DESIGN AND TESTING OF A PROTOTYPE IN-LINE CHIP QUALITY MONITOR

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Design and Testing of a Prototype In-Line Chip Quality Monitor

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Forestry

(Abstract)

This project involved the design and testing of a prototype in-line chip quality monitor for gathering process control information for the manufacturers of wood chips. This monitor specifically addresses three common complaints with current chip sampling procedures. Chip sampling occurs too late in the process. It is inadequate. It is too infrequent to develop management information.

The monitor is composed of a double screen drum separator to divide chips into oversize, accepts, and pins/fines. Counterbalanced tip buckets are used to weigh each size class. Tip bucket cycles are recorded by a computer via magnetic proximity switches attached to each bucket. This information is then used to chart production of chip size classes, updated continuously over the sorting period. This monitor is capable of sorting one ton of chips per hour.

Two trials were conducted to test the monitor. One in a lab environment, and one on site at a chip mill. Both trials compared monitor output with independent samples classified using a Williams classifier. The trials showed that outputs were consistent with Williams output.
This monitor can effectively chart chip distribution information. This process control information provides the manufacturer with immediate knowledge of chipper performance.
Acknowledgments

My sincere thanks to my chairman Dr. William Stuart, Dr. Richard Oderwald, and Dr. Audrey Zink, for their guidance and assistance in the completion of this project. I would also like to thank Jon Sharp for showing me how to build my project, and Steve Shaffer for writing the computer program.

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Chapter 1. INTRODUCTION

Background

Pulp mills acquire their wood chips from a variety of sources. Some buy roundwood and chip a portion themselves while others rely totally on outside sources, including satellite chip mills and sawmill residues.

Chip size is an important aspect of overall chip quality for pulpmill furnish. It affects digester performance, fiber recovery, and load on the recovery boiler. There are three basic size categories that describe chips used in the manufacture of paper: oversize, acceptable, and pins/fines. Oversize chips are chips that are too large to be pulped effectively, acceptable chips are optimal for pulping, and pins/fines are too small, they block liquor flow in the digesters and are often completely dissolved. Chips are screened at the point of production to separate out oversize and pins/fines, sampled upon delivery to the pulpmill, and screened again en route to the digester. However, screening in and of itself does not ensure optimal size distribution.

Size distribution is also an indicator of the capability and condition of chip producer's machinery. Chippers always create all three types of chips because of the variability of raw material. However, they are adjusted to produce the maximum amount of acceptable chips. Deviations from the optimal quantity of acceptable chips being produced is usually indicative of a problem with the chipper settings. With the increasing popularity of satellite chip mills, several problems with the current method of sampling have become apparent:
1) The sampling occurs too late in the process.

2) Sampling is inadequate.

3) Sampling is too infrequent to establish management information.

It is essential that sampling occur at the pulpmill to provide indicators of quality at the point of consumption, but chip manufacturers produced those chips as much as a day or two prior to mill sampling. If the chipper, at the point of production, is out of adjustment the producer is not aware of the problem until too many more poor chips are produced. Large chip suppliers are being encouraged to do sampling in house as a means of early problem identification.

The volume of chips sampled is inadequate, because most size distributions are predicted using a sample as small as four or five pounds for 25 ton loads.

The time, manpower, and equipment requirements to pull even a single sample from every load is considered prohibitive. These sampling systems offer only historical information instead of information useful in the management and control of the process. Consequently, chipper knives are changed and adjustments are made on a time dependent schedule as opposed to when needed, unless an obvious problem arises.

Solution

Modern manufacturing processes increasingly rely on instrumentation to monitor and adjust machine performance while work is in progress rather than relying solely on
measures of product quality after the fact. A similar machine that measured and reported the distribution of chip size concurrently with production would eliminate the need for much of the current chip sampling. An in-line chip quality monitor installed at the point of manufacture to act as a process control tool for the chip producer would be an indicator of chip quality for the purchasers and signal the need for knife changes or other maintenance as soon as the problem arises.

First, it should provide timely information to the producer about chip size distributions. This information would be noted immediately, chipper adjustments could be made before a large quantity of unacceptable chips are produced.

Second, it should be capable of sampling a larger quantity of chips than classical sampling methods. This would improve the predictions made about chip distribution. If this machine is designed to be placed in the chip stream, the amount of chips sampled is simply a matter of machine size.

Last, this machine should stand alone and require no additional personnel. Once it is installed, the output can be directed to an existing work station.

GOAL

The goal of this project was to develop and test a prototype in-line chip quality monitor that was capable of accurately measuring and reporting the three chip size classes as a percent of total weight sampled. The prototype was designed to be portable to allow testing in various locations. This limited the throughput capability to one ton an hour.
because of the relatively small size of the monitor. The machine had to be robust to withstand harsh mill environments. Finally it had to be relatively inexpensive.

Testing was divided into two segments, shop trials and on site mill tests. The first was for calibration and to ensure all components worked properly, the second was to see how well the prototype worked in a mill setting.
Chapter 2. LITERATURE REVIEW

"Technology will be called upon to deliver a better, more uniform furnish." (Meadows, 1995)

Meadows’ statement is the impetus for this project. Paper is the primary packaging product, communications medium, disposables base, and industrial sheet material in the United States (Haygreen and Bowyer, 1989). The manufacture of paper is simply a process of reducing wood chips or furnish to its constituent fiber or pulp, suspending the fibers in water, refining, introduction of additives, formation of a fiber mat, then draining and drying the paper (Haygreen and Bowyer, 1989). Pulping can be achieved several ways; mechanically, chemically, heat, or some combination of the three. The pulping method determines paper quality.

