

Quinnesec woodyard focuses on chip thickness control at the chipper

Steven L. Nelson and Paul Bafile

A quality control chart system is used in a mill setting to predict or change the chip thickness distribution of unscreened hardwood chips under a variety of temperatures and chip length settings.

Chip quality control is changing today in many aspects. Advances in chip handling systems, for instance, have helped to minimize chip degradation. In chip screening, new technologies have increased the uniformity of chip dimensions, particularly in regard to thickness. The challenge to improve quality is met by first maximizing the quality of the primary chipper product before screening.

The importance of thickness to kraft pulping has been well documented. Akhtaruzzaman (1) concluded:

In kraft pulping, chip thickness is the most critical dimension for transport of chemicals. The rate of delignification, screened yield, viscosity, fiber length, and strength properties are markedly reduced by an increase in chip thickness.

Forbes (2) also discusses the importance of chip thickness in kraft pulping. Hatton (3) gives a good overview of the developments, illustrating the importance of chip quality parameters to the pulping processes and identifying thickness as one of the key factors. Other important factors are chip length, bulk density, bark content, and moisture content.

Here, we will consider distributions of chip length and chip thickness as related to the season and chipper maintenance.

Objective

Our objective was to develop a control system that would allow us to react to changes in the chip thickness distribution, especially those caused by seasonal variation. We wanted to remove any known variation not being controlled in the chipping process before trying to determine what the seasonal relationships were between chip length and thickness. Sources of such variation included knife angles, grinding and babbitting proce-

dures, chipper maintenance, chipper set up, and feed speed.

After the first year of operation, we had known there was a seasonal effect and had made some chip length adjustments to reduce overthick chips during the summer of 1986. The next step was to develop a predictive model that would tell us which process adjustments to make to achieve the target thickness distribution. This model could also be used to observe the effects of making changes to the chipping process.

The most important benefits would be less material losses to wood fuel from excessive fines, consistent production of chips in the range of 0-4 mm, and more consistent furnish to the digester when further screening was not available. If chip thickness screening is used after storage, the chips leaving the chipper could be varied to match the performance characteristics of the screening system. Producing chips to coincide with screening would give the target digester furnish with minimum material losses or chip downgrading.

Overview of Quinnesec's woodyard

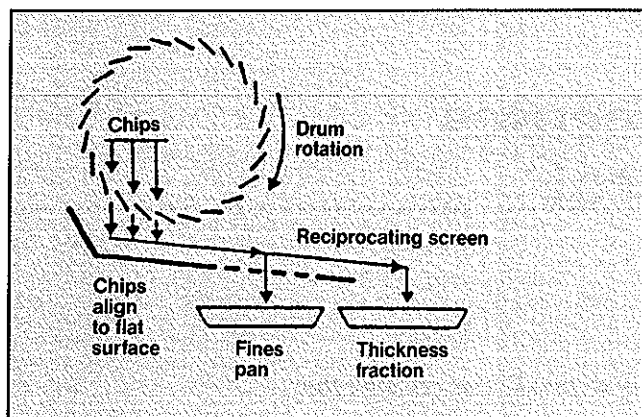
Our company's pulp mill at Quinnesec, Mich., started production in the fall of 1985. The mill produces 850 metric tons/day of bleached Northern hardwood kraft pulp. All of the mill's production is "market" pulp primarily distributed in the North American market. The production of high-quality, consistent pulp has been a primary goal of the mill team since startup.

Principles of statistical quality control have been used in many phases of the process to ensure the product quality. Methods have been used in the woodyard operation to improve and control the quality of the chip furnish produced by the chipper prior to chip screening.

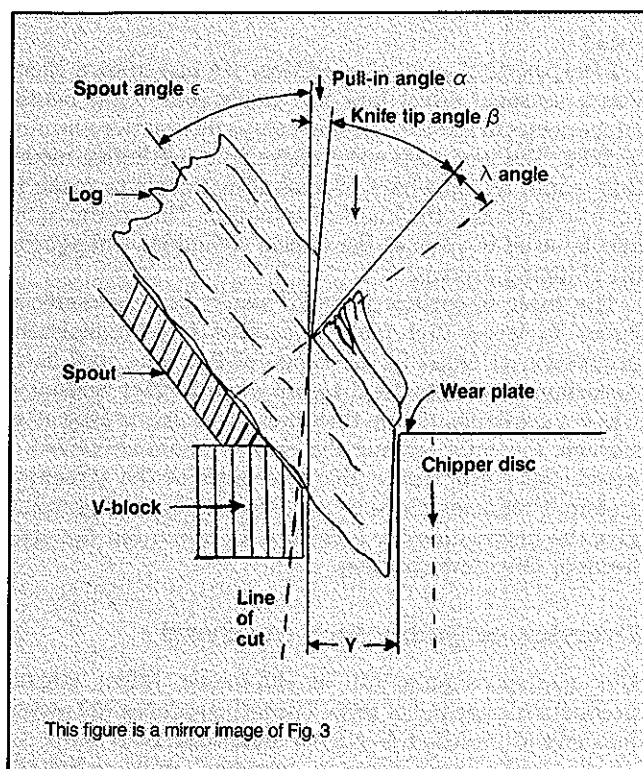
The Quinnesec woodyard uses a single-line chipping system. Logs of 2.5 m are received by truck delivery at the rate of 150 loads/day. Truck loads are delivered as "birch" or "hardwood" and are blended at the loading decks to achieve a consistent birch mixture of 27% in the final pulp fiber analysis. Another 55% of the species mix consists of maple. The remaining 18% consists of other Northern hardwoods. Inventories are managed to ensure fresh cut

Nelson is woodyard shift manager and Bafile is process specialist at Champion International Corp., Quinnesec, Mich. 49870.

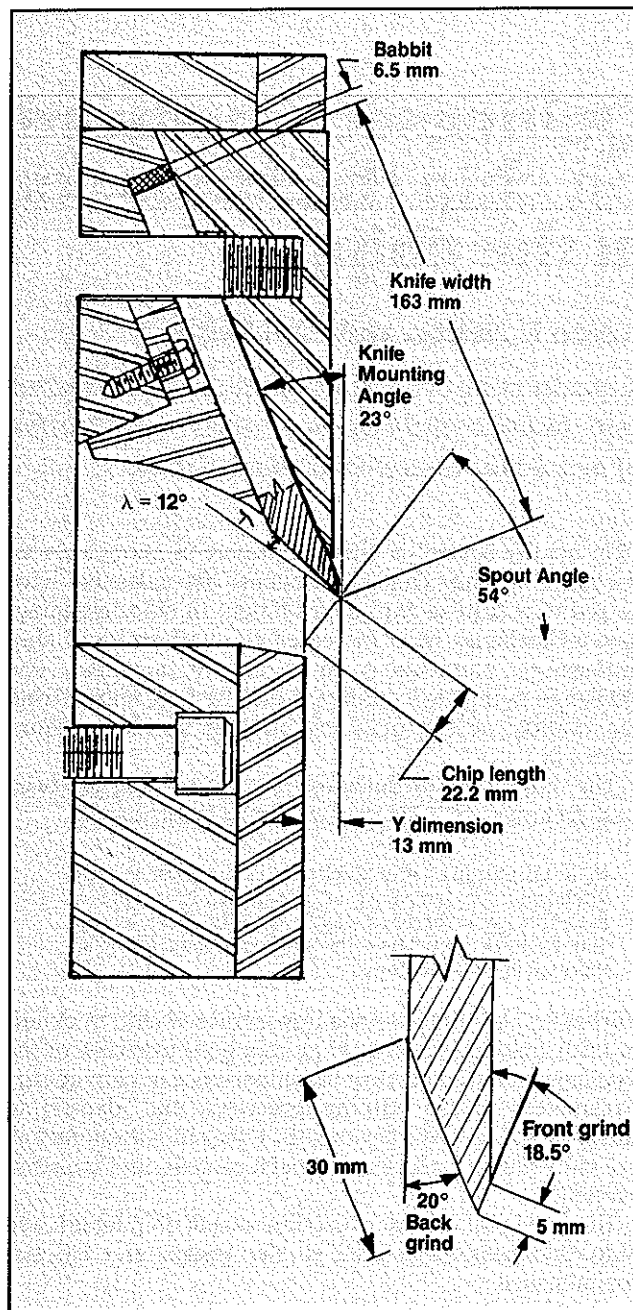
1. Diagram of Domtar classifier for separating wood chips



2. Diagram of the knife tip traveling through a log as chips are formed



3. Knife mounting arrangement for a 22.2-mm chip length



wood to the chipper.

