Industrial implementation of motor load and freeness control of chemimechanical pulp refiners

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ABSTRACT

A simple refiner control strategy aimed at minimizing variations in freeness of an ultra-high-yield sulfite (UHYS) pulp has been implemented in a newsprint mill.

The feeder screw speed is being manipulated to compensate for variations in the bulk density of the chip feed and to maintain a constant motor load at the primary refiners. This ensures a more constant mass flow rate through the primary refiners, which translates into a more constant primary specific energy. This has resulted in a reduction in motor load fluctuations of about 60% and a reduction in freeness variations of 40%.

The final pulp freeness is regulated by manipulating the plate gap of the secondary refiners using on-line freeness measurements made at the outlet of the latency chest. Control of the secondary plate gap has led to an additional 30% reduction of the variation in freeness. This two-stage refining control strategy has reduced the 2-sigma confidence interval for variation in pulp freeness from 48 mL to less than 14 mL, a reduction of more than 70%. The complete strategy has reduced the average refiner energy consumption per ton of pulp by 3.5% and has increased the average paper machine production by 2.5% by reducing the number of paper breaks.

In addition, the strategy has compensated for changes in cooking conditions and their effect on the refining properties of the chips.

Application:

The proposed refiner control strategy significantly reduced the refiner motor load and pulp freeness variability. It also stabilized the refiner operation and improved pulp quality uniformity.

As the newsprint market becomes increasingly demanding, ensuring a uniform-quality product offers a significant competitive advantage. The characterization of mechanical pulps is still largely based on Canadian Standard Freeness (CSF) measurements in the newsprint industry for several reasons. First and most importantly, CSF is an indication of bonding and correlates well with tensile properties. Furthermore, it is used to characterize pulp drainage and therefore pulp behavior on the paper machine. Finally, on-line freeness measurement is available at a fairly fast rate (every 20–30 seconds), while the other fiber and pulp properties, such as fiber length distribution, shive content, fiber coarseness, and curl, are available at a slower rate (every 15–20 min). For all these reasons, freeness still remains the most important on-line measurement used for mechanical pulp quality control.

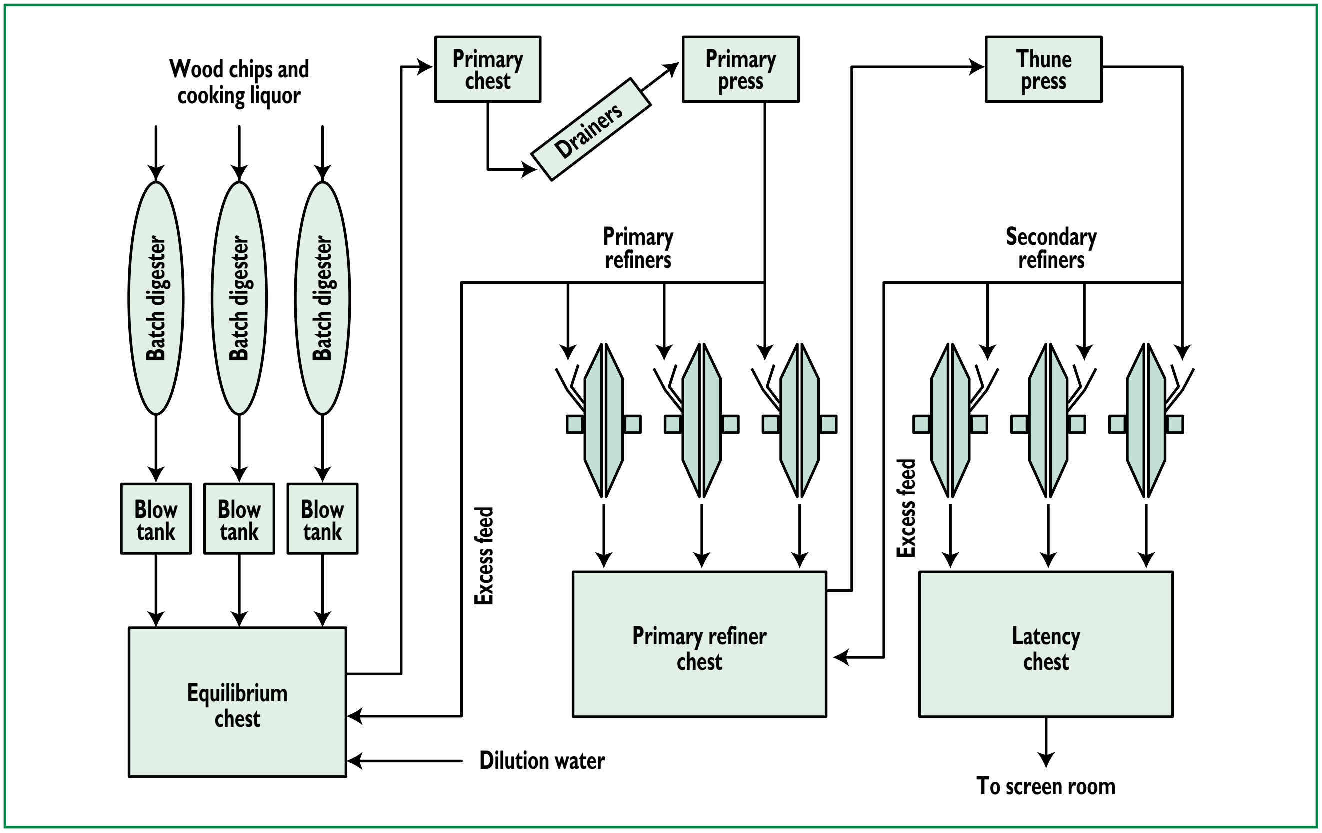
In this paper, we describe the design and implementation of a simple control strategy used to reduce freeness variations in a high-yield sulfite pulping plant. Mill results are presented that illustrate the beneficial impact of the control system on motor load and freeness variations as well as on refining energy consumption and paper machine production.

