Improving cross-directional hardness control

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ABSTRACT: A rebuild of the hardness control system with induction heating actuators, and a single-window integration to the mill distributed control system (DCS), produced a powerful, fast-acting control system. Aggressive system tuning resulted in significantly reduced cross-direction 2-sigma variation and paper loss due to poor reel building. This project also transferred maintenance responsibility of the control system to the mill.

KEYWORDS: Computers, control systems, cross direction, hardness, induction heating.

The Daishowa America Port Angeles mill produces lightweight directory paper from refiner groundwood, purchased kraft, and recycled pulp. A project was undertaken to improve hardness control, which was limited in its range and rate of response, on the No. 2 paper machine. Hardness control was chosen as there currently is no caliper gauge on the No. 2 paper machine. The startup of this system occured in July 1991. The measurement system was modified to improve sensitivity. New induction heating coils were installed to replace existing cold air showers. The controls for this system were integrated into the mill DCS to follow the mill's single-window philosophy. The project exceeded expectations for reducing cross-directional (CD) 2-sigma variation.

Background

Hardness is measured by a rotating wheel, known as the back tender's friend (BTF), which traverses the paper roll at the reel. Every rotation of the wheel produces a displacement of a piezoelectric crystal as it contacts the paper, resulting in an electrical output pulse (see **Fig. 1**). The amplitude of the pulse is the force applied to the piezoelectric crystal, while the slope of the pulse is the pressure gradient at the moment of contact with the paper roll. Hardness is related to the force and pressure gradient by:

$$H \propto P/(F)^{2/3} \qquad (1)$$

where

H = hardness

P = pressure gradient

F = force.

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A hard roll of paper produces a sharp spike from the piezoelectric crystal, while a soft roll produces a broad pulse with smaller amplitude.

Hardness is controlled by adjusting the temperature of a calender roll. Heating or cooling can be used to expand or contract the calender roll surface, thus affecting paper thickness and hardness. Proper temperature control produces paper with minimal CD variation, resulting in a better quality roll, i.e., improved winder and pressroom runnability. The control system must be able to react quickly to respond to changes in hardness plus provide sufficient range to correct large variations. The control system at Port Angeles was found to be lacking in both rate of response and range, which provided an opportunity to improve the quality of our sheet. An upgrade of our control system was required.

Measurement and controls

Measurement system

The existing measurement system consisted of a BTF wheel connected to an 1180M control computer. Only 120 measurement databoxes were provided with the 1180M since it was installed before computers became powerful and fast enough to handle multiple databoxes for each actuator. This resulted in a lack of resolution on the measurement profile. Maintenance of this system required vendor support. However, with replacement of the control system and actuators, to be maintained by mill personnel, it was not practical to have vendor maintenance of the measurement system. The mill chose to rebuild the measurement system so maintenance could be handled by mill personnel.

A Sensor Interface Unit (SIU) was chosen for the new measurement system. The SIU is an industrialized 80386-based computer with interface boards to the BTF wheel. An isolated

RS-232 serial link is used to transfer measurement profiles to the DCS, where control action is calculated. Greater measurement profile resolution was provided by increasing the number of databoxes to 256. A major factor in choosing the SIU was its open architecture. All of the setup parameters are modified with DOS-like commands, thus transferring knowledge and responsibility to mill personnel. This allows a more aggressive and customized setup of the measurement system. The SIU is a measuring device only, with no host or control capability, which saved money with a single-window philosophy.

The new measurement system required modifications to the BTF frame (see **Fig. 2**). The BTF wheel traverses the paper roll via a chain-and-sprocket mechanism. A variable-frequency DC drive was purchased to provide a compatible interface to the SIU. The drive speed was set to traverse the paper roll in 40 seconds.

