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Performance metrics for web-forming processes

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ABSTRACT

There exists a number of performance metrics for different types of processes, particularly for univariate control loops. This paper proposes performance metrics for two-dimensional web-forming processes, that are found in paper, plastic film and steel industries. A simulation example shows that the metrics are able to differentiate between typical disturbance classes. An industrial implementation example demonstrates the use of the metrics as a part of the quality monitoring system of a paper mill. The system currently in use at the mill provides plant personnel with additional quality information that is considerably more detailed than the quality information obtained from laboratory measurements.

1. Introduction

Modern research in the field of CPA began when Harris presented the minimum variance benchmark derived from the theoretical background of the minimum variance controller [1]. Ever since, a number of methods have been developed for measuring the performance of control loops. For a review of different metrics, see [2–4]. Proprietary software for evaluating controller performance is on the market [4–6], and several industrial applications have been reported [4,7–12].

Most performance metrics concentrate on one-dimensional measurements. This paper proposes several performance metrics to be used in evaluating the performance of two-dimensional web-forming processes. Such processes are found, for instance, in paper, plastic film and steel industries.

In a two-dimensional web process the product is a planar object being relatively thin when compared to the width and the length of the object. The direction of product movement is called the MD, whereas the direction perpendicular to the MD is the CD. Material flow is provided to the headbox, which is the device responsible of distributing the material in the cross direction. Because of the configuration of the web process, the CD and MD are also called the spatial and temporal dimensions, respectively.

As a result of the different physical configuration of the web-forming process in CD and MD directions, the dynamical properties of the product in CD and MD directions tend to be unalike: the variations in the MD are due to variations, e.g., in the input to the headbox, whereas the variations in the CD are caused for instance by the headbox and the devices following the headbox. An example in Fig. 1 illustrates the differences between CD and MD dynamics by showing a set of moisture data from a paper machine. Although corrupted by measurement noise, the overall profile in the CD remains the same. In the MD, however, there are fast variations in the measurements.

Fig. 2 illustrates a measurement arrangement that uses a scanner traversing the web with constant speed. Since the web travels in the MD, the relative path of the scanner with respect to the web is of zig-zag shape. There exist also measurement arrangements that use a variable-speed scanner to improve accuracy, and full-web width scanners that measure the entire CD simultaneously.

Because of the zig-zag movement of the scanner, the raw profiles are a combination of three components [13]:

- *The machine direction (MD) component.* Variations occurring along the sheet travel direction of the machine and affecting the whole width of the machine. MD variations are expected to affect the whole width of the sheet similarly.
- *The cross-direction (CD) component.* Variations occurring perpendicularly to the sheet travel direction of the machine. Generally speaking, CD variations are slower than MD variations, and can be assumed to be nearly time-invariant. CD variations will persist in successive profiles.
- *The random component.* Random variations that occur neither along nor across the machine. These variations are due to measurement noise etc.

The process of separating the MD, CD, and random components is referred as CD-MD separation. The problem that needs to be

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