The wood is fed to the system by the loader operators onto two variable-speed log decks. The wood drops onto a "dry" jackladder, which conveys the wood to two Murray debarking drums with dimensions of 4.4 m × 24.4 m. The bark is removed, conveyed to a shredder, and finally conveyed to hogged fuel storage.

From the debarking drums, the wood is conveyed by two in-line belts to a single chipper. A metal detector and splitter are located along the second belt. At the chipper spout, three spike rollers are used to feed the wood. A 0.3-m gap between the head pulley and the first spike roller is used to drop out loose bark, wood chunks, and rocks.

At a rate of 100 metric tons/hour, wood is drop fed to

the Murray knife chipper, which is 3 m in diameter and has 12 knives. The chipper rotates at 300 rpm and is powered by a 300-hp, synchronous, d.c., direct-drive motor. Cardbreakers are used, and the chips are bottom discharged onto a belt conveyor that feeds a surge bin with a 10-ton capacity.

A variable-speed drag chain pulls the chips from the surge bin onto a belt conveyor, which feeds two Rotex Hi-Cap screens. A Rader disc scalper with 55-mm interface opening (IFO) is used to remove grossly overthick chips and slabs just before the Hi-Cap screens. No overthick chips are currently removed at the Hi-Cap screens.

The fines screens are sized with 0.9-mm² holes for pin chip and fines removal. The "accept" chips are conveyed

I. The effect of key factors on the Y dimension and chip length

	Change in width, mm	ΔY , mm	Δ Chip length, mm
Front grind width	1.6	0.5	0.85
Babbitted knife width	1.6	0.6	1.0

II. Length adjustments to reduce overthick chips during March-June 1986

	Length, mm	Chips in classification, %	
		2-4 mm	>8 mm
March	21	23.9	11.6
April	21	22.0	12.3
May	20	20.2	13.6
June	20	13.5	17.8

III. Control chart for the base period, July 27-29, three shifts

	July 27			July 28			July 29		
	1	2	3	1	2	3	1	2	3
Measurements									
Sample 1	17.0	14.3	13.4	18.0	11.7	13.0	16.5	16.8	16.4
Sample 2	15.1	16.5	16.2	14.2	13.6	14.6	13.6	15.3	19.8
Sample 3	12.9	14.8	18.0	13.3	16.0	16.6	...	13.6	15.3
Sample 4	...	...	...	15.5	14.2	15.7	...	13.6	15.3
Sample 5	...	...	...	...	0.0	0.0	...	...	...
Sum	45.0	45.6	47.6	61.0	55.5	60.7	30.1	59.3	66.1
Average, $\bar{X}$	15.0	15.2	15.9	15.3	13.9	15.2	15.1	14.8	16.5
Range, R	4.1	2.2	4.6	4.7	4.3	2.8	2.9	3.2	4.9

by belt to a Rader pneumatic system that transports the chips a distance of 200 m to outside storage. The stockpiled chips are reclaimed with an International TD-25 track dozer.

Two drag chain reclaimers drop onto a belt conveyor that feeds a three-stage Rader system for chip thickness screening. The primary stage screens out the 8-mm chips and delivers them to two chip slicers. The throughput of the primary and the slicer product is fed to the secondary screen, which separates the chips that are under 4 mm thick. These chips are delivered to the tertiary screen, where the chips under 2 mm are sorted. The accepts are transferred to wood fuel storage, while the 2-8 mm chips are transferred to the digester by a belt conveyor. The Rader system has been operational since November 1987.

The woodyard operation is run by three nine-member teams that control all phases of the operation from the trucks to the digester. One member per team is designated as the "chip tester," who performs all sampling, test runs, and manual and computer recording of the test results. The computer program calculates the percentages of fines and bark losses to fuel inventory, percentages which are reported based on daily averages. The chip tester is also responsible for reporting quality changes, and the team is involved in troubleshooting and quality improvement.

The control room operators perform the important tasks of bed knife and V-block replacement, bed knife setup, and all other hardware replacement and maintenance traditionally done by maintenance personnel. Any needed welding, bearing, or motor maintenance is done by maintenance personnel or vendors.

A quality improvement group was formed in June 1987 to focus on chip quality. The expertise and involvement

of this group and other team members was the most important factor in achieving better control of the chip thickness distribution at the chipper.

General methodology

Chip sampling and testing

Chip samples are taken from three points:

1. Before Hi-Cap fines screening
2. After the Hi-Cap screens before blowing to storage
3. Digester furnish.

Samples are all taken from drop points with a round bucket sampler 200 mm in diameter that holds about 900 g of green chips. Three of these samples yield a sample of "2800" g that will vary from 2.5 kg to 3.0 kg. The samples are taken through the thickness of the chip flow and from three different points across the flow. Samples are taken three times per shift for the before-screens tests and the digester furnish test and twice per shift for the after-screens test.

A Domtar thickness classifier is used to analyze the sample for thickness distribution. From startup trial comparisons, we concluded that the Domtar was 95% repeatable between test runs (4). The Domtar does measure for the maximum chip thickness of each individual chip, so the average thickness of each class will be slightly less than the median of each class.

The "effective" chip thickness will also generally be less, especially in the overthick classes of greater than 8 mm. Lamellations or fractures in the overthick chip will allow the cooking liquor to penetrate the fractional thickness

equivalent to a smaller chip. No attempt has been made to quantify these factors here.

All tests are broken down into classes of 2 mm thickness from 0 mm up to 10 mm. The chips over 10 mm thick are treated as a single class. A class mean of 12.5 mm was experimentally determined for this class for calculating mean chip thickness. The "oversize" round hole screen is not used on our Domtar (Fig. 1). This allows us to obtain a pure thickness classification, except for the fines, which are those chips that pass through a screen with 4.8-mm round holes.

The Domtar is run for 2 min for each class. Proper calibration is achieved by measuring chips in the 0-2 mm class individually with a hand caliper, to look for chips over 2 mm in thickness. If any are observed, the bars are inspected and regauged. Over 16,000 samples consisting of 45 tons of chips have been tested since startup in Sept. 1985.

Temperature, length, and thickness plots

We looked at the effect of temperature on the thickness distribution at a given chip length in two different ways. In the first case, the temperature is calculated as a period average over one to several days during which the temperature was observed to be fairly stable. The thickness distribution data were also averaged for this same period, giving a data point.

In the second case, the daily mean temperatures and the daily mean thickness were recorded and plotted. Points were plotted on the same graph when correlating temperatures only for equivalent chip length settings on the chipper.

In both cases, the temperature data were obtained from an on-site weather station. In this station, elevated 6 m, observations were recorded every 2 h. In the "after improved maintenance" grouping (July 1987-May 1988), the only significant differences were (a) the chip length setting achieved by a longer or shorter babbitted knife width and (b) a problem with excessively worn face plates that caused the chip length to shift upwards. The angles of the knife-ground surfaces were the same in each case ($18.5^\circ \times 20.0^\circ$).

Chipper specifications and geometry

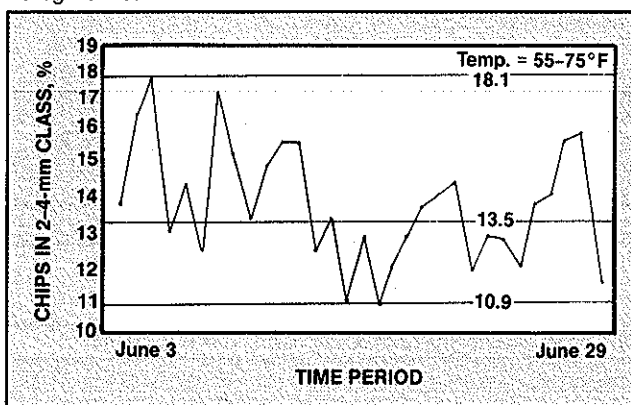
The design of the chipper affects the distribution of chip thickness. Factors include the orientation of log feeding, knife-point grind angle, pull-in angle, and " λ " angle. Chipper parts and wear surfaces must be properly maintained.

