Quality control system validation by using a web analysis

BY M. MÄKELÄ, O. PYRHÖNEN, T. MYLLER AND M. HIERTNER

Abstract: Consistency in paper and board quality improves the competitiveness and productivity of paper and board producers. Standardized quality management is an important issue in mills. The total product quality depends on many different things: the raw materials, the capability of the process machinery with its automation and, last but not least, the competence of the personnel. An automatic quality control system is one part of the quality control. There are more variations in paper and board quality variables than automatic quality control systems show. The traversing scanner measurement data is neither cross-directional nor machine-directional. The performance assessment of quality control systems is discussed within a life-cycle model. The evaluation of the performance in a validation phase is presented, with a case study utilizing detailed web analysis.

A significant part of quality control in a mill is the automatic quality control system (QCS) of a single paper or board machine. In this article, the concept QCS refers to the quality control automation: the hardware, software and maintenance services used specifically for quality control purposes. On-line quality measurement and process control are essential parts of the QCS.

Principally, modern quality control system hardware consists of process stations, operator stations and scanners. The system components are integrated in a computer system network of automation, Fig. 1. Process stations and operator stations are common commercial computers, which communicate with each other via a modified TCP/IP protocol system bus. Some process stations are dedicated to quality control software, while others to quality measurement scanners and basic instrumentation. Scanners communicate with process stations through field buses. Operator stations are used for control room operations. The components on the left side of the dashed line may be seen as a part of the quality control system (QCS), while the components on the right side belong to the main distributed control system (DCS) of a paper or board machine.

The paper and board quality variables - basis weight, moisture, caliper, ash, color, gloss and fiber orientation may be controlled automatically in machine direction (MD) with feedback control loops, Table I. MD control loops are cascading, consisting of lower level PID loops and upper level advanced loops. The periodic measurement principles of traversing scanners and remote actuator positions from measuring devices imply long time delays, which may be partly compensated by using model predictive control (MPC) algorithms on the upper level. Due to strong interactions between different controllable variables, multivariable control strategies may be useful for better performance. The MD controllability is mainly dependent on the time delay between the measurement and the actuator. Basis weight, moisture, caliper, coat weight and fiber orientation may be controlled automatically in cross direction (CD) with feedback control loops, Table II. Optimization computing is utilized in large-scale multivariable CD control algorithms for hundreds of measurement points and dozens of actuators to minimize CD profile errors. The spacing between single actuators typically varies from 25 mm to 150 mm. The spacing width sets the lower limit of the CD controllability. A typical sensing width of a sensor’s databox in traversing scanners is 10 mm in cross direction.

QUALITY CONTROL SYSTEM PERFORMANCE ASSESSMENT WITHIN A LIFE-CYCLE MODEL

The life-cycle model of process control systems may be applied to quality control systems. The life-cycle may be categorized into eight phases [1,2]:

1. specification
2. system design
3. implementation
4. mechanical installation
5. functional test
6. performance validation
7. production
8. decommission.

The quality control systems may be evaluated with respect to the following properties: functionality, performance, dependability, operability, safety and non-task-related properties [3]. The dependability and performance of advanced quality control systems are discussed in terms of process control, quality control, maintenance and process development. The specification phase should describe the objective QCS as exactly as possible. The purchaser defines measured, controlled and manipulated quality variables and main quality control principles. After an investment decision, quotations are requested from suitable QCS supplier candidates. If a supplier intends to make a quotation, the functional QCS description is developed. Scanners, sensors, process modules, other...
computer components and a network structure are specified. The structure of a quoted QCS is based on the supplier’s commercial modules, which are customized to the purchaser’s requirements as far as possible. Special attention should be paid to the quality of the application software documentation, because of future maintenance and development needs. The quality control principles are discussed and defined loop-by-loop by process engineering, automation engineering and operator teams. QCS suppliers are encouraged to define the QCS performance indices and the ways of monitoring, and purchasers are encouraged to require it.

In the system design phase, a QCS supplier is chosen and the documents of the specification phase will be completed. The QCS design phase consists of three main areas: mechanical design, hardware design and software design. In the QCS software design, a main program structure, lower and upper control model loops are determined. Detailed program module descriptions are worked out. Special attention should be paid to the descriptions of customized upper level control modules because of maintainability.

In the implementation phase, the QCS supplier acquires, manufactures, assembles and tests the designed QCS concept. After the completion of configuration and programming, a factory acceptance testing (FAT) is performed by the supplier in cooperation with the purchaser. The testing procedure shall cover all MD and CD control loops and the documentation of customized program modules shall be inspected. The purchaser’s teams are encouraged to take advantage of the FAT as much as possible.

