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A multivariable CD control application approach may be beneficial for certain applications; coordination is the key

USE A MACHINE'S FULL CAPABILITY

Cross-machine direction (CD) profile control has been a key area of advanced control applications in the paper industry since the early 1970s [1-11].

In the past 30 years, the number of profile control applications on paper machines has increased dramatically. The 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 recognized 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 minimize 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 synchronized. All these approaches have had limited success and can only be applied to special cases.

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

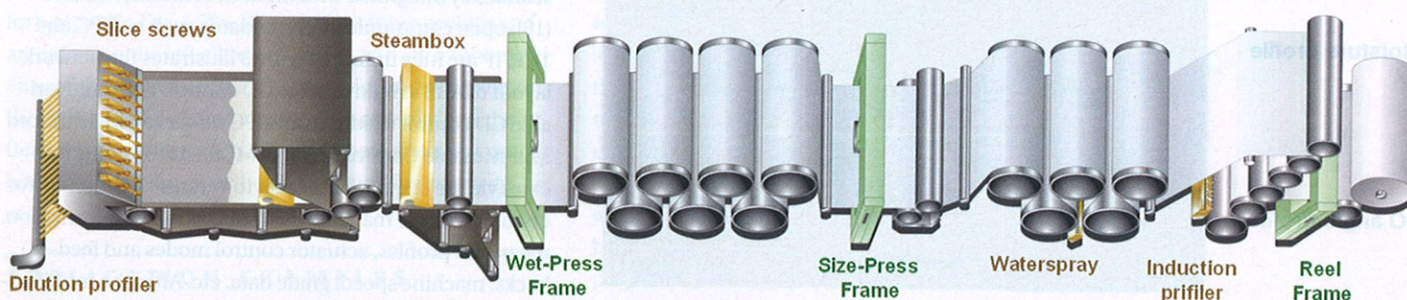


Fig. 1 - AN EXAMPLE OF MULTI-INPUT AND MULTI-OUTPUT CD PROCESS

control becomes the latest advanced control technique for paper machines [17-19].

MULTIVARIABLE CD PROCESS RESPONSE MODELING

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 databoxes 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.

Figure 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 synchronized 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 (CD) and temporal (MD) 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. Figure 2 shows examples of several possible spatial responses.

CONTROL OBJECTIVE AND CONSTRAINT HANDLING

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 the need for trading priorities among different profiles while keeping all actuators within constraints. The multivariable CD control scheme has weighting factors that allow users to make their trade-off among different profiles. In practice, not all profiles and all actuators are always needed in a single multivariable control configuration. Depending on different process conditions, a subset of the full multivariable control may be more appropriate. The multivariable CD control is also flexible enough to accommodate this requirement.

SYSTEM ARCHITECTURE

To make the implementation of multivariable CD control seamlessly integrated with modern control architecture [16], open communication standards such as OPC and TCP/IP are fully utilized. Figure 3 illustrates the network layout of ABB's multivariable CD control. The multivariable CD control resides in an OPC server called Advanced Multivariable Control Server (AMCS). AMCS communicates via the standard Ethernet to various OPC servers for obtaining paper machine data such as frame information, measured profiles, actuator control modes and feed-backs, machine speed, grade data, etc. After the multivariable CD control derives desired control actions, it sends setpoint outputs to the various actuator systems via OPC.