Mechanical pulping is achieved by pulling the wood fibers apart. Lignin, which serves to strengthen solid wood through stiffening fibers, remains in the pulp. Although pulp yield is almost 100% of the wood dry weight in this process, the still rigid fibers have little fiber to fiber bonding and result in a coarse bulky mat. The paper made from this process has poor strength and poor surface quality. (Haygreen and Bowyer, 1989)

A combination of heat and mechanical refining is thermo-mechanical pulping or TMP. TMP uses heat to soften the lignin before mechanical refining. This method allows fiber separation with less fiber damage. Though lignin is still present in the paper, both strength and surface quality are improved. Another process which achieves the same
result is chemi-mechanical pulping. Chemi-mechanical or neutral sulfite semi-mechanical, commonly called NSSC, uses short term chemical exposure rather than heat, to partially degrade the lignin before mechanical refining. In addition to strength and surface improvements, mechanical energy required and damage to fibers are further reduced. (Haygreen and Bowyer, 1989)

High quality paper requires that the lignin be removed through chemical dissolution. If left in the paper, lignin deteriorates with age and exposure to ultraviolet rays, shortening the life of the sheet. High quality paper is the major product in the U.S. and the reason chemical pulping accounts for over three fourths of pulp production from raw wood (Haygreen and Bowyer, 1989).

Wood chips are loaded into a vat or digester. A chemical solution or cooking liquor is added and the digester is brought up to temperature and pressure using steam heat. As the lignin dissolves, the fibers separate. This results in the smooth undamaged fibers that create high quality paper (Haygreen and Bowyer, 1989).

There are two types of chemical pulping processes, sulfite and sulfate. The difference between the two lies not only in the chemicals but the product as well.

Sulfite pulping results in the high quality pulp that is used for fine writing papers. This process does not work well with highly resinous softwoods. Sulfate pulping works on any species equally well. This process, also known as Kraft pulping, is the most widely used process in the U.S. The paper made from Kraft pulping is strong and has a variety of
uses that range from grocery bags to common writing paper. (Haygreen and Bowyer, 1989)

Unfortunately one cost of quality paper is low yield. Only 44 to 55% of the furnish is reduced to usable fiber. "This is less than the lignin content may indicate. Conditions which solubolize lignin also degrade both cellulose and hemicellulose." (Haygreen and Bowyer, 1989) Low yield is the reason chemically pulped products are more expensive than those from mechanical process which leave the lignin in place (Haygreen and Bowyer, 1989).

All wood chips are pulpable, but chemical pulping requires a certain range of chip sizes to ensure an even liquor penetration and a pulp of consistent quality and optimal yield.

**CHIP CLASSIFICATION**

Chip length and thickness are the critical dimensions in determining acceptable sizes for pulping. Andreas Uhmeier (1995) stated that a relatively thin chip with a minimum of fiber damage as well as a narrow chip size distribution is desired. However due to the correlation between chip length and thickness for a given species processed with a disk chipper (the most common method of chipping), classifying chips by size is generally accepted to mean length (Dorman, 1991). A simplified version of Dorman’s chip classifications has three size classes that are used when classifying by length. These
are overlength/thick, accept, and pins/fines. Table 2-1 shows the typical limits used in the industry for separating chips using round hole screens (Dorman, 1991).

Table 2-1. Three basic chip sizes.

<table>
<thead>
<tr>
<th>Size Class</th>
<th>Screen Size Chips are retained on</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overlength/thick*</td>
<td>1 1/8 inch round hole</td>
</tr>
<tr>
<td>Accept</td>
<td>3/8, 5/8, and 7/8 round hole</td>
</tr>
<tr>
<td>Pins/Fines**</td>
<td>1/8 and pan</td>
</tr>
</tbody>
</table>

*This will be referred to as oversize throughout the paper
**This will be referred to as fines throughout the rest of paper

Oversize chips and fines affect the pulping process differently. Fines allow liquor to penetrate quickly and attack the fibers as well as the lignin. This reduces yield and paper strength. Conversely, the pulping liquor does not penetrate oversize chips, especially overthick, quickly enough, and the pulping process is incomplete when the digester is “blown”, or emptied. (APA, undated)

CHIPPING

Wood chips are obtained from a variety of sources. In 1993, 102 pulp mills were in operation in the southeastern U.S. alone. Their productive capacity was over 132,000 tons of pulp per day, requiring over 66 million cords of raw material for the year (Howell, 1995). Two thirds of this material was produced from roundwood while the remainder was made up of sawmill residue. Chemical pulping accounted for 85% of this capacity.
Chipping roundwood is a fairly straightforward process. The material is obtained
tree length, log length, and shortwood length depending on the individual mill’s woodyard
and wood room equipment. The processor’s system normally consists of a debarker, a
chipper, a fines screen, and perhaps an oversize screen. If the mill has an oversize
separator, only grossly oversize chips are removed. These may be routed to another
chipper set up to rechip them or they may be fed back through the roundwood chipper.

A sawmill has several different chipping stations throughout the mill. While not
the primary product, chips are often a significant source of cash flow for sawmills. White
(1992) stated that sawmills break-even with lumber and make a profit on residuals. A
typical southern pine mill has a log deck chipper for cutoffs and rejected logs, a chipping
headrig, a chipping edger, and another chipper to handle trim ends and slabs. These chips
are then screened much the same way as roundwood chips before being shipped or stored.