PROCESS DESCRIPTION

The mill, located in Québec, produces different grades of newsprint from a mixture of groundwood, recycled fiber, and high-yield sulfite pulp. The high-yield sulfite pulp is used as the main strengthening agent in the furnish and is produced in three batch digesters from black spruce chips cooked to a yield of about 85% using a sodium bisulfite liquor. The softened chips are then subjected to two stages of atmospheric refining, where a total specific energy of roughly 1600 kW·h/ton is applied to produce a freeness of about 630 mL at the outlet of the latency chest. The pulp freeness drops to about 580 mL after screening and cleaning.

As shown in **Fig. 1,** the chips from the digesters are blown in three blow tanks and then pumped to a 600-m^3 storage chest called the equilibrium chest. The chips are then pumped to a 0.5-m^3 stuff box that feeds two drainers. The drained chips are fed to a primary press, where the stock consistency is increased to about 30%. Conveyors are used to transfer the chips from the primary press outlet to the feeder screws of three primary refiners (Sprout-Bauer 45-1B, 4500 hp) operating at atmospheric pressure. The excess feed is recycled to the equilibrium chest, forming the first fiber flow loop.

The pulp from the three primary refiners is discharged and diluted to about 6% into a common chest referred to as the primary refiner chest; the residence time here is about 15 min. The pulp is then pumped to a Thune press, which increases the consistency to about 30%. Conveyors are used to transfer the pulp from the secondary press to the feeder screws of three secondary refiners (Sprout-Bauer 45-1B, 4500 hp), also operating at atmospheric pressure. The pulp from the three secondary refiners dis-



1. Process flow sheet

charges to a common latency chest with a residence time of about 20 min, where it is diluted to about 3% consistency and then sent to the screen room. The excess feed to the secondary refiners is recycled to the primary refiner chest, forming the second fiber flow loop. The presence of the primary refiner chest between the primary and secondary refiners provides some flexibility in the operation of the two fiber flow loops compared to a typical two-stage refiner process, where the pulp from the primary refiners is directly fed to the secondary refiners.

Prior to implementing the present refiner control system, a 2-sigma confidence interval for variation in pulp freeness of 48 mL for a pulp freeness setpoint of 630 mL was common because of the difficulty associated with manual operation of the process. Operators were responsible for maintaining the level of the primary stock chest and the primary refiner chest within acceptable limits while keeping the freeness on target by manipulating the primary and secondary refiner plate gaps. It became obvious that a control system should be implemented for the two-stage refining process to help the operators meet the required pulp quality targets.