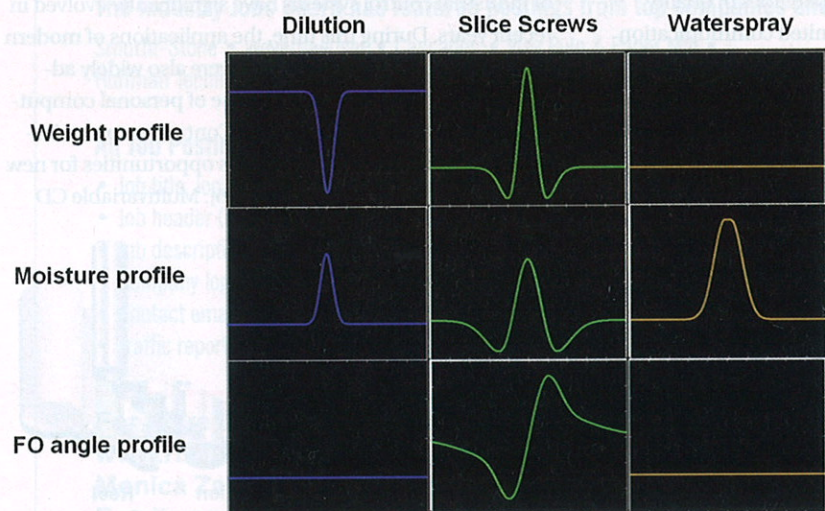


Fig. 2 - EXAMPLE OF DIFFERENT SPATIAL RESPONSES

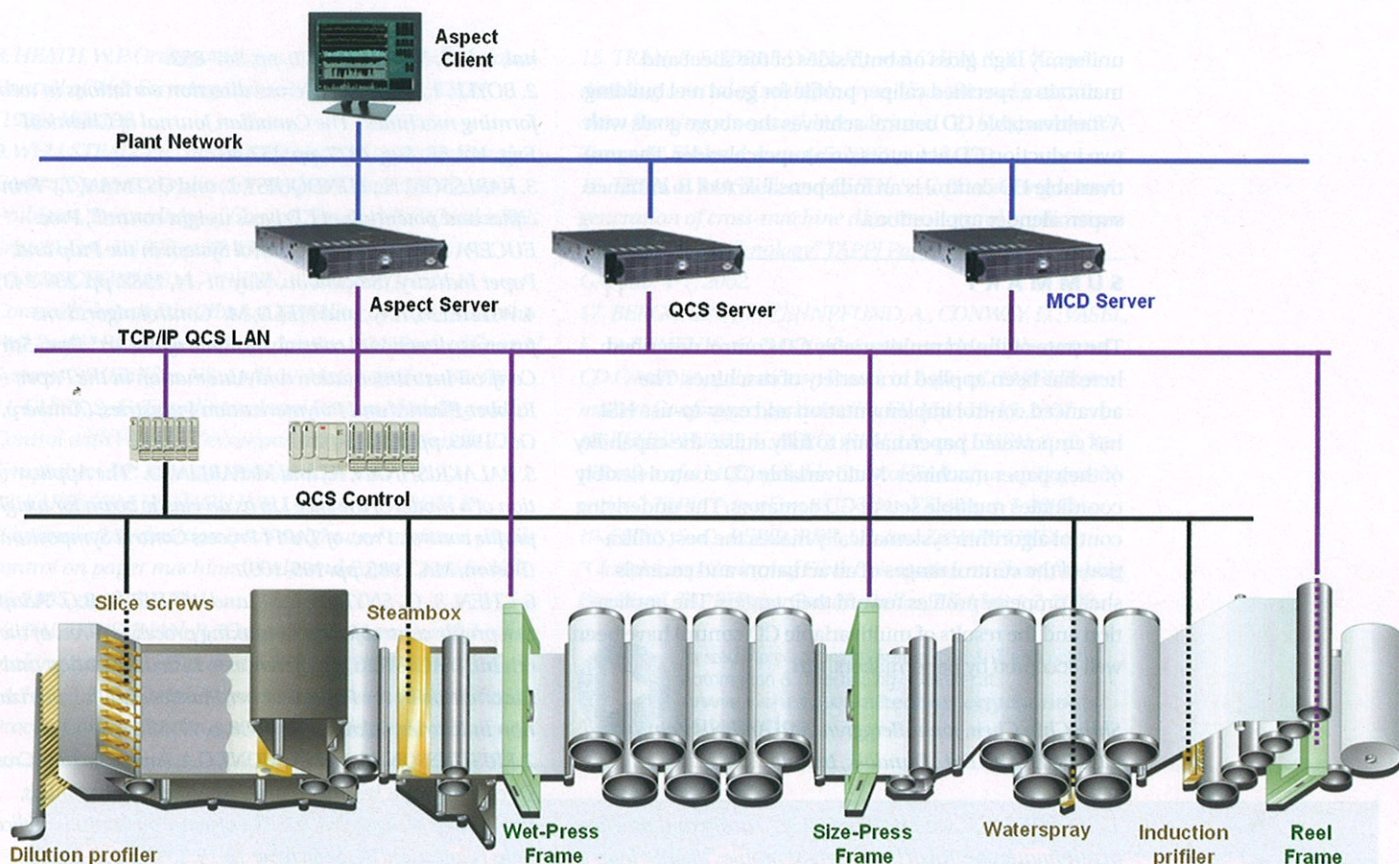


Fig. 3 - TYPICAL NETWORK LAYOUT OF A QCS SYSTEM WITH MULTIVARIABLE CD

This architecture allows the multivariable CD control to be integrated with many existing QCS. AMCS can be installed on nearly any paper quality control system that supports standard OPC communication.

HUMAN SYSTEM INTERFACES (HSI)

There are different types of users who need to interact with multivariable CD control. The primary HSI requirement for multivariable CD control is to properly display multiple profiles and actuator arrays on a single window for operators, Fig. 4. The display of multiple profiles and actuators on the left allows operators to have a bird-eye view of the entire process. The statistics and priorities on the right provide operator with precise results and the flexibility to make clear trade-offs. There are also a number of displays that specifically designed for engineers to setup and configure a multivariable CD controller.