In 1954, Edwards (5) demonstrated that slower chipper speeds produce less fines, that dull knives produce more fines, and that bedplates should be kept sharp to minimize fines production. Ranhagen (6) compared four different orientations for spout angle and found the best orientation to be a horizontal feed at the bottom of the y axis of the disc.

Robinson (7) showed the importance of:

- A constant spout feed angle
- Properly maintained bed knife and spout surfaces
- Proper clearance between the bed knife to the high knife

4. Variation in the class of 2-4-mm before the change to a constant front grind width



- Proper knife pull-in angle
- Proper conveyance of wood to the chipper.

McLaughlin and LaPointe (8) explain the chipping process and the effect of changing various angles on the forces and on the chips.

Figure 2 shows the knife tip traveling through a log as chips are being split off. The angles are defined as follows:

- ϵ = spout angle to vertical plane; determines the angle of travel of the log as it is cut by chipper
- α = pull-in angle; affects the feed of the log
- β = knife tip angle; has an effect on the shearing and cleavage action that frees the chips
- λ = angle formed by the background surface of the knife and a line 90° to the direction of log travel
- Y = horizontal distance from the knife tip to the leading surface of the wear plate.

If the pull-in angle α is correct, the surface of the log having just been cut will feed properly into the next pocket, and uniform chips will be cut. If α is too low, the log will not feed, even in a drop feed chipper.

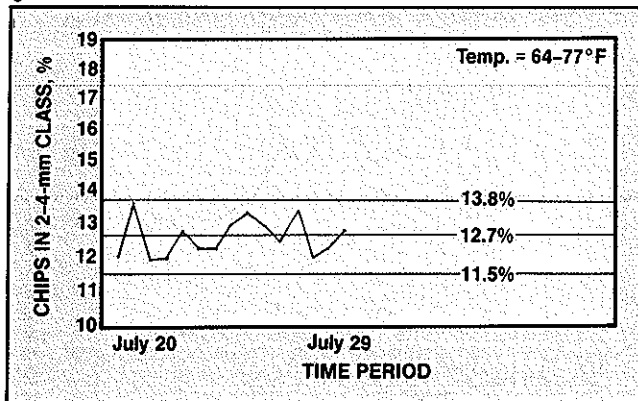
Lower values of λ , say 16° or less, will tend to cause more shearing off of the chips. Higher values, between 20° and 36° , will cause the chips to separate by cleavage (8).

The chipper used at Quinnesec is of Murco design and is equipped with helical face plates to maintain the Y dimension constant at the inner and outer zones of the disc. When Y is kept constant, chips of equal length are cut across the entire disc slot.

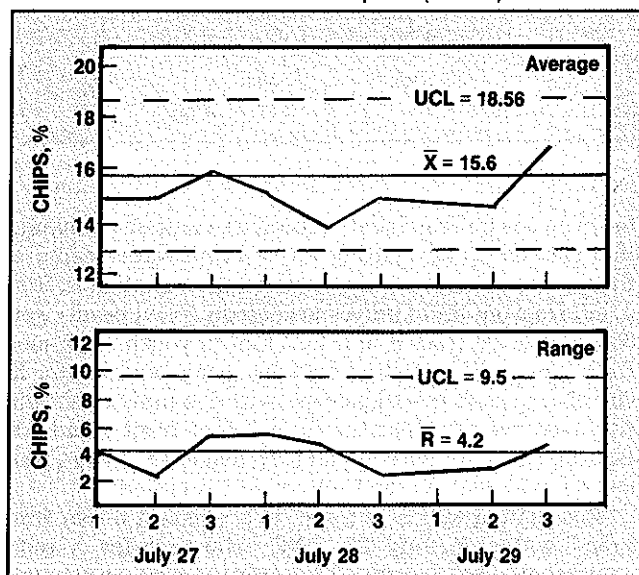
The knife is ground with two bevels. The short bevel is nominally 6 mm wide, and the long bevel is nominally 30 mm wide. The short-bevel grind angle determines the pull-in angle, which arrangement is opposite to the design of most chippers. To set the proper pull-in angle, the knife is mounted in the disc at a steeper angle (23°) than single-grind chippers.

The knife angles, bevel widths, and the pocket arrangement for Quinnesec's chipper are shown in Fig. 3 as set for a 22.2-mm chip length. The spout angle to the vertical plane is 36° . The chip length is found by the following

5. Variation in the class of 2-4-mm after the change to a constant front grind width



6. Plot of the control chart for the base period (Table III)



formula:

$$\text{chip length} = Y/\sin \theta \quad (1)$$

Knife grind, knife width, and cut length

Here, we will refer to the short grind on the knife as the "front" grind (18.5°) and the long-grind bevel as the "back" grind (20°).

Front grind

Due to the knife projection geometry, the changing of the front grind width will cause a change in Y according to Eq. 2:

$$\Delta Y = \frac{\Delta(\text{front grind width}) \times \sin(\text{front grind angle})}{\cos(\text{knife mounting angle})} \quad (2)$$

This relationship holds true when the knife is rebabbitted to the same width. A wider grind width will result in a shorter Y , and vice-versa.

Knife width

The knife width will affect the Y dimension by the formula:

$$Y = \text{knife width} \times \sin(\text{knife mounting angle}) \quad (3)$$

The greater the knife width, the greater the Y dimension, and vice-versa. The combination of the knife width, front grind width, and front grind angle are the key variables in determining the Y dimensions and chip length. Depending on the situation, each could combine to produce a large change, or they could negate each other and cause little or no change. The changes in Y and chip length for a 1.6-mm change in the knife width or front grind width are shown in Table I.

The changing of the back bevel width or back angle will not affect the chip length as long as the front angle and grind and the knife width are kept constant. Changing the back bevel width or angle *will* change the λ angle.

Thickness and length

Chippers can only be set for a design length. If the design length is set for a longer chip, the average thickness will be greater. The length normally runs about five times the average thickness (9).

These generalities hold if all other variables remain the same—wood density, spout angle, seasonal factors, moisture content, chipper speed, etc. The thickness distribution will be determined by the chip length and these other variables.

Start-up adjustments

In September 1985, the chipper was started up with 171.5-mm-wide knives and grind angles of 19.5° × 23°. The original specifications were for a 22-mm chip length. To achieve this length, the pull-in angle was decreased 1°, with the front grind becoming 20.5°. The mean chip thickness was roughly 5 mm.