REVIEW

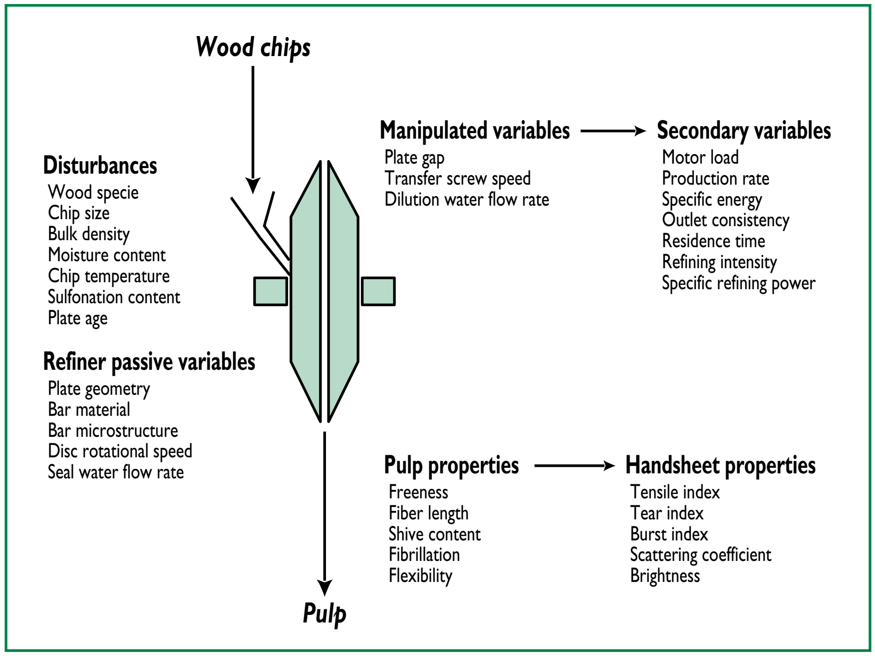
Research on control strategies for wood chip refiners has been underway for nearly 20 years, and a survey of the research work done in the 1970s and 1980s can be found in the papers by Battershill and Rogers *(1)* and Dumont *(2)*. As the newsprint market is becoming more competitive, there is a revival of activity in refiner control as pulp and paper producers try to provide their customers with a uniform-quality product. A summary of more recent works on chip refiner control can be found in Allison *(3)*.

Control of chip refiners is still a major problem for three main reasons. First, the disturbances coming with the feed, such as bulk density, chip size distribution, moisture content, and fiber quality, are difficult if not impossible to measure on-line. Second, refiners are multivariable and nonlinear systems. The motor load–plate gap curve is nonlinear, and the gain is time-varying because of plate wear. This makes motor load control with a fixed-parameter controller extremely difficult for refiners equipped with a hydraulic loading system. This problem was addressed by Allison *et al. (4, 5)*, who designed a dual adaptive controller that was successfully tested on an industrial reject refiner, and by Dumont and Fu, who designed a nonlinear controller *(6)*. Third, the relationships between the final pulp quality and the refiner operating conditions are complex and affected by plate wear, although our understanding of the refining process has improved *(7–9)*.

Figure 2 shows the variables used to describe refiner operation. The variables that affect the refining operation and thus the final pulp quality are the plate gap, transfer screw speed, and dilution water flow rate. Once set, these variables can be used to compute the secondary variables. For instance, motor load, production rate, and consistency are commonly used instead of plate gap, transfer screw speed, and dilution water flow rate to describe refiner operation. The relationships between the different variables shown in **Fig. 2** can be found in the mathematical models developed by Qian and Tessier *(10)* and Broderick *et al. (11)* for predicting pulp properties from refiner operating conditions.

Since wood chip refiners are fed by volumetric means, changes in wood density, chip size distribution, chip packing, and moisture content affect the mass flow rate of fibers and hence affect the refiner specific energy and refining consistency. Some control strategies use on-line chip density and moisture content measurements in a feed-forward scheme to manipulate the screw feeder speed and dilution water to keep the specific energy and refining consistency steady. An Ohmart mass flowmeter was used at the Donnacona thermomechanical pulp (TMP) mill; this approach worked fairly well as long as the chip moisture content remains constant *(12).* If the chip moisture content does not remain constant, then the mass flowmeter must be combined with a chip moisture sensor to obtain a true dry fiber mass flow rate *(13).*

Alternately, the refiner motor load can also be used as an indicator of the chip bulk density variations as long as the chip moisture content remains steady. The metering screw speed is thus used to regulate the motor load and, therefore, the specific energy *(14).* Should the moisture content not be constant, consistency should be measured directly or inferred from a water mass balance, and the dilution water should be manipulated accordingly in a feedback manner. High-consistency sensors are now available from ABB, Papertech, Andritz-Sprout Bauer, and others for measuring consistency in the blow line.