Regardless of the amount of screening done prior to sale, chips still must be
sampled at the pulpmill to assure quality. The “purpose of testing and classification is to
ensure consistent quality feed to the digester at minimum cost” (Dorman, 1991). Two
very common testing methods involve sampling and mechanical segregation into size
classes. The first is a sieve type shaker and the other is a Gradex type separator.

The sieve classifier is composed of several trays with different size holes stacked
atop one another. The largest holes are on top. A predetermined sample weight of chips
is spread on top of the stack. The shaker is then turned on and left running for a fixed
time period. After the run is complete, the trays are removed one at a time. The chips
left on the trays are poured into a tared bucket and the weight is recorded. Once all the 
trays are weighed, total weight and size class percentages are recorded. This information 
is then used to make inferences about total chip distribution of a load or a pile. A typical 
sampling system would be a four liter sample, shaking time of ten minutes, and a rate of 
184 samples per week. This regimen covers two production shifts with samples taken 
from both trailers and rail cars (Brown, 1993).

The Gradex classifier is an automated analysis tool that requires a quarter cubic 
foot sample. This sample is poured into the center of an hexagonal screen chamber. Five 
sides are screen decks with the sixth side open for removal of oversize chips. This method 
separates one size category at a time, the smallest first. The size classes are dropped onto 
a scale and weighed. The control system is a dedicated computer, power supply and I/O 
relays to control all machine functions, data collection and printout. Typical analysis time 
is seven minutes with the ability to analyze 50 samples in a single shift (Robins, 1989).

UNACCEPTABLE CHIPS

Information from chip sampling is imperative for the chip producer wishing to 
keep the process “in control”. Wood chipping is a complicated process that depends on 
many factors (Uhmeier, 1995). Raw material quality, chipping equipment, and weather all 
can adversely affect the production of acceptable chips. Table 2-2 describes some of the 
causes for oversize chip production, and Table 2-3 shows some causes for the production 
of fines.
Table 2-2. Oversize Chip Production (Timber Processing; 1990)

<table>
<thead>
<tr>
<th>Material Causes</th>
<th>Mechanical Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear strength greater than compression strength</td>
<td>Knife angle too sharp</td>
</tr>
<tr>
<td>Unusual grain patterns</td>
<td>Velocity too low</td>
</tr>
<tr>
<td>Exploded tail end of logs</td>
<td>Shear angle too small</td>
</tr>
<tr>
<td></td>
<td>Dull knives</td>
</tr>
<tr>
<td></td>
<td>Rounded anvil</td>
</tr>
<tr>
<td></td>
<td>Piece turned sideways</td>
</tr>
</tbody>
</table>

Table 2-3. Fines production causes (Timber Processing; 1990; Wallace, 1993)

<table>
<thead>
<tr>
<th>Material Causes</th>
<th>Mechanical Causes</th>
<th>Weather Related</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broomed ends</td>
<td>Shear angle too great</td>
<td>Frozen wood</td>
</tr>
<tr>
<td>Rotten pieces</td>
<td>Knife velocity too high</td>
<td></td>
</tr>
<tr>
<td>Low strength fiber</td>
<td>Spout angle incorrect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incorrect feed speed</td>
<td></td>
</tr>
</tbody>
</table>

These causes of unacceptable chips can be broken down into two categories, common and special. What distinguishes these two types is the ability to control them (Walton, 1986). Common variation is not easily controlled and includes variation in material and weather. Special variation on the other hand is controllable. Shear angles, feed speed, disk speed, knife angle, and the rest can all be adjusted to reduce or eliminate mechanical causes. "It appears that the many other factors able to be varied to or on
individual chippers can overwhelm (material causes) as managers attempt to manipulate the trade off relationship between unders and overs production, or as maintenance standards vary” (Twaddle and Watson, 1991).

Control of special variation is the responsibility of the chip producer. Chip distribution information has to be known immediately so corrective action can be implemented. Waiting for results from the pulp mill means continuing production of unacceptable chips for hours, an entire shift, or sometimes a couple of days. Unacceptable chip production reduces yield which raises the cost of each load chipped by increasing the raw material requirement. “The best way to determine when your chipper knives need sharpening is to maintain a regular chip classification control” (Williams, undated).

TOTAL QUALITY MANAGEMENT

“The modern approach to quality and reliability concerns excellence; excellence when the product is designed, excellence when the product is made, excellence when the product is used, and excellence throughout its lifetime” (Schilling, 1992). These fundamentals are the basis for the current trend in total quality management for manufacturing and service oriented companies around the world. Because many companies market products internationally, a set of guidelines has been introduced by the International Standards Organization to harmonize the large number of national and international quality standards (Lamprecht, 1992). These guidelines are referred to as ISO 9000. Its primary goal is to install and maintain a quality system that will strengthen its
own competitiveness and achieve the needed product quality in a cost effective way (Lamprecht, 1992). Forest products industries utilize these guidelines in an effort to assure quality in all aspects of their operations, from the woods to the retailer. Quality control is not something to achieve but a way to “improve constantly and forever the system of production and service” (Deming, 1986).

As stated earlier, ISO 9000 has guidelines for every aspect of industry. One section of the guidelines deals directly with process control. “The supplier shall monitor, control and approve processes during production” (Lamprecht, 1992). This has direct bearing on the wood chip suppliers for pulpmills, and is what this project is trying to address. “As many industries today are focusing on total quality management philosophies, tools to accomplish continuous process improvement are essential” (Cook, 1992).