In the mechanical installation phase, the QCS is installed in the purchaser’s mill. A system platform with its scanners, sensors, computers, monitors, system racks, networks and cables are installed. The tested system and application software is loaded into the operator and process modules and servers. After the installation process machinery and piping trials, instrumentation calibration inspections and wired protection electronics trials, signal and loop testing (SLT) takes place.

In the functionality testing phase, the functionality of the whole QCS is evaluated. In a cold commissioning, a paper or a board machine is run with water. In a hot commissioning, a paper or a board machine is started up with real pulps and chemicals. The QCS application software for every process section is checked, the control loop tuning and parameter optimizing are performed. Often the 2-sigma deviations of MD profiles and CD trends are monitored. External foil samples and offline roll samples may be used as a reference for calibration. After the commissioning procedures, a final system acceptance test (SAT) is performed to show that the QCS works according to its functional descriptions in a full production load. The performance indices are compared with the values given in the functional descriptions. The supplier is responsible for the SAT.

In the performance validation phase, the purchaser must be satisfied with the functionality of the quality control automation. The whole performance validation phase consists of a technical validation of automation and a process validation. The technical validation of automation aims to show that the QCS works according to its specifications. The supplier is responsible for the technical validation. The process validation aims to show that specified paper or board products can be manufactured. The capacity of a paper or a board machine is increased to its nominal values by optimizing the operations and the

### TABLE I. Controlled and manipulated variables in machine direction control.

<table>
<thead>
<tr>
<th>Controlled quality variable</th>
<th>Main manipulated variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis weight</td>
<td>Thick stock flow</td>
</tr>
<tr>
<td>Moisture content</td>
<td>Main steam section pressure</td>
</tr>
<tr>
<td>Coating moisture content</td>
<td>Infra-red drying power</td>
</tr>
<tr>
<td>Caliper</td>
<td>Air-impingement drying power</td>
</tr>
<tr>
<td>Ash (filler content)</td>
<td>Filler flow</td>
</tr>
<tr>
<td>Ash (coat weight)</td>
<td>Blade angle or blade loading pressure</td>
</tr>
<tr>
<td>Color</td>
<td>Flow of colorants brighteners and fillers</td>
</tr>
<tr>
<td>Glass</td>
<td>Calender nip pressure</td>
</tr>
<tr>
<td>Fiber orientation</td>
<td>Jet-wire-ratio</td>
</tr>
<tr>
<td>Caliper</td>
<td>Headbox pressure</td>
</tr>
</tbody>
</table>

### TABLE II. Controlled variables and manipulated actuator sets in cross direction control.

<table>
<thead>
<tr>
<th>Controlled quality variable in cross direction</th>
<th>Manipulated actuator set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis weight</td>
<td>Headbox slice screws</td>
</tr>
<tr>
<td>Moisture content</td>
<td>Headbox dilution valves</td>
</tr>
<tr>
<td>Coating moisture content</td>
<td>Steambox</td>
</tr>
<tr>
<td>Caliper</td>
<td>Moisturizer</td>
</tr>
<tr>
<td>Coat weight</td>
<td>Induction heater</td>
</tr>
<tr>
<td>Fiber orientation</td>
<td>Calender nip</td>
</tr>
<tr>
<td>Caliper</td>
<td>Coater</td>
</tr>
<tr>
<td>Caliper</td>
<td>Headbox slice screws</td>
</tr>
</tbody>
</table>

![FIG. 1. Quality control system configuration.](image)
validation. The validation of a QCS refers to a task in a mill’s quality assurance, which begins in the specification phase of a QCS update project, reaches its culmination in the validation phase and continues in the production phase. An offline web analysis may be used for the process validation of a QCS.

Offline Web Analysis

The variations of quality variables in paper and board products may be divided into three categories: 1) variations in cross direction, 2) variations in machine direction and 3) residual variations. The strip samples, taken from customer rolls, may be analyzed with lab analyzers, but only cross direction and residual variations may be analyzed. During the web analysis, the updated QCS scanner took about one minute and, during this time, a web travelled about 400 m.

Before the QCS update, the basis weight profile was controlled by the slice screws of three different headboxes. In the update, the actuator set of one headbox was changed from slice control room display and operation purposes. The CD profile data of traversing scanners is preprocessed for different purposes:

1. The quality measurement data is preprocessed separately for control room display and operation purposes. The CD profile databases may be averaged to actuators’ width. Adjustable digital signal processing is used.

2. The quality variable CD and MD profiles are preprocessed for control room display and operation purposes. The CD profile databases may be averaged to actuators’ width. Adjustable digital signal processing is used.