The BTF wheel is raised to its onsheet position with a single-acting air-operated cylinder. Initially air is bled through a needle valve to raise the arm slowly to prevent paper damage upon impact with the paper roll. The BTF wheel is then subjected to full air pressure for scanning. Proper air pressure is required to provide smooth wheel contact with the paper roll while preventing paper damage. Air pressure of 179 kPa (26 psig) provides the proper contacting force on the wheel: 44.5 to 53.4 N (10 to 12 lbf). The BTF wheel is lowered to its offsheet position by releasing the air pressure; the weight of the arm causes it to drop. A frame air control box was installed to provide a compatible interface to the SIU. This consisted of two 4-way solenoid valves, a needle valve, air piping, and a new air cylinder to control the BTF arm.

The final modification was to the electronics itself. A signal amplifier was installed at the BTF arm to provide signal isolation between the BTF wheel and the SIU. The reel hardness measurement board was also modified to provide improved measurement to the SIU.

Actuators

The existing actuators consisted of two cold air shower plenums, one located on each side of the calender stack. In addition, Impact infrared heaters were operated in manual mode to provide additional controllability. There were also four manually operated hot air showers on the king roll of the calender stack. The reel building procedure was complicated and time consuming due to the multiple actuators. The actuators were also limited in range and rate of response, resulting in paper loss due to poor reel condition.

The actuator chosen for this project had to provide sufficient range and rate of response to improve paper quality. A trial was run on the No. 3 paper machine at Port Angeles to compare hot air showers and induction heating coils. Three hot air shower actuators were turned on at 100% setpoint for eight minutes. This produced a 3.33 hardness unit change, which occurred five minutes after the actuators were switched off. Three induction heating actuators were temporarily mounted on the calender stack. They were turned on at 100% setpoint for four minutes. This produced a 9.70 hardness unit change, which occurred one minute after the actuators were switched off. The calender stack temperature rose more quickly with the induction heating actuator, which was reflected in the hardness response. After the actuators were switched off, the calender stack roll cooled much faster with the induction heating actuators. These actuators were chosen due to their increased range and rate of response in both heating and cooling as compared to the Thermoprofiler units.

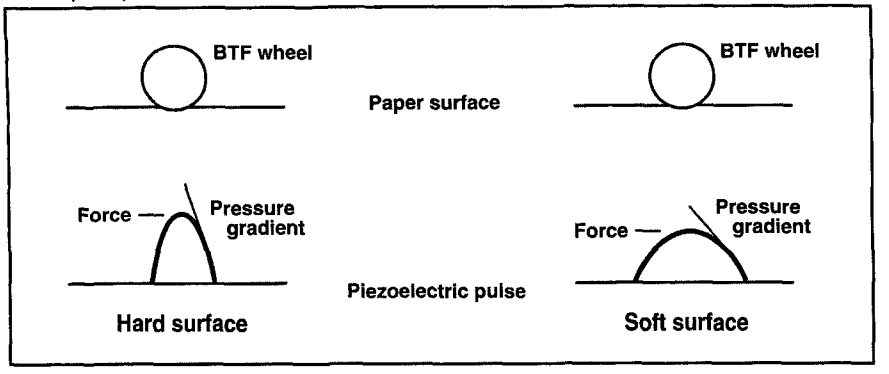
The principle of operation with the induction heating actuators is that induction heating can be used to expand calender roll diameter. Induction heating is an efficient method of generating heat on a calender roll with minimal overlap between adjacent actuators. An alternating current is used to induce a fluctuating magnetic field around work coils in the actuator. The magnetic field overlaps the calender roll surface, producing eddy currents on the roll. It is electrical resistance to the eddy currents that generates heat, thus expanding the roll. This increases the nip loading in the heated area and subsequently affects hardness. Since eddy currents are produced only at the roll surface, the paper sheet acts as a heat sink to quickly cool the calender roll. The placement of 54 3-in.-wide induction heating actuators across the No. 2 paper machine allows CD hardness variations to be reduced by independently adjusting each actuator output.