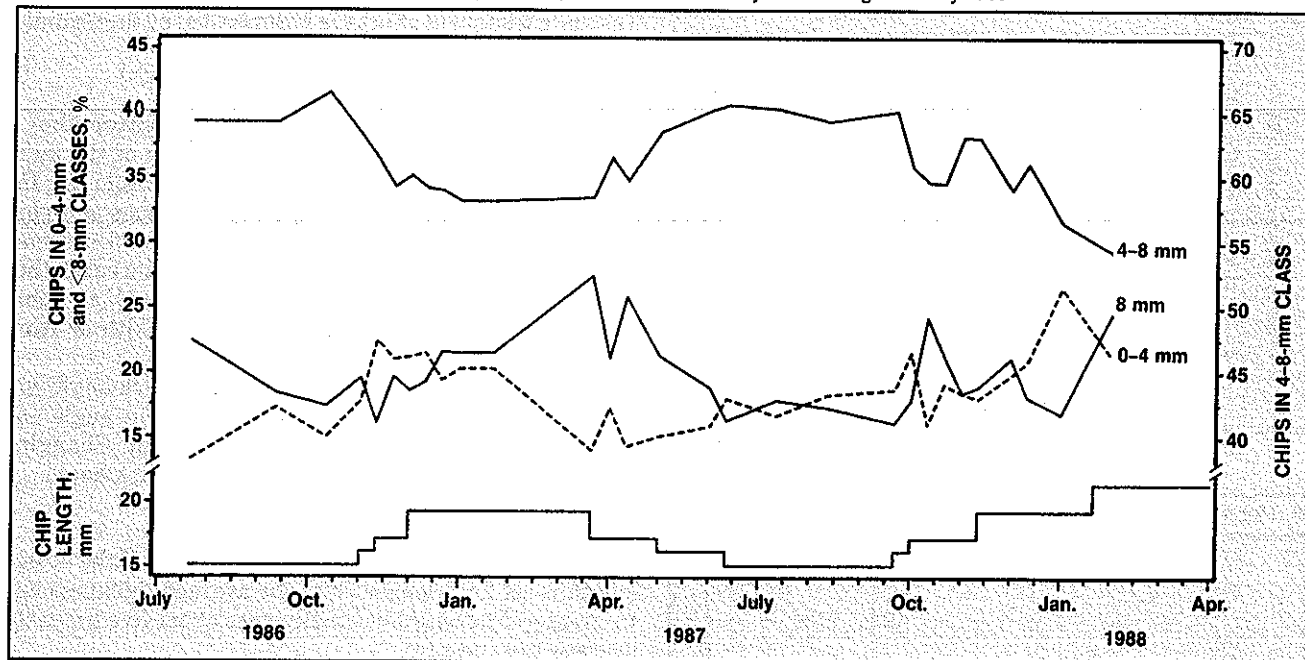
In December 1985, the mean thickness decreased with winter conditions, and knife life problems were encountered. The pull-in angle was increased 2°, with the front grind angle becoming 18.5°. The back grind angle was decreased by 3° after a trial period to find the best settings for winter conditions. The knife width was decreased to 170 mm at the original settings resulting in a 21 mm chip length.

The pull-in angle can decrease slightly with worn knives. The knives with the 19.5° or 20.5° front grind still felt sharp, but they would not pull the wood into the chipper after minimal run times.

Problems with extraction zone plugging occurred in the Kamyr digester operation the first winter. The 2-4-mm class was identified as a possible cause. In May 1986, 18.5° × 20° knives at 169 mm were used. The mean chip thickness increased when the chip length was decreased to 20 mm, which is the shortest length we can run.

The chipper samples before the screens were not routinely broken down at this time to 2-mm classes. The digester furnish monthly averages illustrate the magnitude of the changes that occurred from March through June 1986. In Table II, the class of over 8 mm is also shown, to illustrate the shift in overthick chips, which occurred at the same time. The change to 20 mm in May helped

7. Chip length and thicknesses classes for 0-4-mm, 4-8-mm, and >8-mm from July 1986 through January 1988



hold down the amount of overthick chips, but the seasonal warming to June could not be counteracted with a shorter length.

From this period on, the knives of $18.5^\circ \times 20^\circ$ angles were used, and the knife width was changed to make any changes in the chip length. The chip length was varied between 20.1 mm and 24.3 mm as the amount of overthick chips became excessive in the summer or the amount in the 0-4 mm class increased under winter conditions. Until tracking was improved through control charts, the changes were made too late in many cases, resulting in wider swings in the classes of 0-4 mm and >8 mm.

The quality improvement task force

On June 12, 1987, a quality improvement task force was formed for the woodyard. The objective of this task force was to look at everything from wood receiving to the chip pile, to monitor, correct, and maintain the highest possible chip quality by looking at the areas that affect it. Through the course of its work, the task force found it necessary to develop a control chart that would show us changes that occur and allow us to track these changes.

Through the use of statistical analysis, we found that the 0-4-mm class best predicted the change in chip thickness distribution. By using multiple correlations, each class of 2 mm increments was correlated with all other classes to form a matrix of correlation coefficients (r^2). The classes of 2-4 mm and 0-4 mm both correlated with an r^2 of 0.90 to 0.97 compared to the other classes.

After we began using the control charts, substantial changes occurred in our processes to improve chip quality. We also began to develop a consistent method for collecting chip samples to allow for the least amount of variation, and we started looking into the possibility of using automated chip samplers.

Problems with our babbiting jig and inconsistency

between our knife grinder techniques resulted in changes that showed up by plotting the 0-4-mm class (including fines). A task force member noticed the variation in front grind from one set of knives to another. Front bevels were observed to be from 3 mm to 9 mm in width, with most front bevel widths falling between 4 mm and 7 mm. By correlating each thickness class with the individual knife sets used, we saw that the inconsistent front grind was causing our Y dimension and chip length to change from one set to another as the front grind fluctuated.

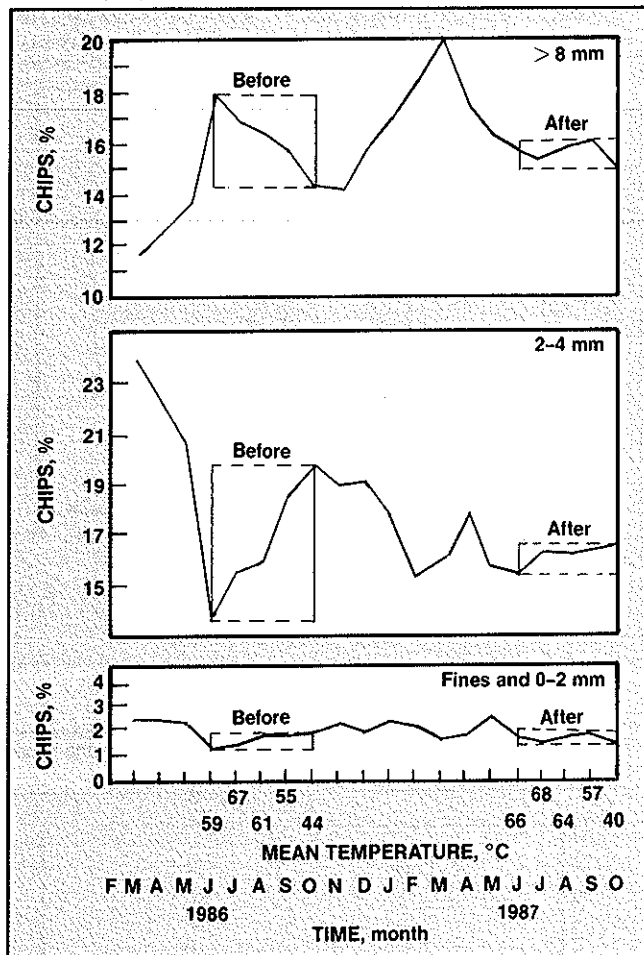
This finding led us to resort to a constant 6-mm front grind width on July 21, 1987, allowing for a more consistent chip length. The front grind width was decreased to 4.8 mm in December 1987 to slightly lengthen the nominal chip length. It has been kept at that width.

Figure 4 shows the variation in the percentage of chips in the thickness class of 2-4 mm in the period just before making the change to the consistent front grind width. The data points are averages over all the knife sets. Figure 5 shows the variation immediately after changing to the constant width of 6 mm. As the two figures show, the range dropped from 7.2% to 2.3%, while the mean decreased by only 0.8%. (Each data point on the x-axis actually represents one set of knives used, rather than a single day. We classified data this way because we were looking at variation between each knife set and the result on chip quality.)

