structures: the Decentralized Decoupling Control and the feedforward torque control. The new strategies were implemented on the actual plant via the extended electronic interface between the dSPACE system and the VESTRA.
Decentralized Decoupling Control provides a simple, efficient, and automatable tool for controller design for coupled subsystems in continuous production. It achieves high to very high control performance quality: good reference tracking, good disturbance rejection, and great robustness for use even under widely varying production conditions. For a particularly smooth web run, Decentralized Decoupling Control should be installed at every defined nip section.
The feedforward torque control of the applicator roller greatly reduces the risk of a web break. The effect of applying and removing the coating knife (blade) can be compensated for almost completely.
Both control concepts and the simulation toolbox are generally suitable for use in continuous production processes (paper, foil industries, etc.). Our results show a considerably smoother web run due to stabilized web tensions that overcome the disadvantages of conventional control and minimize the risk of web breaks and associated idle times.

Christoph M. Hackl
Lehrstuhl für Elektrische Antriebssysteme (EAT) (Institute for Electrical Drive Systems)
Technische Universität München
Germany

Beatrix Mair
Papiertechnische Stiftung
(The Paper Technology Specialists, PTS)
Munich
Germany