ISO 14000, covering the management of environmental systems, is an additional set of guidelines proposed by the International Standards Organization. Environmental impacts are important to the forest products industry, and these new guidelines were developed to “support environmental protection in balance with socio-economic needs” (Technical Committee #207, 1994). Process improvement that increases yield from natural resources is an important step in ensuring protection of the environment, while meeting the demand for products.
Chapter 3. METHODS AND MATERIALS

DESIGN AND CONSTRUCTION

The design of the prototype in-line chip quality monitor was based on a conventional drum screen that could separate chips into three size categories. In addition to multiple separation, the monitor had to be portable for field testing, adaptable to different mill sites, robust enough to withstand harsh mill environments, and inexpensive.

Drum Screen

The first task was to build the drum screen. The core of the unit consists of a 12 foot length of 1.5 inch diameter round shaft stock mounted at a ten degree angle on a frame that is 10 feet long, 4 feet wide, 6.5 feet high in the front, and 8.5 feet high in the back. The slope of the frame follows the slope of the screen. Three sets of spokes were placed along the shaft creating a sorting distance of 9.5 feet. Each set has eight spokes 22.75 inches long for a final diameter of 4 feet.

Sorting into three size classes required a double screen, one set inside the other. (Figure 3-1) The inner screen captures oversize chips, the outer screen captures accepts, and the pins/fines pass through the outer screen. To mount the inner screen, 1/2 inch angle iron was welded lengthwise across the three sets of spokes 15.5 inches out from the shaft. This was repeated on each spoke. Once these supports were in place, 4 inch wide strips of 20 gauge sheet metal were riveted on either side of the
Figure 3-1: Illustration of Screen Attachments
middle set of spokes and the inner sides of the others. Wider sheet metal was extended outside the front and back set of spokes to aid in feeding material into the screen and staging the output. (Figure 3-2) The sheet metal formed round mounting surfaces for the screen. Two pieces of 4 foot wide, 1 inch mesh chain link fence were cut and wrapped around the drum frame. This screen was then wired into place on the sheet metal and angle iron.

The outer screen was attached in a similar fashion. Angle iron was welded to the ends of the spokes along the sorting length. The screen used to separate pins/fines was formed from 1/4 inch hardware cloth. This was mounted directly to angle iron with wire. The outer screen has eight flat sides. This configuration facilitates the mixing of the chips for better separation. This screen is shorter than the oversize screen.

The drum is powered by a single phase, 110 volt, 1/4 horsepower, 1725 rpm motor drawing 8 amperes. The motor speed was reduced to 8 rpm on the drum via two belt reductions and one gear reduction.

Tip Buckets

Keeping track of each size class depended on continuously weighing the individual size classes. Various devices for weighing material on a moving belt are available, but were considered too sensitive and expensive for this application. Tip buckets, that collected the chips then dumped at predetermined weights and automatically rester for the next cycle were a more robust and inexpensive alternative.
Figure 3-2: Illustration of Oversize and Accept Chip Output Conveyors
The easiest way to accomplish this was to use counterbalanced tip buckets. A tip bucket has a collection area on one side of an axis with an extended weight holding it upright on the other. When the bucket gathers enough chips to counteract the weight, it drops forward dumping the contents. After the chips fall out, the weight returns the bucket to the rest position. Adjusting the axis position and the amount and location of the counterbalance changes the weight of material necessary to tip the bucket forward.

(Figure 3-3)

Parameters from previous studies were used for the design and construction of the tip buckets. Throughput was set at one ton an hour, and the chip distribution was assumed to be 90% accepts, 5% oversize, and 5% pins/fines. These parameters were used to calibrate the buckets so they would cycle about the same number of times per hour. The buckets were constructed to dump at about 15 to 17 pounds for accepts and one pound for both the oversize and the pins/fines. Dump weights were recalculated for each trial.

Material Handling

Conveyors were needed to move chips from the screens to the individual buckets. The configuration of the screen and the necessity to keep the device compact and portable, dictated the location and the length of each conveyor. The inner screen, which captures oversize chips, extends beyond the outer screen, and deposits chips the furthest forward. The outer screen, which captures accepts, deposits chips directly behind the overs. The fines fall out along the entire sorting length. Therefore, two
Figure 3-3: Illustration of Accept Bucket Cycle
conveyors were placed laterally at the front to capture oversize and accepts. The fines conveyor runs longitudinally under the entire screen. These conveyors were made of 2” x 2” box beam with 7” diameter rolls at each end. A 6 inch belt is used on all three conveyors. The accepts and oversize conveyors are 5 feet long and the fines conveyor is 9 feet long. Each conveyor is powered by a single phase, 1/3 hp, 220v right angle gear motor, chosen on the basis of availability rather than power demand. The buckets were placed at the output of each conveyor.

The buckets were designed to reset themselves by rotational inertia. The relatively short length of the oversize and accepts conveyors did not allow belt storage, chip flow had to be stopped to ensure proper resetting. This was accomplished using motor starters on the accepts and oversize motors. Magnetic proximity switches, which were used to count bucket cycles, also served as signals to the motor starters to stop the belt when the bucket begins to tip. The buckets are allowed to cycle without interference from a continuous flow, and the belts are restarted only when the bucket returns to the rest position. This serves to ensure more accurate weighing. The fines belt is long enough to allow storage on the belt and does not need to be stopped.