3. The quality measurement data is preprocessed separately for quality control purposes. The CD and MD profiles have to be estimated and CD profiles averaged for actuator widths for control loops. Adjustable digital signal processing is used. Some improvement in CD and MD estimation by using wavelet-based methods is reported, for example, in [6].

When the variations of paper and board products and the performance of quality control systems are evaluated according to online measurements, the signal processing of the measurement data has to be taken into account. Monitored variations even out with more filtering and averaging.

Online vs. Offline Measurement Datas

In the case study of a board machine, quality variable profile data from the QCS was stored in an information system. The CD basis weight profile variances, calculated from the QCS profiles before the update, gave the variances 0.6 (g/m²)² for base board and 1.1 (g/m²)² for coated board, when normalized to 60 g/m². These variance values were clearly less than those measured in an offline analysis. In the old scanner, profile points were taken with a resolution 50 mm in cross direction, giving 120 profile points. When the online variances were compared to the ATPA variances, some variations had smoothed out. A single scan of the old QCS scanner took about one minute and, during this time, a web travelled about 400 m.

After a system update, basis weight CD profile variances had values of 0.3 (g/m²)² for base board and 0.5 (g/m²)² for coated board, when normalized to 60 g/m². The CD profile online data was sampled over 30 rolls at a time, about two months after the system update. CD profiles could be stored with an actuator width basis, giving 79 profile points. The regular information system did not store the online CD profile data of 600 points with the resolution of 10 mm in cross direction. The online CD profile values before and after the system update were not directly comparable, due to different data box sizes and signal processing methods.

In functional tests, according to the supplier’s additional QCS data sampling and reports, the CD basis weight variable variances of base board were 1.4 (g/m²)² for the old QCS and 0.2 (g/m²)² for the new one, given in normalized 60 g/m² values. The calculations were performed over 200 reels with the resolution of 10 mm in cross direction, before and after the system update.

FIG. 2. Averaged basis weight CD profiles before and after a process and QCS update in an offline analysis [5].
update. The variance levels of basis weight CD profiles in online systems matched well with the results of the offline analyses.

Power spectral analyses can be used to look for periodic phenomena in the process. In the offline analysis after a system update, a clear peak of 5.8 Hz with the wavelength 1.23 m in a logarithmic variance spectral density function of MD basis weight and the MD variance of 0.9 (g/m²)² were found [5]. The share of the disturbance peak in the variance was 0.7 (g/m²)². The disturbance was not seen in the QCS MD trends and its compensation is beyond the MD controllability. On this board machine, the variation wavelengths longer than 400 m could be monitored by the QCS. With the ATPA, the frequencies from 0.01 to 100 Hz in machine direction were observable.

In online systems, the MD trend calculation of quality variables is based on scanned data. Thus the calculation of MD variances from MD profile values does not give any new information. Scanners can be operated in a fixed point mode in order to get information on MD variations. This kind of evaluation may be used for calibration purposes, when the conformity of quality sensors and lab analyses is determined (dynamic correlation).

CONCLUSIONS
By approaching the assessment of quality control systems within the whole life-cycle, suppliers and purchasers are encouraged to improve and systemize QCS automation for better performance. The validation of a system continues through the life-cycle with different qualifications and culminates in the validation phase. As long as traversing scanners are used in paper and board production, an offline web analysis helps the evaluation of quality control systems in a process validation.

LITERATURE
1. PSK 4601 (1996). (more info is needed here)

Résumé: La réduction des variations en matière de qualité du papier et du carton améliore la compétitivité et la productivité des fabricants de papiers et de cartons. Une gestion uniformisée de la qualité est un problème important dans les usines. La qualité totale du produit dépend de divers facteurs : matières premières, capacité de la machinerie de fabrication et son degré d’automatisation, et aussi de la compétence du personnel qui joue un rôle important. Un système automatisé de contrôle de la qualité doit faire partie du contrôle de la qualité. Les variables en matière de qualité du papier et du carton sont plus nombreuses que ne l’indiquent les systèmes automatiques de contrôle de la qualité. Les données fournies par le balayage défilant ne sont ni dans le sens travers, ni dans le sens machine. L’évaluation de l’efficacité des systèmes de contrôle de la qualité fait l’objet de discussion par rapport à un modèle de cycle de vie. L’évaluation de la performance à une étape de validation est présentée avec une étude de cas, lorsqu’une analyse détaillée de la feuille en continu est utilisée.


Keywords: QUALITY CONTROL, CONTROL SYSTEMS, AUTOMATIC SYSTEMS, PERFORMANCE EVALUATION