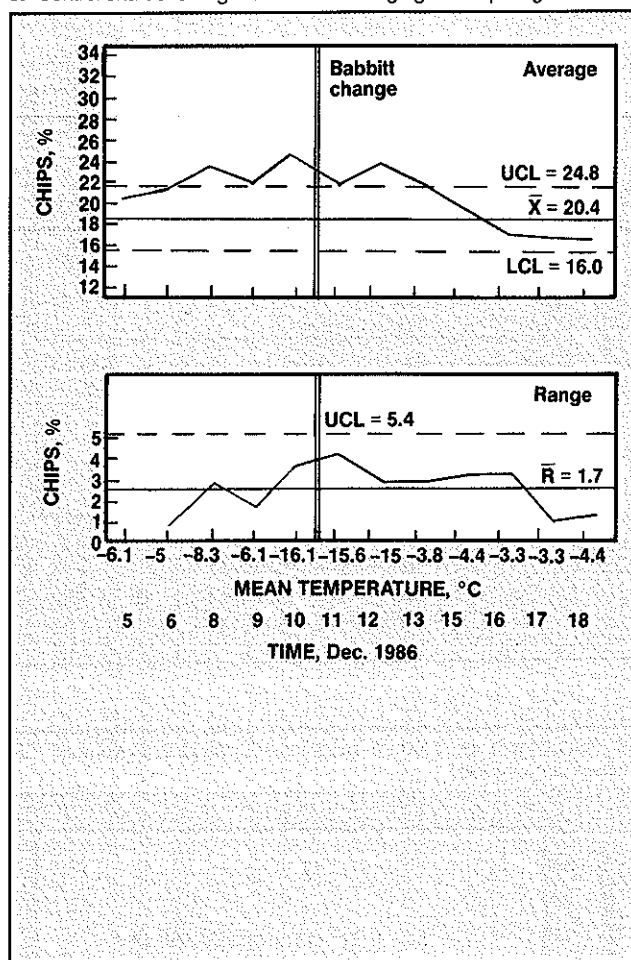
We also found that we could improve our chipper maintenance program by observing bed knife wear and establishing timely bed knife changes. We had been changing bed knives every 3-4 months. Our bed knives and base block were badly worn.

Now, our base block and bed knives are inspected at every knife change when setting the high knife to the bed knife at a gap of 0.5 mm. Bed knives are currently changed every 2-3 weeks. Since replacement on July 29, 1987, we have not had any major wear on our base block, and we

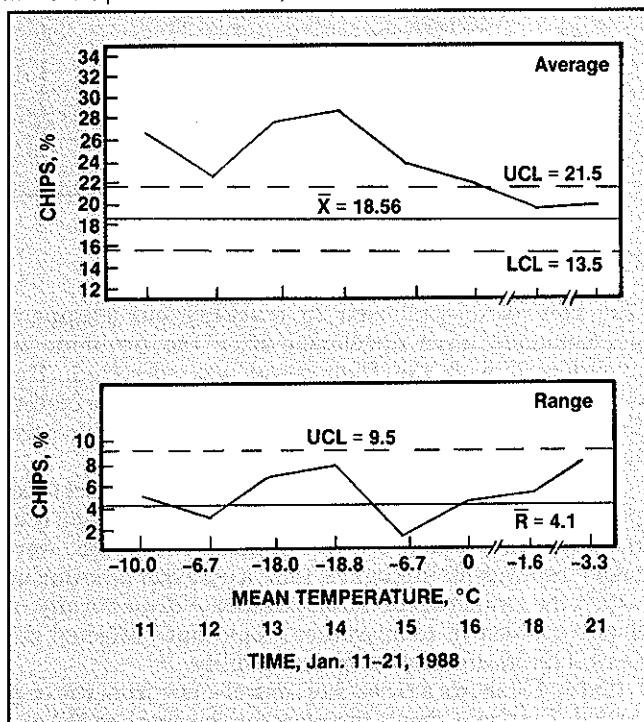
8. Monthly digester furnish



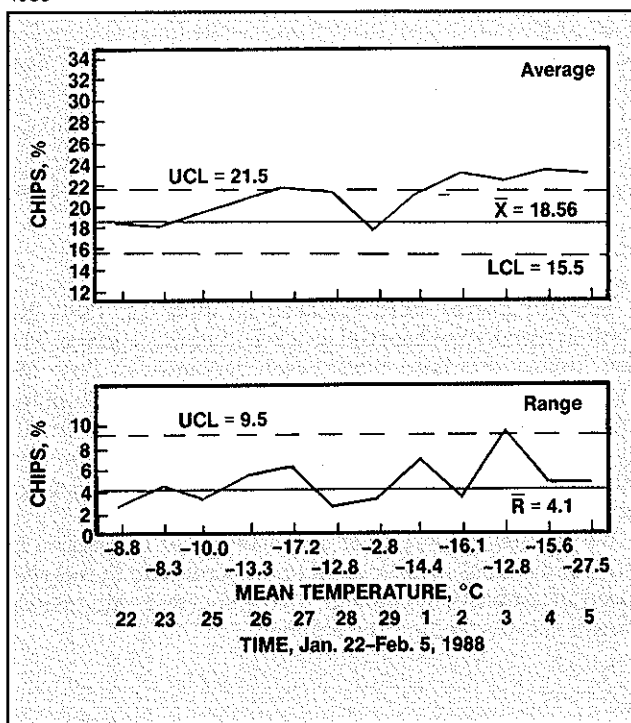
9. Control chart showing the effect of changing the chip length



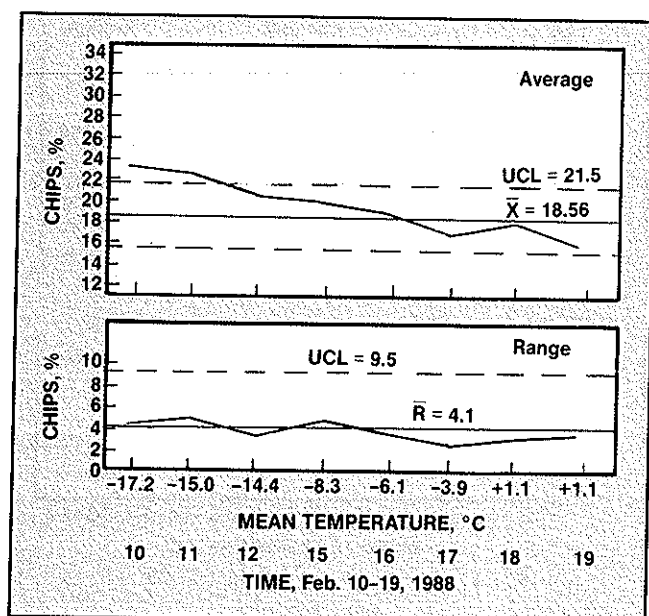
10. Control chart for the 0-4-mm chip class at a chip length of 24.3-mm for the period of Jan. 11-21, 1988



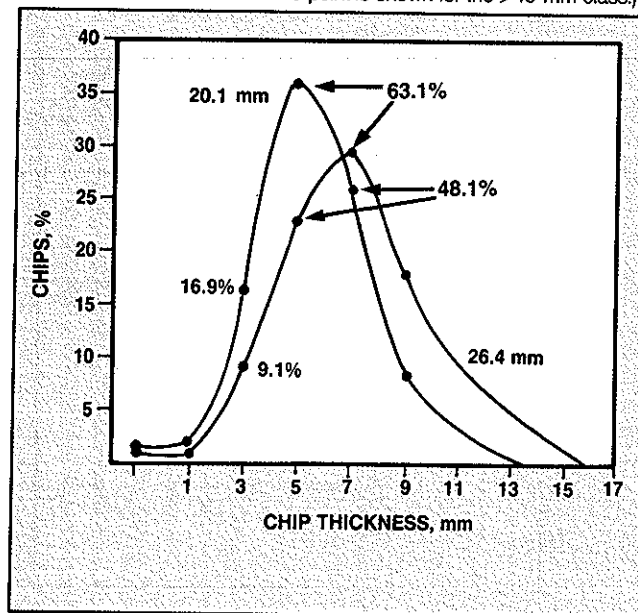
11. Temperature effect at a chip length of 26.4-mm for Jan. 22-Feb. 5, 1988



