Multivariable CD control applications
By Shih-Chin Chen, Jonas Berggren, and Andreas Zehnpfund, QCS R&D

Cross-machine direction profile control has been a key area of advanced control applications in the paper industry since the early seventies [1-11]. In the past thirty years, the number of profile control applications on paper machines has increased dramatically. The total number of CD actuators installed between 1990 and 2007 exceeds 6,000 sets. As a result, many paper machines today are equipped with multiple sets of CD actuators. It is quite common that different CD actuators are added sequentially to existing machines for controlling particular sheet property profiles. Therefore, many paper machines have multiple sets of CD actuators working independently on the same machine. Even though papermakers recognised that one set of actuators may influence multiple sheet properties and one sheet property may be affected by multiple sets of actuators, there is no easy way to coordinate multiple CD actuators through independent single-input, single-output CD control applications.

Early attempts to coordinate multiple CD actuators were severely restricted by the capabilities of quality control systems (QCS) and the limited communication available among multiple actuators. A few alternative approaches were implemented to handle special cases [4, 12-15].

For cases where one actuator set influences multiple profiles, these profiles are combined together with proper weightings to generate a weighted profile and a CD control was designed to minimise the variation of the weighted profile [4, 12]. The implementation was simple and results were effective for specific applications. In other cases where one profile is changed by multiple sets of actuators, one approach [13] separates the input profile in multiple profiles based on the spatial frequency contents in the profile and then feeds one separated profile to each actuator set. Each actuator set controls the separated profile independently. Another approach [14, 15] predicts profile changes based on the control actions derived for the first set of actuators. The predicted profile changes are removed from the source profile. The difference profile is fed to the second set of actuators for control. Similar steps are applied to multiple sets of CD actuators in cascade. The execution of control actions is synchronised. All these approaches have had limited success and can only be applied to special cases.

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While alternative solutions have been applied in the past, the computing power and network communication of industrial control systems have significantly evolved in recent years. During this time, the applications of modern multivariable control techniques were also widely adopted in the paper industry. The use of personal computers and the OPC (OLE for Process Control) communication standard in the industry opens opportunities for new ways to control paper machines [16]. Multivariable CD control becomes the latest advanced control technique for paper machines [17-19].

In practice, a paper machine is a multi-input and multi-output process at different levels. In the case of a single profile controlled with a single set of actuators, multiple databases that represent a profile and multiple actuator zones are treated as multivariable inputs and outputs to a CD process for advanced controls [4-11]. The process of multiple CD actuator sets and multiple sheet property profiles represents a different level of multivariable complexity.

Fig. 1 illustrates an example of a process where profiles may come from several machine locations and control actions are applied to multiple sets of CD actuators, such as slice screws, steam box, water sprays, and/or induction profilers. In some sections of machines, the sheet width may change and the sheet may oscillate sideways, so the scan limits may be different at each frame. The threading distance between each frame and actuator location is different, hence transport delays vary. Sensors on different scanners may not be synchronised and profiles may not be updated at the same time. Therefore, profiles from different frames may have different sizes, may not align ideally, and may not update simultaneously.

Similar to the complexity of measured profiles, CD actuators are located in different sections of the paper machine. Each actuator set consists of a different number of zones across the web with...
different zone widths. Zones among different sets may not be aligned and may have different edge references.

To implement an advanced control for this multivariable process, we need models and alignment relationships for each input and output pair to describe the responses of each actuator zone.

The model of each zone consists of both spatial (cross-machine direction) and temporal (machine direction) responses. The temporal response is typically modeled as a first order dynamics with transport delay. Depending on actuator types, the spatial response could have a few different response characteristics. Fig. 2 shows examples of several possible spatial responses.

There are multiple objectives for a multivariable control to achieve. The primary goal is to produce a paper sheet where all profiles (weight, moisture, caliper, fiber orientation, etc.) are uniform. The control performance is quantified by profile variance relative to a target profile. Therefore the primary control objective is to minimize the variance of all profiles with respect to their target profiles. However, to minimize profile variations may require competing control actions among multiple actuator sets. This leads to a complex optimization problem.

References