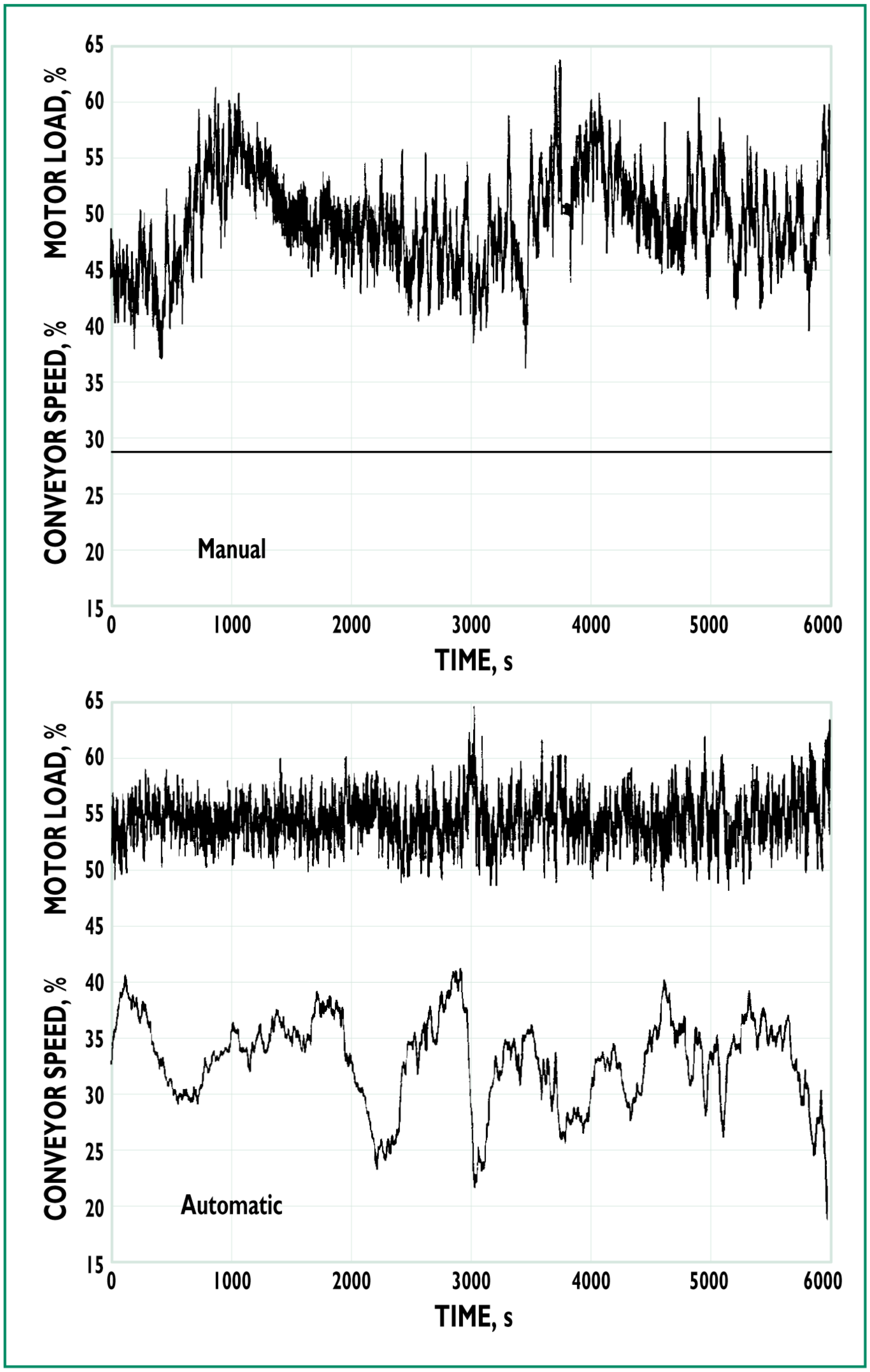
2. Refiner variables

Note that the previous control strategies focused on maintaining a constant refining consistency and specific energy by manipulating the chip volumetric flow rate and dilution water to compensate for changes in chip bulk density and moisture content. There is, however, no provision for the effect of chip species, chip quality, and fiber characteristics. Therefore, there is no guarantee that the final pulp quality will remain steady. Another approach is to use direct measurements of pulp properties, such as freeness, fiber length distribution, and/or shive content, to manipulate the refining consistency and specific energy via the dilution water and fiber throughput or plate gap. On-line sensors for freeness, fiber length distribution, and shive content *(15–18)* are now available for on-line monitoring and control of the final pulp properties. Some mills are now taking advantage of this new technology *(19).*

REFINER CONTROL STRATEGY

Manual control of this wood chip refining plant is made difficult because of the necessity to keep the levels of the equilibrium chest and the primary chest within acceptable limits to avoid overflows or disruption in the production. This difficulty originates from the batch cooking process, which causes huge swings in the chip flow rate to the equilibrium chest and stuff box and subsequent deviations from the freeness target. The equilibrium chest and stuff box cannot fully damp these variations partly because the production rate has doubled since the time of the original design. The objective, therefore, was to provide a control strategy that was as simple as possible so that it could be readily understood by the operators and be easily maintained by the mill instrument technicians. There are plenty of examples in our industry of sophisticated control strategies that were no longer used soon after the strategy developer left the mill. As an additional constraint, the control strategy had to be designed for implementation on an old Sentrol distributed control system (DCS) with limited programming capabilities.