When the chips are dumped from the buckets, they are collected in one of two auger conveyors for return to the mill’s chip stream. One auger is used for the fines and the other is used for both the accepts and oversize. The fines auger runs the length of the screen in the opposite direction of the fines belt. This auger empties into the accepts and oversize auger which runs across the width of the machine. (Figure 3-4)
Figure 3-4: Illustration of Oversize and Accepts Return Auger
The chips are then emptied onto a conveyor that returns them to the original chip stream. The conveyor troughs were formed from 16 gauge sheet metal bent into five sided open top troughs. Motors mounted at the end of each trough power the 6.5 inch in diameter, 10 foot long augers, with a flight every 4.5 inches. The motors are 1/3 hp, 115v in-line gear motors with a final rpm of 60.

Feeding chips to the monitor as well as returning them to the mill stream required customization at each site. Therefore, power requirements and conveyor configurations changed. Individual setups will be described for each test.

**Trailer**

The trailer serves a dual purpose. First it is essential for machine operation, because it raises the monitor to the proper height for all parts to function. The tongue jack serves to level the entire machine so the unit can be adapted to most mill and yard conditions. The second function is portability. The utility of the device could only be demonstrated by testing on location. Field testing was also critical for refining the design and application.

The trailer itself is constructed on a 3” x 5” I beam frame, with 2” x 4” box beam for central support of the tongue, and 2” x 2” box beam for the decking and tongue. A 6,000 pound axle supports the trailer on a set of 3,000 pound leaf springs. Height is 34” to the top of the decking. The trailer has an overall length of 16.5 feet with a main deck
of 11 feet. The frame is 61" wide with an overall width of 91". While size may limit installation in very close quarters, the device is small enough to fit most installation areas.

Computer

A single Quick Basic program on a 286 lap top computer is used to collect data from the tip buckets. The computer is linked to the buckets by the same proximity switches used to control the motors. As the buckets tip, contact is broken and a signal is sent to the computer which records how many times this occurs. Each bucket has a proximity switch and since tip weight is known, a simple equation to sum total weight sampled and breakdown percentages is used to convert the data collected by the computer. This program also uses an adjustable interval prompt to set data download intervals in minutes. The interval is determined by individual sampling needs. Once the interval is established, cumulative bucket cycles are downloaded to a storage file after each interval period.

Control

All power required for operating the screen, conveyors, and computer was routed through a single electrical panel to simplify installation at field sites. The panel box has a three phase bus bar that directs power to the motors and the computer through circuit
breakers, providing individual surge protection for each device. An additional circuit breaker is installed at the mill power source.

The supply of chips from and the return of chips to the mill’s stream were customized for each installation. Modification of the infeed and return required a separate power source depending on the equipment used. This power requirement, however, was minimal. Auxiliary outlets were built into the monitor and were used when necessary. The preferred alternative was to access an existing outlet at the mill.

Electrical service is universally available, but not always in the voltage and phase configurations required for this monitor. The basic power requirement for the monitor, without infeed and return, is 35 amps of 220 single phase electricity. Different feed and return set ups can raise demand to as much as 57 amps. Mill requirements are usually met using 480 volt three phase service with little reserve capacity. This necessitates the use of transformers or generators to supply the power needed by the monitor, which in turn increases test costs.

TESTING

Monitor testing was divided into two sets of trials. The first were calibration trials. These tests were performed to calibrate the performance of individual monitor components as well as the complete system, and to assure that performance was consistent with extended operation. The second series of tests were run on site at mills to ensure the monitor’s ability to perform in an industrial environment.
All of the samples referred to in the following sections were analyzed using the Williams chip classifier located at the Harvesting Lab, VA Tech. This classifier separates chips by length into eight size classes using the following round hole screens: 1 15/16 inch, 1 9/16 inch, 1 1/8 inch, 7/8 inch, 5/8 inch, 3/8 inch, 1/8 inch, and a pan to collect dust. This classifier separates samples of not more than 5 pounds in a single run. The weights of these classes were then combined to reflect the three basic size classes used by the monitor. The oversize category is a combination of chips retained on the 1 1/8 inch and larger screens. Acceptable chips are retained on the 7/8 through 3/8 screen. Fines are retained on the 1/8 inch screen and the pan.

Shop Trials

Shop trials were run on each system to calibrate the monitor before field testing was started. Components were tested as they developed then retested as a whole after assembly was complete.

Drum Screen

An extended set of trials were conducted on various screen types and materials to determine the best screen meshes and types for this application. Several different screen meshes for both the overs and fines screens were tested. The choice of chain link fencing for the overs screen was made on the basis of weight, cost, durability, availability and ease
of installation. Quarter inch hardware cloth performed well as a fines screen, and again was inexpensive, light, and readily available. Chips were metered into the drum and then classified after separation using the Williams classifier. Screen rotation speed and slope were adjusted to meet breakdown specifications.

The second set of tests were conducted to estimate maximum throughput capacity. The one ton an hour rate was established by manually feeding the monitor to approximate different throughput rates and measuring its ability to properly segregate the chips. Samples were taken from each of the monitor classes and run through the Williams. Poor segregation was assumed to be the result of two factors, insufficient dwell time, or screen overload. Insufficient dwell time is caused by excess slope on the drum, and overloading is the result of an excessive infeed rate or insufficient screen angle. Adjustments to the drum angle ensured proper separation at one ton an hour.