Control system

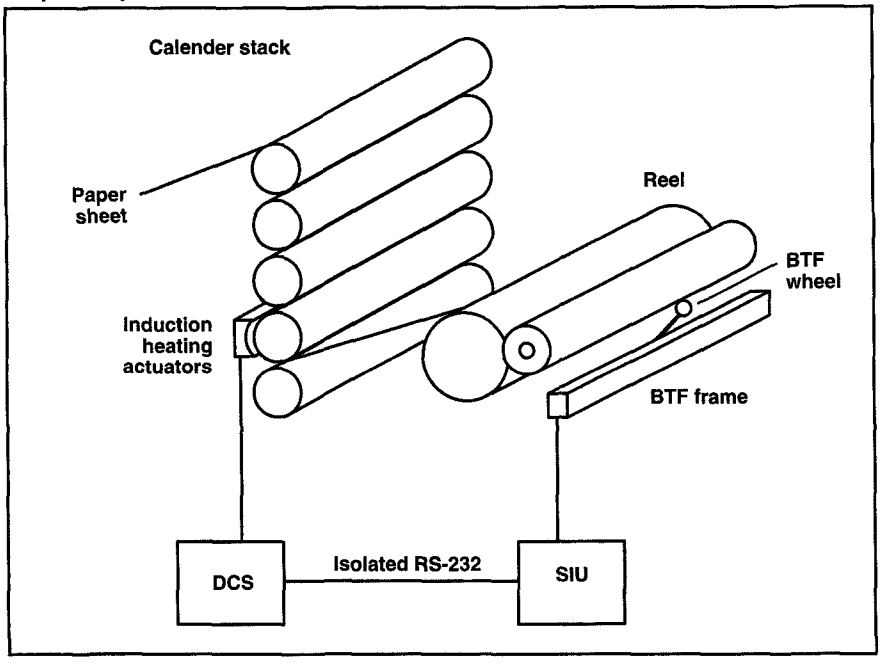
A new control system was required to close the hardness loop. Several goals for the control system were created to aid the selection process. A single-window philosophy (i.e., all operator control actions are taken from a single interface) was adopted by Port Angeles to reduce the computer arcade that had accumulated at the dry end of No. 2 paper machine. The transfer of knowledge and responsibility, as with the measurement system, was applied to the control system. This required the control system to be user-friendly, with easy access to all setup and tuning parameters. The control system also had to be modular to allow future expansion to more paper machine controls.

A software package that matched the mill's goals was chosen. The software integrates the CD control algorithm into the DCS environment, since it consists of a combination of standard DCS control blocks and C-language code operating in standard DCS hardware. There is an isolated RS-232 serial link to the SIU to obtain hardness-measurement profiles. The communications interface includes BTF diagnostics to alert the back tender to specific problems with the measurement system at the DCS operator interface. Upon receipt of a measure-

1. BTF principle of measurement



2. System layout



ment profile from the SIU, data verification is performed to ensure control action is taken only on valid profiles. Valid profiles are then mapped to spatially relate the 256 databoxes in the measurement profile to the 54 induction heating actuators used to adjust the hardness profile. The mapped profile is then filtered and sent to the control algorithm to determine the actuator settings required to smooth the hardness profile. The mill has access to all the mapping, filtering, and tuning constants to customize control to our paper. These parameters are password-protected to prevent unauthorized access.

An addition was made to the standard software package to allow statistical reporting of hardness control. This was required to replace a function previously provided by the 1180M. Data include average hardness, long-term machine direction (MD) 2-sigma variation, short-term MD 2-sigma, long-term CD 2-sigma, total 2-sigma, and percentage of system utilization in automatic control on a reel, shift, and daily basis. For trending purposes, these data are available for any reel of paper manufactured in the previous 24 hours. This information is printed at each reel turn-up for long-term documentation.