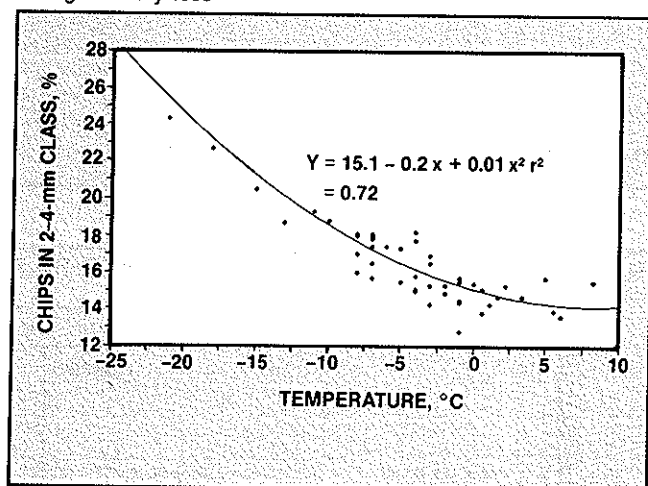
12. Gradual temperature change at a constant length of 26.4-mm, Feb. 10-19, 1988



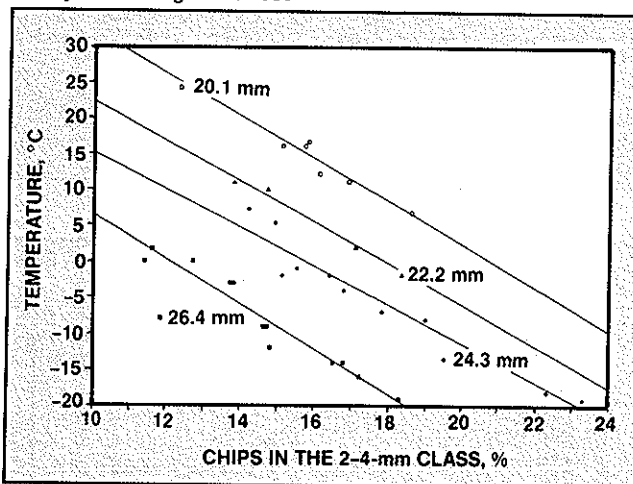
13. Before screen results for the May 1988 run at two chip lengths. (On the x-axis, "5" is for the 4-6-mm class, "7" is for the 6-8-mm class, and "9" is for the 8-10-mm class. No point is shown for the >10-mm class.)



14. Temperature vs. 2-4-mm chips for the period of November 1987 through January 1988



15. Temperature vs. 2-4-mm chips at various chip lengths for the period of July 1987 through June 1988



have not changed it.

The bed knives were replaced on June 14, 1987. No distinct trend was observed as a result of this change. The bed knives and base block were replaced on July 29. Through the transition, the range of the shift groupings increased only from 4.1% to 4.25%, while the mean did shift by +1.4%, from 14.9% to 16.3%. We discovered later that the bed knife on one side had been set too wide (3-5 mm), causing the higher fractions in the 2-4-mm class.

We studied the effects of conveyor speed in relation to chipper drawing speed to ascertain that we had the correct speed to prevent log tipping. At the shortest chip length, we are not overfeeding the chipper.

Control chart development

The control charts used in tracking our chipper's performance were developed after the problem we experienced with the front grind was corrected. This correction allowed us to eliminate most of the variability that we were aware of before the upper and lower control limits were set.

Our control limits were calculated on a worksheet provided to us by our statistical analysis department. (See the appendix.) Data used in the actual worksheet were taken from July 22 to Aug. 14, 1987, a period of time during which the temperature did not fluctuate dramatically. A wide variation in temperature would have affected our control limits and altered our variability.

Table III shows a three-day control chart from the base period. Figure 6 shows the plots for the average ($\bar{X}$) and

IV. Comparison of two periods in Jan. 1988

	Fines	0-2 mm	2-4 mm	Total
Chips produced, %				
Period 1	2.5	2.6	23.6	28.7
Period 2	1.5	2.0	15.2	18.7
Difference	1.0	0.6	8.4	10.0
Fuel loss, %				
Period 1	2.2	1.5	4.6	8.3
Period 2	1.1	1.3	2.4	4.8
Difference	1.1	0.2	2.2	3.5
Net retained ^a , %				
Period 1	0.3	1.1	18.0	19.4
Period 2	0.4	0.7	12.8	13.9
Difference	-0.1	0.4	5.2	5.5

^aRetained in the digester flow.

range (R). However, during the time period of June 22 to July 14, we did change the base block and bed knives at the halfway point in the time period when we were collecting data. This change reflected a slight change of 1.4% in the 0-4 mm class, as mentioned. However, this change did not show any effect on the range, which was 4.1% before the change and 4.2% afterwards.

This time period showed that the variability on our averages and ranges did not change dramatically. The base block and knife change increased our variability only slightly, giving us a little wider range on our control charts.

To calculate upper and lower limits, we used 44 data points broken down into subgroups of four, which we will call our "n factor," calculating the averages and ranges of each subgroup. We calculated the upper limit as 18.6% and the lower limit as 12.6% with a mean of 15.6% for the average amounts. On the range chart, the upper limit was calculated as 9.5% with a mean of 4.1%. The range is considered the upper control limit, where the lower control limit is always zero unless you use an n factor or subgroup of 7 or greater. The reason for using a subgroup of 4 was that we sampled our chippers performance about four times per shift, or every 2 h.

Realizing that we could not make the same chips in the winter condition as we could in the summer, we used data collected from the month of October 1987 to set our targets for the start date of Nov. 1, 1987.

By not physically changing our variability, we were able to use the same control limits, and we shifted our mean. The control charts gave us a much more current picture of what was happening and consistently showed us any shifts in the chip thickness distribution. Our variability has not increased since the trial period. For example, the range for March 1988 was 3.3% for 50 sample groups. There were also no points above the upper control limit on the range for that period. We are in the process of switching our control charts to use the 2-4-mm class only

and an n factor of 3 for the subgroup size. These parameters should make our charts more efficient.

Results

Control by using the chart

Figure 7 shows the breakdown of the Domtar thickness classes of 0-4 mm, 4-8 mm, and >8 mm from July 1986 through January 1988. Chip length changes are shown along the bottom of the chart. Each point represents several days' to two weeks' worth of test results.

We began changing the knife width to control the upper and lower limits of the thickness distribution in the fall of 1987. These changes were sometimes made after we had made excessive overthick chips for some time. The period of March-April 1987 shows two large spikes of overthick chips that could have been prevented by switching sooner to a shorter chip length. The drop in the >8-mm class from the June-October 1986 period to the same period in 1987 was caused (a) by correcting the babbitting jig for the chipper knives to cut the 20-mm chip and (b) by adopting a constant front grid width and a constant schedule for replacing the bed knives. This drop corresponded with slightly higher percentages of 0-4-mm chips as a result of the shifting of the distribution curve.

The better consistency seen in the digester furnish during the same period of June-October 1986 vs. 1987 is shown in Fig. 8. In the "before" period, the 2-4-mm percentage ranged from 13.5% to 19.5%, and the 8+ range was from 14% to 18%. The "after" period shows 15.5-16.5% in the 2-4-mm class and 14.5-15.7% in the >8-mm class. The peak in March 1987 on the overthick chips reflects the late change mentioned in not shortening the chip length soon enough. The high 2-4-mm and low >8-mm chip classes in March-May 1986 reflect the use of a 21.2-mm chip length in winter conditions after startup. "The level of 2-4-mm chips was reduced the following two winters by using a longer chip length of 24-26-mm."

In Fig. 7, the 0-4-mm class did show a high peak in early January 1988 as a result of the onset of severe cold, with daily temperatures at -25°C or lower. The prior winter was mild, with few days below -9°C average.

The 4-8-mm class cycles between 58% in winter to 65% in summer. The production of more overthick chips in the winter to reduce the 0-4-mm class portion is the cause of this effect. Under summer conditions, the production of low amounts of chips in the 0-4-mm class is easily attained, and the >8-mm class can be minimized by running the shortest chip lengths available (20.6 mm). The trade-off is that the average fiber length decreases as a result of more cutting of the fibers. This trade-off is not as critical with hardwoods with a fiber length that varies from 1.0 mm to 1.5 mm (at Quinnesec) as it would be with softwoods at roughly 3-5 mm in length (9).