The presence of the primary refiner chest allowed some decoupling between the primary and secondary refining stages. This made it possible to break down the strategy into two main components. The first phase of



3. Motor load regulation of the primary refiners

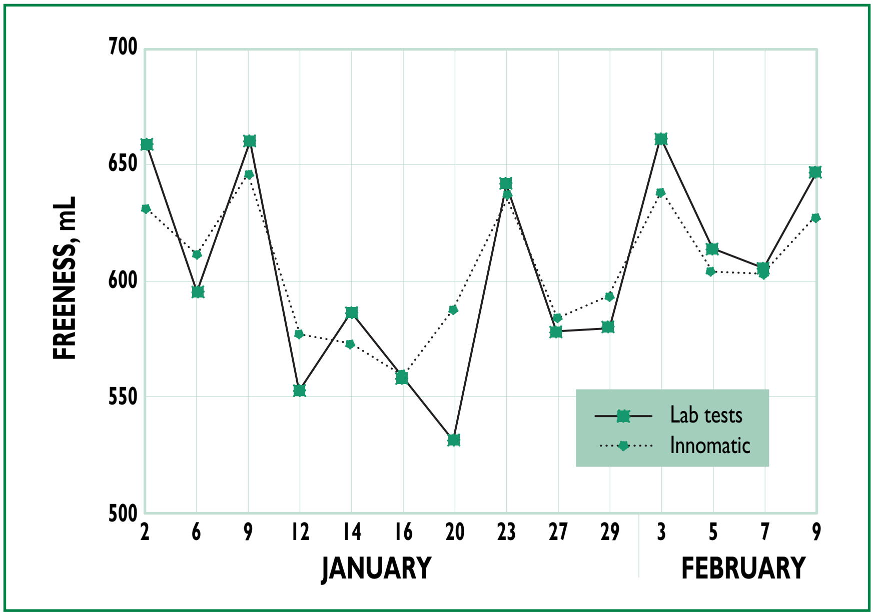
the project involved the feeding system and the regulatory control of the primary refiner motor load and chest level, and was in operation by the spring of 1995. The second phase involved controlling freeness after the latency chest by manipulating the secondary refiner plate gap and was in operation by December 1995. The entire system required about 1 year to implement, including operator training.

PRIMARY CHEST LEVEL CONTROL AND PRIMARY REFINER MOTOR LOAD CONTROL

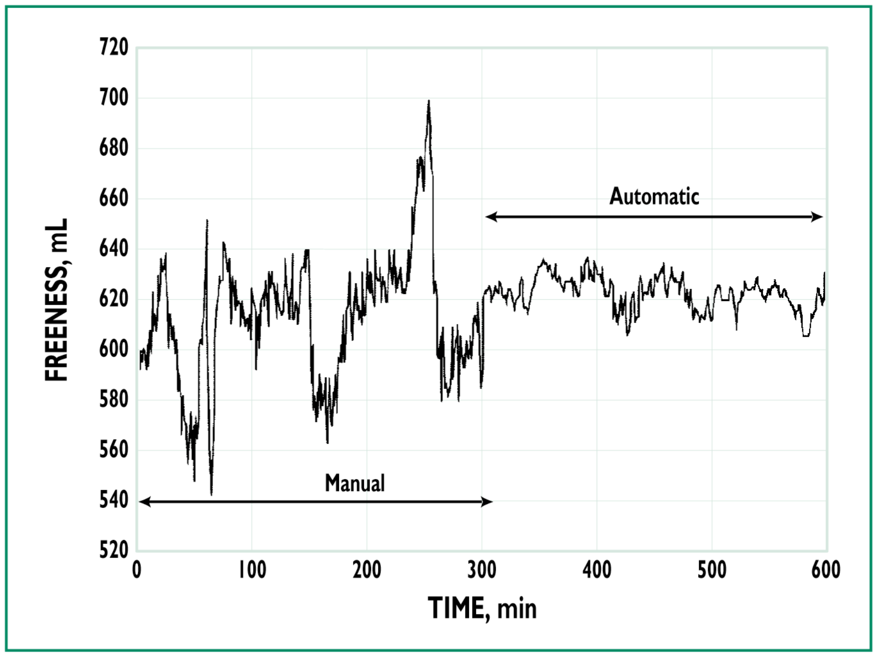
A number of changes to the operating practices were implemented beforehand to provide a strong foundation for the control strategy. Most importantly, the pumping sequence was modified to provide a more constant feed of chips from the blow tanks to the equilibrium chest. In addition, a feedback control loop was installed on the chip metering belt to ensure an excess feed to the conveyors discharging to the refiners. This ensures that the feeder screw will always remain full and that the throughput can be changed reliably by manipulating the screw speed. This surplus of chips is recycled to the equilibrium chest and contributes to the stabilization of the chest level.