**Tip Buckets**

Design and construction of tip buckets were the next step. The size of each bucket was determined by converting expected tipping weight to loose chip volume. The shape of each bucket, especially the oversize bucket required customization to work properly. The conventional flat bottomed shape worked well for the accepts and fines bucket, but was sensitive to the variation in the shapes of the oversize chips. Considerable experimentation found that a shallow “v” shape resulted in the most consistent tipping
weight for oversize chips. The buckets were mounted on moveable frames equipped with adjustable legs to facilitate installation. The initial dump weights of each bucket were 1 pound for both the oversize and fines buckets, and 17 pounds for the accepts bucket, were determined to be feasible and sufficiently consistent to meet machine requirements.

Complete Monitor Test

The completed machine went through several tests to determine if all components worked together as planned and to check the computer. These tests were again conducted at the Harvesting Lab, VA Tech, manually feeding chips from a dump truck into the monitor. The chips for this test were obtained from Westvaco’s Covington, VA paper mill. The computer was set to keep track of cumulative bucket dumps for the length of each run. The results of these tests were compared to samples taken from the load prior to sorting with the monitor. The results for this test are described in the results section.

Mill Tests

Testing the monitor at actual mill sites was crucial to determine if this prototype was robust and accurate enough to serve as a tool for process control of chip quality. Two week long tests were scheduled at two different types of mills, a chip mill owned by
Chesapeake Corporation in Keysville, Virginia, and a southern pine sawmill owned by

**Keysville Trial**

Chesapeake Corporation’s Keysville, Virginia chipmill supplies their Kraft pulpmill
in West Point, VA. It is a single shift operation, running about 14 hours a day including
maintenance. The mill output is predominantly pine with a smaller percentage of
hardwood chips. Peak output is 250 tons an hour for pine. The mill layout is typical of
Fulghum chipmills, with single central pivot crane, drum debarker, chipper, and double
fines drum screens. Limited chip storage is available, but most production goes directly
into rail cars or trucks. Knives are changed on regular schedules, once a day for pine and
twice for hardwood under normal conditions. Schedules are altered to accommodate
varying conditions of raw material such as frozen or excessively dirty wood. Damaged
knives are changed as soon as possible. Their fines production is about 4 tractor trailer
loads per day.

A preliminary visit was made to determine the feasibility of the trial and determine
installation needs. This included power supply, where and how the chips would be taken
from the stream and then returned, and a work schedule for the trial. After the inspection,
it was determined that the simplest feed method would be from the transfer point between
the chipper outfeed conveyor and the fines screen. A simple belt conveyor could be used
to return chips to the stream at the end of the fines screen on the outfeed belt. A sliding
gate mounted on one of the slope sheets between the chipper and the fines screen allowed a controllable gravity flow from the mill's chip stream to the monitor. (Figure 3-5) The fines auger was not needed since these chips were not to be returned to the stream. A plastic bucket was used to capture fines and was hand dumped onto their fines auger. The sliding gate was manufactured at the Harvesting Lab, VA Tech, and taken to the mill a week before the trial. An 8 inch diameter hole was then cut into the chute and the gate attached. The gate could be closed while not in use to avoid chip loss. The monitor was brought down a day before the trial and positioned. A feed chute was formed of 22 gauge ducting and attached to the gate. The final electrical hookup was made by an electrician the morning of the first run. (Figure 3-6)

The computer was programmed to download cumulative bucket dumps at 10 minute intervals. The results for this test are described in the results section.

**Armour Trial**

A second trial was scheduled for International Paper's Armour, North Carolina southern pine sawmill. Hurricane Fran caused this trial to be delayed indefinitely.
Figure 3-5: Illustration of Monitor Feed System at Keysville
Figure 3-6: Illustration of Complete Monitor Set-up For Keysville
Chapter 4. RESULTS

Complete Monitor Trial

A two ton load of conventional pulp chips was obtained from Westvaco's Covington, VA mill. Five samples of about ten pounds each were taken at random from the load. These samples were then sorted into eight size classes using the Williams sorter. The Williams size classes were combined to form the general breakdown of oversize, accepts, and pins/fines used by the monitor. The three chip size class percentages for each of the five samples are shown in Table 4-1.

Table 4-1: Percent Breakdown of Samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>% Overs</th>
<th>% Accepts</th>
<th>% Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.72</td>
<td>83.19</td>
<td>10.08</td>
</tr>
<tr>
<td>2</td>
<td>7.07</td>
<td>78.78</td>
<td>14.15</td>
</tr>
<tr>
<td>3</td>
<td>9.03</td>
<td>82.78</td>
<td>8.18</td>
</tr>
<tr>
<td>4</td>
<td>7.94</td>
<td>80.31</td>
<td>11.75</td>
</tr>
<tr>
<td>5</td>
<td>8.81</td>
<td>80.50</td>
<td>10.19</td>
</tr>
</tbody>
</table>

The remainder of the chip load was then used for testing the monitor. Four tests of 480 lbs, 185 lbs, 336 lbs, and 637 lbs respectively, were conducted. The amount of chips used for each test was determined arbitrarily. The summary results for these trials are shown in Table 4-2.
Table 4-2: Percent Breakdown of Monitor Runs

<table>
<thead>
<tr>
<th>Run</th>
<th>% Overs</th>
<th>% Accepts</th>
<th>% Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.75</td>
<td>85.00</td>
<td>6.25</td>
</tr>
<tr>
<td>2</td>
<td>10.27</td>
<td>82.70</td>
<td>7.03</td>
</tr>
<tr>
<td>3</td>
<td>11.90</td>
<td>80.95</td>
<td>7.14</td>
</tr>
<tr>
<td>4</td>
<td>8.48</td>
<td>85.40</td>
<td>6.12</td>
</tr>
</tbody>
</table>

The purpose of segregating the chips in this manner was to establish a basis for comparison between the sorter results and the sampled results. Figure 4-1 shows a graphical comparison of size class means for each separation process. The monitor tended to segregate out more oversize chips and include more fines in the accepts class than the Williams classifier.