APPLICATION EXAMPLES

Weight and moisture control on a dual-headbox liner-board

machine: A linerboard machine is frequently equipped with two or more headboxes. Each headbox has a set of slice screws for controlling both weight and moisture profiles. On the same machine there might also be other CD actuators such as a steambox and a water spray. Figure 4 illustrates an example of such a machine that has four sets of CD actuators. The slice screws from primary and secondary headboxes have been selected to control both the weight and the moisture profiles. The trade-off between weight and moisture allows the moisture profile to be more tightly controlled.

Weight and twist profile control on a multi-headbox machine: On paper machines, it is well known that the slice opening shape influences weight and fiber orientation simultaneously. Fiber orientation determines the twist characteristics of a sheet. Multivariable CD control can effectively control both weight and twist, which is derived from fiber orientation measurements. Multivariable CD control effectively utilizes multiple headboxes to balance the control of multiple profiles so that the sheet properties are fully optimized.

Gloss and caliper control on a supercalender: For a supercalender application it is very crucial to obtain

uniformly high gloss on both sides of the sheet and maintain a specified caliper profile for good reel building. A multivariable CD control achieves the above goals with two induction CD actuators on a supercalender. The multivariable CD control is an indispensable tool to enhance supercalender applications.

SUMMARY

The state of the art multivariable CD control described here has been applied to a variety of machines. The advanced control implementation and easy-to-use HSI has empowered papermakers to fully utilize the capability of their paper machines. Multivariable CD control flexibly coordinates multiple sets of CD actuators. The underlying control algorithm systematically makes the best utilization of the control ranges of all actuators and controls sheet property profiles toward their targets. The application and the results of multivariable CD control have been well accepted by papermakers. **PPI**

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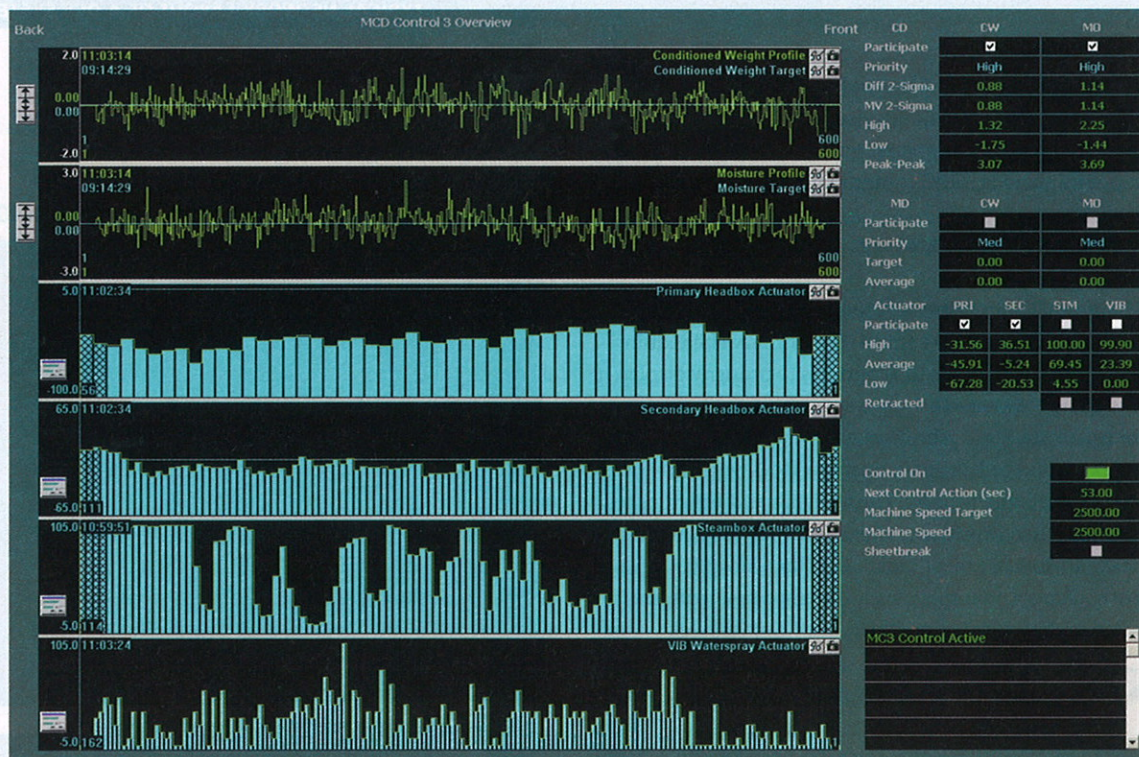


Fig. 4 - MULTIVARIABLE CD CONTROL OF WEIGHT AND MOISTURE PROFILES