The chip moisture content was fairly constant, because the chips are cooked for about 2 hours at maximum temperature and spend another 3 hours in the blow tank before being fed to the refiners. The complete cooking cycle (loading, steaming, impregnation, cooking, and blowing) takes about 8 hours. However, since no chip mass flowmeter was available at the mill, we chose to use the motor load as an indication of the changes in bulk density of the chip feed and to manipulate the transfer screw speed of the primary refiners to keep the load constant. The refiners at this newsprint mill are of the electromechanical type and are equipped with plate clash detectors from Disc Refiner Technology. With this type of refiner, the possibility of plate clash is less of a problem than with hydraulic loading systems, especially with a final freeness target of 630 mL. Nonetheless, the plate clash detectors are used to retract the plates when they are too close and the level of vibrations exceeds a predefined limit.

Identification experiments were performed to determine the dynamic response of motor load to changes in feeder screw speed of each primary refiner. The signals were collected from the DCS inputs with a Protuner at a sampling period of 0.02 seconds. Both signals are given on a 100% scale (i.e., 100% = 6000 kW for the motor load). The screw feeder speed-to-motor load transfer function was found to be the same for the three refiners and relatively time-invariant. A first-order plus delay transfer function was used with a static gain of 0.7% motor load per percent screw speed, a time constant of 2.5 seconds, and a delay of 2 seconds. The velocity forms of Proportional plus Integral controllers were used, as these controllers could be easily implemented on the Sentrol DCS for controlling the motor load by manipulating the feeder screw speed. The motor load setpoint is calculated by the operators from the desired specific energy to be applied in the primary refining stage and the nominal production rate.



4. Comparison between lab and Innomatic freeness measurements



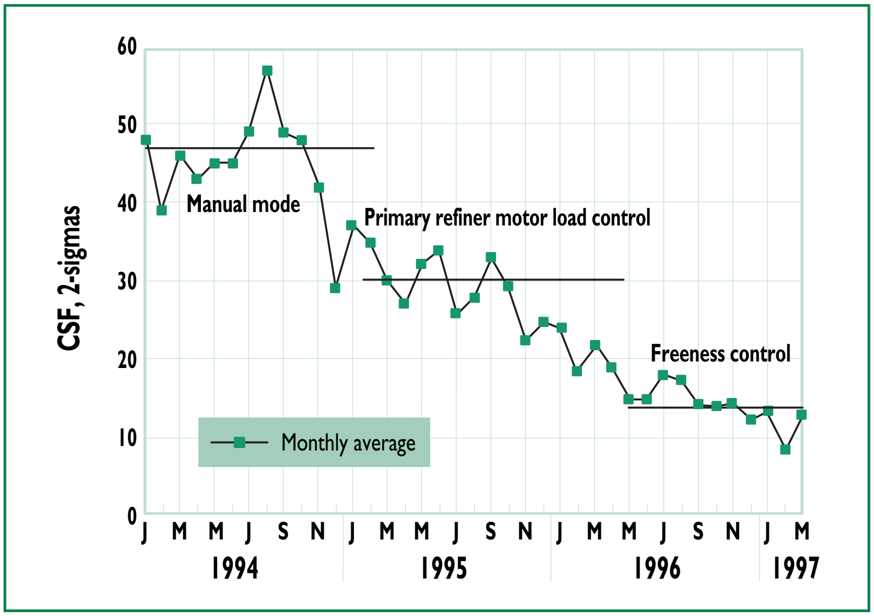
5. Freeness regulation

SECONDARY REFINER FREENESS CONTROL

The final pulp freeness is regulated using on-line measurements made available every 20 seconds to the DCS by the Innomatic freeness sensor, which is located at the outlet of the latency chest. Several tracer responses using lithium chloride were performed at different times during the year to identify the hydrodynamics of the latency chest as it is the main contributor to the dynamics of the secondary refining stage. The tracer was introduced in the secondary refiner discharge, and pulp and filtrate samples were taken at the outlet of the latency chest and analyzed. It was found that the latency behaved like a perfectly mixed tank with a time constant of 20–30 min depending on the production rate and the chest level. A small delay of about 30 seconds was also detected.

A number of pulp samples were analyzed for latency removal, and it was found that during the winter, when the temperature drops below 60°C, the latency was not completely removed. Up to 60 mL of freeness still remained in the pulp. This did not occur during the summer, when the temperature in the latency chest was about 70°C. This problem had to be addressed before implementing the freeness control loop as it would otherwise affect the control performance, increase the long fiber content lost to the screen reject line, and reduce final pulp quality. To remedy this, a steam line was added to maintain the temperature in the latency chest to about 70°C.