Before direct comparisons could be made, the distribution of each size class was determined using a Kolmogorov-Smirnov Goodness of Fit test for normality. This test compared the empirical cumulative distribution function with the normal cumulative distribution function calculated using the sample mean and standard deviation. The test statistic D was the largest of the differences between the two. For each test the null hypothesis was $H_0: \text{Normal}$ and the alternate was $H_a: \text{Not Normal}$. The results are presented in the following tables. All of the tests used a probability of $<.05$ as a basis for rejection of the Null hypothesis.
Figure 4.1: Comparison of Sample Results vs Monitor Results
Table 4-3: K-S Test results for Samples

<table>
<thead>
<tr>
<th>Size Class</th>
<th>Test Statistic D</th>
<th>Probability</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overs</td>
<td>.29045</td>
<td>&gt; .20</td>
<td>Fail to Reject</td>
</tr>
<tr>
<td>Accepts</td>
<td>.21777</td>
<td>&gt; .20</td>
<td>Fail to Reject</td>
</tr>
<tr>
<td>Fines</td>
<td>.14316</td>
<td>&gt; .20</td>
<td>Fail to Reject</td>
</tr>
</tbody>
</table>

Table 4-4: K-S Test Results for Monitor Runs

<table>
<thead>
<tr>
<th>Size Class</th>
<th>Test Statistic D</th>
<th>Probability</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overs</td>
<td>.19243</td>
<td>&gt; .20</td>
<td>Fail to Reject</td>
</tr>
<tr>
<td>Accepts</td>
<td>.26248</td>
<td>&gt; .20</td>
<td>Fail to Reject</td>
</tr>
<tr>
<td>Fines</td>
<td>.27264</td>
<td>&gt; .20</td>
<td>Fail to Reject</td>
</tr>
</tbody>
</table>

The results of the K-S Tests indicated that the data could be treated as normally distributed, therefore, parametric statistics for the normal distribution were used. To compare the results between the samples and the monitor for each size class, a one way analysis of variance was used. The ANOVA tests for difference in the means of the samples. The null hypotheses for each test were $H_0: \text{Mean of the Sample} = \text{Mean of the Monitor Run}$. The alternate hypotheses were the means were not equal. Again, the rejection level for the Null hypothesis was set at a $< .05$ probability of occurrence.

(Table 5)

Table 4-5: ANOVA Results for Size Category Tests

<table>
<thead>
<tr>
<th>Tests</th>
<th>Statistic F</th>
<th>Probability</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overs</td>
<td>4.986</td>
<td>.061</td>
<td>Fail to Reject</td>
</tr>
<tr>
<td>Accepts</td>
<td>3.375</td>
<td>.109</td>
<td>Fail to Reject</td>
</tr>
<tr>
<td>Fines</td>
<td>14.507</td>
<td>.007</td>
<td>Reject</td>
</tr>
</tbody>
</table>
From the results of the ANOVA, Overs and Accepts have no statistical difference, however, the fines showed a difference. This was attributed to several factors. First, the Williams uses a shaker system to separate chips while the monitor uses a rotating method. Second, the screen sizes are not the same. Third, the samples may not have completely represented the load distribution.

Since the goal for the monitor was consistent results over time, reflecting system performance rather than direct replication of results from any one analytical system, the difference may in fact be irrelevant. The trend shown by the previous graph of the means of the results showed enough similarity to continue the project with the existing screens.

KEYSVILLE TRIAL

The trial at Keysville was conducted basically the same way as the shop trials. Runs were made for three consecutive days and the results were compared to samples taken from the mill sampling point. Total run time was 17 hours and 8 minutes. This was compared to 11 samples averaging 3 pounds each.

Because this prototype is a dynamic system, recalibration was necessary to achieve accurate results. Each bucket had a series of samples taken from it to provide updated dump weights. The goal was five samples each and the results were as follows:
Table 4-6: Average bucket dump weights used for Keysville trial

<table>
<thead>
<tr>
<th>Bucket</th>
<th>Average Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overs</td>
<td>.937</td>
</tr>
<tr>
<td>Accepts</td>
<td>15.85</td>
</tr>
<tr>
<td>Fines</td>
<td>.88</td>
</tr>
</tbody>
</table>

Four separate runs were conducted over the three days, May 29, May 30, and May 31, 1996. They were grouped by day with May 30 further divided into AM and PM. This was done mainly because each of these periods were continuous. The computer was programmed to download the cumulative totals every ten minutes during each run. During the runs, it was noticed that the computer was miscounting the number of fines bucket cycles. Therefore, actual fines bucket cycles and the corresponding computer counts were recorded during seven ten minute periods over the course of the trial. A regression was performed on the data to determine if a simple formula was available to adjust the fine bucket counts. Figure 4-2 shows the resulting regression line with the formula and R squared value. This formula was used to adjust all fine bucket counts. The underlying problem, one of transducer sensitivity, was corrected before the Armour trial.

Daily Runs

The first comparisons made were between run averages and sample averages for each run. This was done to ensure the trends were similar. It is important to note however, that for safety reasons the samples were taken after the mills fines
Figure 4-2: Fine Count Regression: Computer Count vs Actual Count

Equation and R Square

\[ y = 0.4608x + 5.21 \]

\[ R^2 = 0.878 \]
screen, while the monitor collected chips before the screen. Therefore, differences with the monitor reporting greater fines production than mill samples are expected. The overall trend is what is important. Tables 4-7 and 4-8 show the average percent for each size class for the sorter (Table 4-7) and the samples taken during that run (Table 4-8).