Control chart examples

Figure 9 shows a control chart with daily averages showing the decrease in the 0-4 mm class achieved by increasing the chip length by 2 mm. The visible change was seen two days after the changed length because of a cold snap right at the length change. The limits on this chart are different, because it was made prior to the July 1987 setup period.

16. Fines and 0-2-mm chips vs. 2-4-mm chips before the chipper program began

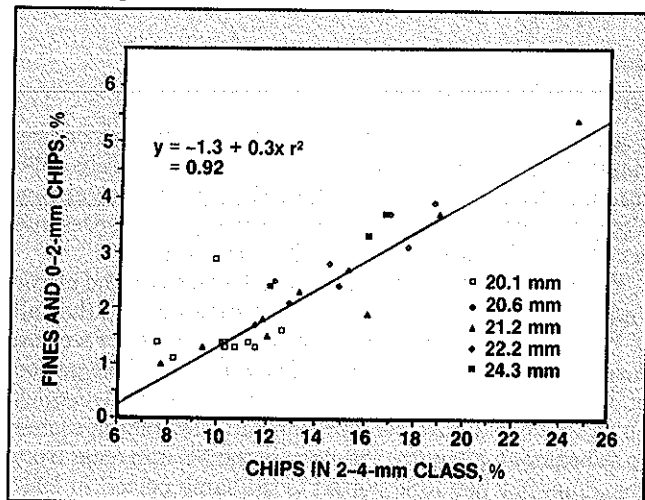


Figure 10 shows an eight-day period at the end of the first severe cold spell in January 1988. The percentage for the 0-4-mm class is out of the October ranges early in the period, but it falls back in the last two days as the temperature moderates to about 0°C.

Figure 11 shows another cold snap period in 1988 from January 22 through February 6. Here, the chip length was increased to 26.4 mm to change the out-of-control situation that occurred as shown in Fig. 10. This change gave a reduction of 5-7% in the 0-4-mm class over similar conditions with the 24.3-mm length. The longer length was used until mild temperatures created a problem with excessive overthick chips at about 12-15% of 0-4-mm chips. Also, more "shearing" action of the chips occurred at the 26.4-mm length in the warmer temperatures (+10°C).

Figure 12 shows the temperature effect on the chip thickness distribution as an eight-day warming trend of 18°C produced a 6.5% drop in the 0-4-mm class.

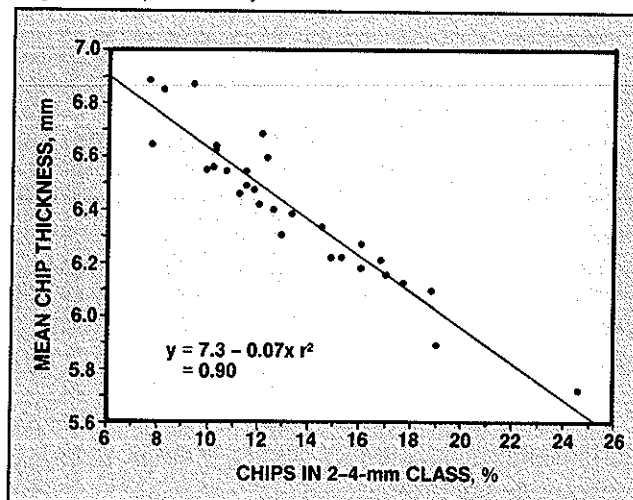
The 0-4-mm class hit the October average target at a 26.4-mm chip length when the daily mean temperature was around -5°C. For the 24.3-mm chip, this average was hit at about 0°C. Some additional upward shifting of the distribution could be obtained by reducing the speed of the chipper disc (10) or by increasing the λ angle on the chipper to reduce the shearing effect, which has been shown to produce more pins and fines (8).

Under winter conditions, several degrees could be added to the λ angle of Quinnesec's chipper with no change to chipper hardware. It is one of the advantages of the double-grind knife design that the λ angle can be changed while keeping the chip length and the pull-in angle the same. Another option would be to suspend chipping during severe periods. Seasonal chip pile management would have to be a consideration in this solution.

Economic importance

The production of excessive 0-4-mm chips will cause higher chip screening losses because of lost or downgraded material, resulting in higher wood costs to the mill. Extraction screen plugging in continuous digesters can also be a serious problem, causing less consistent cooking and washing, lower yield, and poorer quality.

17. Mean chip thickness vs. 2-4-mm chips before the chipper program began, for the period of July 1986 to June 1987



We looked at two January 1988 periods to compare the effect of a 10°C difference, from -8° to -18°C average daily mean temperatures. As Table IV shows, the net results were:

1. 3.5% additional losses to fuel, primary screen only, not including losses from chip thickness screening
2. 5.2% additional 2-4 mm chips in the digester flow
3. 0.4% additional 0-2 mm chips in the digester flow.

The lost value would be found by:

$$\text{loss} = (\text{wood} - \text{fuel}) \times 3.5\% \times \text{tons} \quad (4)$$

where

- loss = lost value, \$/day
 wood = cost of purchased roundwood, \$/ton
 fuel = cost of purchased wood fuel, \$/ton
 tons = wood chipped, tons/day.

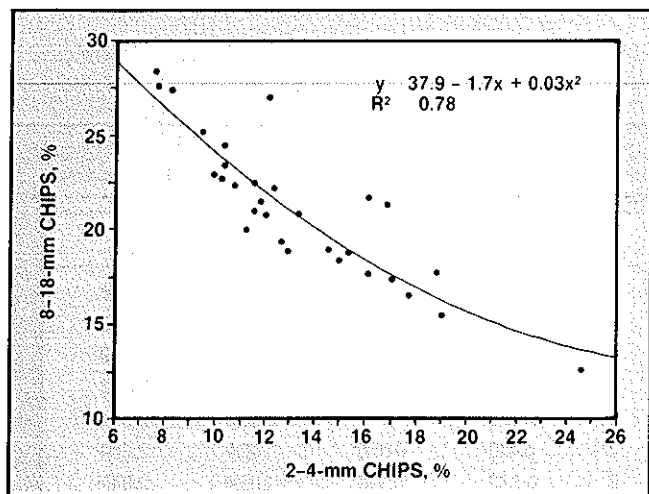
For a wood value of \$30, a fuel value of \$20, and 2000 tons chipped per day, the lost value would be \$700 per day. Each mill would have to calculate its own value; these figures are sample values only.

Additional flexibility will also be available when the relationships between chip length, thickness, temperatures, and other variables are more predictable. In May 1988, during a one-day outage of the thickness screening system before the digester, the chipper was set for a 20.1-mm chip length to prevent feeding more than 30% of chips >8 mm to the digester from chip storage. The longer chip (26.4 mm) was being cut to test the quality of the output from the chip slicers with a higher flow. By shifting to the shorter length, the percentage of >8 mm dropped from 36.6% to 16.9%, while the 2-4-mm class increased from 9.1% to 16.9%. The 4-8-mm class increased from 48.1% to 63.1%. Figure 13 compares the two thickness distributions.

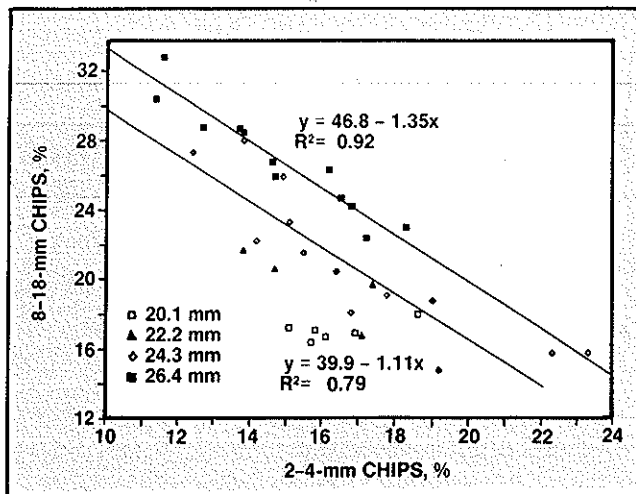
Temperature correlations

Seasonal changes in wood from changes in ambient

18. Chips of 8-18-mm vs. chips of 2-4-mm during the period of July 1986 to June 1987



19. Correlation between the 2-4-mm class and the >8-mm class for period of July 1987 to June 1988 period



temperature caused the chip thickness distribution to shift. We performed a correlation on the daily mean 2-4-mm class vs. the daily mean temperature by chip length grouping where data were available. The purpose was to see if the reaction time was close to one day.