Because the plate positions of the three secondary refiners are used as manipulated variables, the transfer functions between plate gaps and final pulp freeness were identified. Although it is well known that these transfer functions are time varying because of plate wear, the fact that the three refiners discharge into a single latency chest makes this less of a problem. At any given time there is always



6. Freeness 2-sigma reduction

Parameter	Before	After	Improvement, %
Average refining specific energy, kW·h/ton	1450	1398	3.5
Average paper machine production, tons/day	566	580	2.5

I. Impact of the control strategy on refining specific energy and paper machine production

a refiner with fairly new plates, one with plates at the middle of their service cycle, and one with old plates. This averaging of plate age for the three refiners makes this factor less important than it would be on a single refiner line. It was therefore assumed that the static gain would remain relatively constant, whereas the time constant of the secondary refiners and latency chest would vary between 20 and 30 min, depending on the production rate and latency chest level.

The velocity form of Proportional plus Integral controllers was used and tuned with a pole placement technique to give a first-order response with a time constant of 20 min. A stepping motor interface card was installed into the Sentrol DCS for manipulating the plate position. Although the plate gap of the primary refiners could have been used for final freeness control, it would have led to a very slow response because of the presence of the primary refiner chest and Thune press located between the primary and secondary refining stage. In addition, it soon became clear that this was unnecessary, as good control was obtained with the secondary refiner plate positions alone.

KEYWORDS

Bulk density, chemimechanical pulps, control systems, freeness, high yield pulps, load control, loads, motors, picea mariana, refiners, refining, sulfite pulps, two stage process, variations.

RESULTS AND BENEFITS

Figure 3 shows the motor load and the screw feeder speed signals expressed on a 100% scale for one of the primary refiners before and after implementing the motor load feedback control loop. The data were collected with a Protuner at a sampling rate of 0.5 seconds for about 100 min. When running in manual mode, the operators sometimes keep the screw feeder speed constant for long periods of time. Changes are made only when one of the chest levels reaches a low or high limit or when the latency pulp freeness is too far away from its setpoint. Under these conditions, the motor load will exhibit considerable variability because of the changes in wood density, packing, and chip stiffness (which is highly dependent on cooking conditions and changes from batch to batch). Here, for instance, the average value for the motor load is 49.5%, or 2970 kW with a 2-sigma spread equal to 8.5% or 508 kW. After implementing the motor load control strategy, the 2-sigma spread has dropped to 4.0%, or 240 kW for a mean at 54.3% or 3260 kW. The control strategy has reduced the variability of the motor load as represented by the 2-sigmas by more than 50%. Of course, the screw feeder speed now exhibits much variability as it compensates for the changes in chip stiffness and bulk density.

Before implementing the freeness control loop on the secondary refiner, we investigated the accuracy and reproducibility of the Innomatic on-line freeness sensor. Pulp samples were taken every 3 days over a period of 1 month, and the pulp sample freenesses were measured by a lab technician and compared to the Innomatic measurements. It was found that the Innomatic measurements correlated well with the lab data (**Fig. 4**), and the standard deviation on the error between the lab and the Innomatic measurements is 22 mL. As for the reproducibility of measurements from the Innomatic, we took advantage of a shutdown to recirculate the pulp in the latency chest for about 4 hours. The Innomatic was therefore measuring the same pulp repeatedly. The 2-sigma confidence interval on the Innomatic freeness measurements was 9.2 mL, for an average pulp freeness of 631 mL.

Figure 5 shows the freeness variability with and without control over a period of 10 hours. When in manual (left part of the graph), the 2-sigma confidence interval is about 49 mL in comparison to 13 mL when the control system is on automatic (right part of the graph). In this example, the freeness variability has been reduced by 73%.

The average 2-sigma confidence interval for freeness is calculated on a monthly basis by the mill personnel and is shown in ***Fig. 6*** from January 1994 to March 1997. Prior to the implementation of the control strategy, the 2-sigma spread for pulp freeness was about 48 mL for a freeness setpoint of 630 mL. After the implementation of the primary motor load control scheme, the 2-sigma value dropped to about 30 mL. This dropped to a value of 14 mL after a few months following the installation of the freeness control loop, as the operators gained confidence in the control system and used it more regularly. The control system is now used about 90% of the time, and the level of variation now achieved is close to the best control possible since the accuracy of the freeness sensor is about 10 mL. The total freeness variability has been reduced by about 70% with this simple two-stage control strategy. A similar reduction in freeness variation has recently been reported by Roche *et al. (20),* who implemented a motor load and freeness control strategy at Kruger's TMP plant in Bromptonville ,PQ, (but with a more complicated control strategy).