Table 4-7 : Monitor Run Averages

<table>
<thead>
<tr>
<th>Sorter Runs</th>
<th>May 29</th>
<th>May 30 AM</th>
<th>May 30 PM</th>
<th>May 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overs</td>
<td>7.07 %</td>
<td>5.90 %</td>
<td>3.96 %</td>
<td>6.62 %</td>
</tr>
<tr>
<td>Accepts</td>
<td>83.18 %</td>
<td>80.94 %</td>
<td>78.21 %</td>
<td>80.66 %</td>
</tr>
<tr>
<td>Fines</td>
<td>9.76 %</td>
<td>13.16 %</td>
<td>17.83 %</td>
<td>12.72 %</td>
</tr>
</tbody>
</table>

Table 4-8 : Sample Averages Taken During Each Monitor Run

<table>
<thead>
<tr>
<th>Samples</th>
<th>May 29</th>
<th>May 30 AM</th>
<th>May 30 PM</th>
<th>May 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overs</td>
<td>7.52 %</td>
<td>7.06 %</td>
<td>9.04 %</td>
<td>13.51 %</td>
</tr>
<tr>
<td>Accepts</td>
<td>81.95 %</td>
<td>82.48 %</td>
<td>78.75 %</td>
<td>78.22 %</td>
</tr>
<tr>
<td>Fines</td>
<td>10.52 %</td>
<td>10.46 %</td>
<td>12.21 %</td>
<td>8.72 %</td>
</tr>
</tbody>
</table>

Graphing the daily averages shows that there are comparable trends in the overall averages for each run between the monitor and the samples. (Figure 4-3)
Figure 4-3: Samples vs Monitor Percent of Total by Day
Run Charts

Since the overall goal was to develop a prototype capable of establishing management data, size class percentages were charted for each ten minute interval to form a continuous representation for each run. (Figures 4-4, 4-5, 4-6, and 4-7)

What is interesting about these graphs is that not only can chip size production be seen, but natural mill ebb and flow as well. Each run chart has at least one point where the size class percentages drop to zero. These points represented times when the mill was shut down. The most common reason for shut downs was changing rail cars at their feed hopper. There is no storage area for chips, all chips produced are dumped directly into either rail cars or trailers.

The last two run charts contain points where the fines percentage goes up to 100% while the percentages of oversize and accepts drop to zero. This usually was indicative of fines trickling through the system after the mill shut down. This occurred when the chipper feed was stopped but the transfer conveyors and screens continued to operate. Fines that were suspended on the slope sheets and conveyor transfer points may have broken loose during these periods and skewed the results. The fact that fines count was not accurate was also a factor in this phenomenon.

The interval input into the computer not only allowed continuous percentages, but sorting rate as well. The number of counts for each bucket was used to calculate a sorting rate in tons per hour for each interval. This also reflected mill flow. (Figure 4-8)
Figure 4-4: Monitor Chip Distribution by Interval for May 29
Figure 4-6: Monitor Chip Distribution by Interval for May 30 PM
Figure 4-7: Monitor Chip Distribution by Interval for May 31
Figure 4-8: Sorting Rate in Tons Per Hour Per Data Interval for all Four Runs
Chapter 5. CONCLUSIONS

As stated earlier the main goal of this project was to develop a prototype that was capable of continuous sampling for the purpose of establishing management data for chip producers. This was accomplished. The prototype withstood harsh conditions at the Keysville trial and adequately recorded the chip size classes and mill throughput rates during its more than 17 hours of run time. The data that this machine is capable of producing will prove to be invaluable to the manufacturers and end users of wood chips.

IMPROVEMENTS

Durability

This prototype performed extremely well in the environments to which it was exposed. However, as a prototype, this monitor was never meant to be used permanently. Its sole purpose was testing the concept of this type of machine. Since it is apparent that this design is extremely functional, it can be adapted by chip mill manufacturers and mill operators to best serve particular applications. Permanent installations can be engineered to eliminate the need for chip transfer conveyors from the screen to the tip buckets.

Computer Program

The computer program that controlled the monitor was sufficient for testing purposes, but lacked the ability to show this data in real time. All results were calculated after the tests. To be a true process control tool, a program that continuously charts
breakdown by interval in the form of control charts will be essential. This type of program is infinitely adaptable to a wide range of scenarios, it can be improved to include an alarm system to warn plant operators when the production of fines and oversize chips move beyond pre-determined control limits.

FUTURE RESEARCH

Aside from the improvements listed above, research should continue on this monitor. As many different scenarios should be tested as possible. One area of particular interest would be using this monitor to develop a system of pay incentives for high quality chips. This monitor could be used as proof of quality and therefore encourage all manufacturers to take steps to constantly improve their product to realize the highest return on their investments.
LITERATURE CITED


Williams, F.M. Date Unknown. Chip Classification Bulletin No. XII. Williams Apparatus Co. Watertown, N. Y.
VITA

The author, son of Carl and Marian Auel was born November 27, 1966, in Arlington, Virginia. He completed his Bachelor of Science degree in Forestry in 1992, at Virginia Tech, and decided to continue his Forestry education there. He pursued a Master of Science degree in Forestry, and completed it in September 1996.

John B. Auel