System startup

System startup consisted of three phases. The first phase was to calibrate the SIU. Position of the wheel is measured with a linear trackpot. The voltage from the trackpot is input to the SIU so raw data from the wheel can be placed in the proper measurement databox. Scan limits were adjusted to allow scanning the maximum amount of paper on the reel. A minimum of four raw data points are required per databox in order to obtain an accurate measurement signal. The speed of the wheel was adjusted with the variable-frequency drive to obtain enough raw data points per databox. The pressure and force signals are input to the SIU and adjusted with a 10-point linear interpolation to provide proper hardness sensitivity with changes in wheel measurements. Adjustment to the SIU continued until a stable profile, which matched in position with physical hard and soft spots on the reel, was received by the DCS.

The second phase was to check actuator operation. Each actuator was individually switched on to verify wiring. The feedback signal from the actuator was also verified. All actuators are mounted on a beam that advances the actuators to the onsheet position, 0.25 in. from the calender roll. The interlocks, which allow the beam to advance or cause the beam to retract automatically, were checked for proper operation.

The final startup phase was to set up the control system. Extensive bump testing was performed to accurately align the measurement profile to the actuators. An actuator at the center of the paper was switched on to 25%. The induced hardness change in the 256 databox measurement profiles was found. This procedure was repeated for an actuator near the edge of the paper. Determining the position of the hardness change at the center and the edge allowed adjustments to two parameters: the center line of the measurement profile and the size of each databox in inches. Changes were made to hundredths of inches, and the entire

bump test procedure was repeated until a satisfactory alignment between the actuators and the measurement profile was obtained.

The process gain and the process time constant are determined from the bump test data. Process gain is the ratio of change in hardness to the change in actuator output causing the change in hardness. The process time constant is the time in minutes for the change in hardness to reach 63% of its final value. The controller gain and integral are calculated from the process gain and process time constant. The control system was now placed in automatic mode with conservative controller tuning. Conservative tuning is the accepted norm in cross-direction control with vendor-supplied control systems, i.e., the black box approach. Many vendors do not apply control theory when tuning their systems; they therefore prefer conservative tuning to reduce the risk of system instability. However, this results in slower system response to upsets and setpoint changes.

Transfer of the control algorithm to the DCS environment made tuning accessible to mill engineers. The mill applied control theory to the dead time process in order to produce tuning more appropriate to the process. The delay between the measurement and the controller was reduced by removing all CD and MD filtering. This delay was further reduced by performing control actions on every measurement profile; typical installations take control actions after only three to five measurement profiles. The control dead band, which is the quantity of error from setpoint required before a control action is taken, was reduced to zero. Control dead band is generally used to eliminate control action on measurement noise, which was virtually eliminated with the rebuild of our measurement system. The final control system tuning was very aggressive (high gain and integral) with quick response to system upsets.

Results

Greater measurement sensitivity has been achieved. An increase in the number of databoxes in the measurement profile allows smaller hardness streaks to be measured. The modifications to the BTF wheel and its measurement hardware have resulted in the ability to see finer hardness changes than were previously possible.

Reduction in 2-sigma variability has resulted from this project. Reel CD hardness coefficient of variation (2-sigma divided by reel average) has been reduced ten times to 0.26 with an unfiltered measurement profile. Variability between reels has also been significantly reduced. This has resulted not only from powerful, fast-acting Calcoil actuators but also from improved system control tuning. There is a constant sheen across the reel compared to the visible hard and soft streaks that appeared during operation prior to this project. The winder operators have commented on the improved runnability of the winding operation that has occurred since startup. The sheet flutter from the parent reel has been eliminated.

Costs have also been reduced through a reduction in paper losses that resulted from poor reel building. Prior to this project, 36.5 tons of paper per month were repulped due to poor reel building. Current operation has reduced this to 13.3 tons per month, a reduction of 64%. ■

The author wishes to acknowledge Richard Ziomkowski, Frank Vervaart, Paul Cook, and other mill personnel who contributed to this project. In addition, the author acknowledges Gary Wright for modifications to the standard Measurex-Devron software for the Bailey DCS.

Received for review Sept. 1, 1992.

Accepted Feb. 25, 1993.