In addition, better control of refiner motor load variation and pulp freeness has led to a lower refining specific energy and less paper breaks on the paper machine because of a more uniform pulp freeness. ***Table I*** compares the average value of refining specific energy and paper machine production before and after implementing the control strategy. The specific energy has been reduced by 3.5%, while the paper machine production has increased by 2.5%.

CONCLUSION

The first phase of refiner control dealt with the control of the primary refiner chip feeding system and motor load. The variations in wood chip bulk density are compensated for by manipulating the volumetric feed rate to the primary refiners. This ensures a more constant mass flow rate through the refiners, which translates into a more constant primary specific energy. This strategy is well suited to Canadian mills, where chip feed is often composed of multiple wood species resulting in significant changes in bulk density. In addition, this strategy compensates for changes in cooking conditions and their effect on the refining properties of the chips.

Implementation of the primary motor load control resulted in a reduction of about 60% in motor load variation and 40% in freeness variation.

The second phase concentrated on control of the pulp freeness. The final pulp freeness is regulated using on-line freeness measurements made at the outlet of the latency chest to manipulate the plate position of the secondary refiners. Freeness control using the secondary plate gap lead to an additional 30% reduction of the variation in freeness. In addition, this strategy has significantly stabilized pulp handsheet strength, in particular tear strength, which in turn leads to improved paper machine efficiency. The complete strategy has reduced the average refining specific energy by 3.5% and has increased the average paper machine production by 2.5% by reducing the number of paper breaks.

Support from the operators and close collaboration with mill engineers were essential during the implementation of the control system. The control system is used more than 90% of the time by the operators and is turned off during plate changes, shutdowns, and startups. Finally, it was not only the control system that improved the pulp quality but also some minor modifications to the process, such as stabilizing the chip feeding to the equilibrium chest and increasing the temperature in the latency chest. This work is continuing and will now focus on fiber length control using the Pulp Expert on- line fiber quality tester and refining consistency in addition to the existing strategy. TJ

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LITERATURE CITED

1. Battershill, J. W. T. and Rogers, J. H., *Pulp Paper Can.* 81(8): T177(1980).
2. Dumont, G. A., *Automatic* 22(2): 143(1986).
3. Allison, B. J., "Adaptive Contreol of a Wood Chip Refiner," Ph.D. thesis, University of British Columbia, Vancouver BC, 1994.
4. Allison, B. J., Ciarniello, J., Tessier, P., *et al., Pulp Paper Can.* 96(3): T73(1995).
5. Allison, B. J., Ciarniello, J., Tessier, P., *et al., Automatic* 31(6): 1169(1995).
6. Dumont, G. A. and Fu, Y., *Proceedings of the 2nd Workshop on Adaptive Control: Applications to Nonlinear Systems and Robotics,* Cancun, Mexico, 1992. Wiley & Sons, New York, 1992, p. 367.
7. Miles, K. and May, W., *J. Pulp Paper Sci.* 16(2): J63(1990).
8. Miles, K., *Paperi Puu* 72(5): 508(1990).
9. Miles, K., *Paperi Puu* 73(9): 852(1991).
10. Qian, X. and Tessier, P., *Tappi J.* 78(4): 215(1995).
11. Broderick, G., Paris, J., and Valade, J. L., *TAPPI J.* 79(4): 193(1996).
12. MacDonald, J. E. and Guthrie, J. J., *International Mechanical Pulping Conference Proceedings,* Vancouver, 1987. EUCEPA/TAPPI/CPPA, Stockholm/Atlanta/Montreal, 1987, p. 187.
13. Fournier, M., Ma, H., Shallhorn, P. M., *et al., J. Pulp Paper Sci.* 18(5): J182(1992).
14. Cort, J. B., Keller, W. F., Larose, J-P., *et al., Pulp Paper Can.* 94(12): T450(1993).
15. Kaunonen, A. and Luukkonen, M., *Tappi J.* 75(3): 159(1992).
16. Hill, J., Westin, H., and Bergstrom, R., *International Mechanical Pulping Conference Proceedings,* Toronto, 1979, p. 111. TAPPI/CPPA, Atlanta/Montreal, 1979, p. 111.
17. Nordin, J. A., Hill, J., and Nelvig, L., *Proceedings of the CPPA Process Control Conference,* CPPA, Montreal, 1980, p. 121.
18. Rydefalk, S., Petersson, T., Jung, E., *et al., International Mechanical Pulping Conference Proceedings,* Oslo, 1981, p. 1. EUCEPA, Stockholm, 1981, p. 1.
19. Strand, W. C., Ferritsius, O., and Mokvist, A. V., *Tappi J.* 74(11): 103(1991).
20. Roche, A., Owens, J., Miles, K., *et al., Proceedings of Control Systems '96,* Halifax, 1996, p. 129. CPPA, Montreal, 1996, p. 129.