Figure 14 shows this correlation for the 2-4-mm class for a 24.3-mm chip from Nov. 11 through Jan. 20 for the previous fall and winter (1987). The coefficient r^2 was 0.72 on a daily correlation. When the correlation was done based on temperatures of the day before and two days before, the coefficient dropped to 0.41.

This relationship is more complicated to track, because the temperatures of the previous several days probably have some lag time in their effect in the wood temperature. More complex treatment of the data is planned when our daily test records can be accessed for use in a statistical computer program.

A strong factor in the temperature effect being seen so quickly is probably that the wood received is mostly fresh cut and is hauled to the mill only several days before use. Decked wood that has been stored for weeks or months would be less likely to show this reaction.

With a better understanding of the temperature effect on the thickness distribution at a given chip length, the short to mid-term temperature forecasts could be used to plan which chip length to cut.

Figure 15 shows the 2-4-mm relationship to temperature at four chip lengths. These data points represent several days to a week of production at stable temperatures for the period from July 1987 to May 1988. The curve is not completely accurate for the 26.4-mm length because worn face plates during January through March 1988 caused a longer chip to be cut, probably in the neighborhood of +2 mm. At a given temperature, the 2-4-mm class will increase with the shorter chip length.

Correlations for the 2-4-mm class

The 2-4-mm class has been identified as the best indicator of change in the thickness distribution. Several correlations were done to see if the 2-4-mm class could also be used accurately as a "predictor" of thickness class

percentages and of the mean chip thickness. If so, the sampling of the chips could be reduced to the 2-4-mm class instead of breaking down the entire distribution, making sampling less time consuming.

The >8-mm class is of major interest because of the impact of overthick chips, as mentioned. In individual tests, the individual values of the >8-mm class vary more than the 2-4-mm class. This wider range of variation is probably caused by the relationship of the sample size used vs. the chip size of the >8-mm class. Ideally, a sampler size of five times the maximum particle size is the minimum required for a good sample. (Our sample size is less than ideal for >8-mm chips which can reach 100-mm or more in length, while 2-4-mm thick chips normally run a maximum of 20-30-mm long.) By being able to use the 2-4-mm class as a predictor of the >8-mm class, the accuracy of the short-term results could be better than the sampled values.

The correlations in Figs. 16-18 are for the period of July 1986 to July 1987. Correlations were also run from July 1987 to June 1988 but were biased because worn faceplates had affected the data for January-March for the 26.4-mm chip length. The worn faceplates caused the chip length to increase by increasing the Y dimension. Further work will be done with both periods when the data are sorted out. Since the correlations from July 1986 through July 1987 are not classed by chip length, the differences related to the front grind width and other factors do not disrupt the data to as great an extent.

Figure 16 shows the fines and 0-2-mm class vs. the 2-4-mm class with an r^2 of 0.92. Figure 17 shows the mean chip thickness vs. the 2-4-mm class, with r^2 equal to 0.90. Figure 18 shows the >8-mm class vs. the 2-4-mm class with an r^2 of 0.78. The 24.3-mm chip seemed to produce about 4% more overthick chips relative to the other lengths.

Figure 19 shows the correlation between the 2-4-mm class and the >8-mm class for the July 1987 to June 1988 period. In this graph, we dropped the data points for the 26.4-mm length that were affected by the worn faceplates. Each chip length plot shows a clearer relation in this graph when compared to Fig. 18, which is based on measurements made prior to the improved chipper program. This

Appendix: the calculations

First, calculate the average range.

$$\bar{R} = \Sigma R/k = 182.64/44 = 4.151 \quad (1)$$

where

k = the number of subgroups.

Second, calculate the control limits on the range.

$$UCL = D_4 \bar{R} = 2.282 \times 4.151 = 9.47 \quad (2A)$$

$$LCL = D_3 \bar{R} = 0 \times 4.151 = 0 \quad (2B)$$

where

D_3 = a factor used to calculate the lower control limit for the range control chart. D_3 varies with subgroup size, n .

D_4 = a factor used to calculate the upper control limit for the range control chart. D_4 varies with subgroup size, n .

Third, calculate the grand average.

$$\bar{X} = \Sigma \bar{X}/k = 686.76 = 15.608 \quad (3)$$

Fourth, calculate the control limits on the grand averages.

$$A_2 \bar{R} = 0.729 \times 4.151 = 3.03 \quad (4A)$$

$$UCL = \bar{X} + A_2 \bar{R} = 15.61 + 3.03 = 18.64 \quad (4B)$$

$$LCL = \bar{X} - A_2 \bar{R} = 15.61 - 3.03 = 12.58 \quad (4C)$$

where

A_2 = a factor used in quality control to calculate the upper and lower control limits for the $\bar{X}$ control charts. A_2 varies with sub-group size, n .

Factors for the control limits are given in Table V.

V. Factors for control limits

n	A_2	D_3	D_4	d_2
2	1.880	0	3.268	1.128
3	1.023	0	2.574	1.693
4	0.729	0	2.282	2.059
5	0.577	0	2.114	2.326
6	0.483	0	2.004	2.534
7	0.419	0.076	1.924	2.704
8	0.373	0.136	1.864	2.847
9	0.337	0.184	1.816	2.970
10	0.308	0.223	1.777	3.078

clearer relationship is the result of consistently cutting the design chip length with less variation after the chipper program improvements went into effect.

Overall, the correlation coefficients are good, supporting the idea that the 2-4-mm class can be used as a predictor of other classes and as an indicator of change in the thickness distribution.

Summary

Critical to obtaining a consistent chip thickness are factors that include the maintenance of chipper hardware and wear surfaces, proper knife-grinding consistency, and the proper setup for the target chip length and the clearance of the bed knife to the disc. Within the limits of the chipper used, thickness can be successfully controlled and increased uniformity of the digester furnish can be achieved by varying the chip length in reaction to seasonal temperature changes.

A quality improvement program that involves personnel in using control charts can be successful in reducing factors that increase the variability of the chip thickness. Such factors include the variation in the front grind width, variation of the knife width variation, and inconsistent setup of the V-block or bed knife.

The 0-4-mm class was identified as an accurate indicator of change for our chipper. Control charts developed with this class tracked changes caused by temperature variations and by changing chip lengths. The relationship between temperature and chip thickness distribution at a given chip length indicates that it is possible to use temperature forecasting to plan which chip length to cut, on sites where freshly cut and freshly delivered wood makes up the major part of the wood usage.

Finally, in addition to decreasing the variability of chip thickness, wood costs can be reduced, and more flexibility of the chipping operation can be achieved by using chip

length as a controlling factor. We found that the thickness class of 2-4 mm is an accurate predictor of the mean chip thickness, the class of >8 mm, and the combined class of the fines plus 0-2 mm. Depending on the test method, there may be other sample fractions, such as pins or thins, that would also work for these correlations. This predictability model could be used to optimize the chipper product with a chip thickness screening system to give the best quality output and to lower material losses. □

The authors would like to thank George Gentry and Andy Smith at the Quinnesec Mill for their support. Frank Sinibaldi at the West Nyack Technical Center, Bill Dorman at the Pensacola Technical Center, and Don Mroz helped greatly in analyzing the data. Thanks are also extended to Bob Young, who helped in providing the resources needed for all aspects of the project. Credit is due the members in the chip lab, the CROs for their commitment to quality chipper maintenance, and the Quality Improvement Group. Vicki Jensak's work in preparing the original manuscript is also greatly appreciated.

Received for review July 13, 1988.

Accepted Oct. 6, 1988.

Presented at the 1988 Pulping Conference.

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