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PROOF OF CONCEPT TEST AND EVALUATION
(PILOT/MILL TESTING) OF LASENTEC REFINING SENSOR

FINAL REPORT

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N O T I C E

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**DEVELOPMENT AND EVALUATION
OF THE
LASENTEC REFINING SENSOR**

PROJECT DESCRIPTION AND OBJECTIVE

On-line measurement of refining development is of vital concern to the papermaker since its control directly affects the uniformity of the product, drainage, drying and energy consumption. The current methods of monitoring fiber development during refining rely on secondary measures such as: drainage rate, either measured off-line as Canadian standard freeness, or on-line with a number of commercial sample and test devices; energy consumption at the refiner; or changes in vacuum on the paper machine.

To overcome these limitations of the existing technology, this project was designed to evaluate the use of a new type of sensor to monitor fiber development during refining. This sensor, a Lasentec Scanning Laser Microscope (SLM), is currently used as a particle size analyzer for slurries. The sensor will be described in more detail later. The use of this sensor had been successful in the laboratory. This project, was to establish this instrument as an in-line means to directly monitor refining.

OBJECTIVE

This project was designed to evaluate the Lasentec Scanning Laser Microscope as a means of monitoring fiber development during refining, as indicated by handsheet physical strength properties. The proposal included the evaluation of the sensor for conventional refining and TMP applications.

The conventional refining program was outlined as follows:

1. Verification of Previous Data.

Duplicate the results of the work done by Lasentec at the University of Washington in a Valley beater and described by Mustonen, et. al¹.

¹Mustonen, M., Hanseler, J. and Preikschaht, E., "'In-Line' Measurement of the Refining Effect - An Important New Tool in the Pulp and Paper Industry", presented at the 19th Annual Meeting of the Fine Particle Society, 1988, Particulate Powder Technology, July 18-22, 1988.

2. Pilot Scale Study

Install the sensor in a continuous refining system based around a 16" Beloit-Jones Double-D refiner. In this phase, various process variables and pulp types would be evaluated.

3. Commercial Application

Install the sensor in a commercial mill and monitor results in a plant setting.

The TMP program was outlined as follows:

1. Laboratory Evaluation

Perform laboratory tests to establish a correlation between SLM readings on TMP pulp and handsheet strength properties.

2. Pilot Scale Study

Install the sensor in the Herty pilot scale 12" Sunds Defibrator for the evaluation of various process variables.

3. Commercial Application

Install the sensor in a commercial mill and monitor results in a plant setting.

The results of the laboratory testing and pilot scale conventional refining trials showed that the sensor was sensitive to fiber changes caused by refining as well as process variables such as consistency or flow rate. The project shifted from providing a testing facility whose objective was to determine if the instrument was ready for installation in a mill environment to more fundamental and developmental goals. The ultimate goal was still to determine if the instrument is capable of monitoring fiber development in an in-line environment.

BACKGROUND

The purpose of refining is to enhance the properties of individual fibers in the pulp slurry by means of mechanical treatment. A direct measure of the changes taking place in the individual fibers could provide direct control of fiber development and therefore, overall pulp quality. The on-line measurement of pulp refining is at the top of the priority list of the needs of the paper industry.

The measurement of the pulp quality of pulp slurries is a major concern to pulp and paper mills since its control directly affects the uniformity and quality of the product produced. It has been estimated that 85% of the refiners in this country are not optimized and an in-line device such as this sensor would reduce the energy required for refining by insuring that it is effectively utilized.

The Lasentec LAB-TEC 150 scanning laser microscope is an instrument which measures the size of particles in a slurry. In this end use, those particles would be pulp fibers. Changes in mean fiber diameter and the quantity of fines produced can be measured on a statistically significant basis in real time. This provides valuable information which could be used to control the refining process. The use of this instrument in this manner was described by Mustonen, Hanseler and Preikschat².

The SLM was shown to measure changes in fiber structure (Figures 1 and 2) by detecting changes in the weighted average fiber size (dWA). These fiber changes were accompanied by changes in physical properties of pulp. The suitability of this system for monitoring fiber development in-line was the subject of this investigation.

FIGURE 1 - Changes in burst, fold and tear strength of a sulfite pulp as a function of beating action (minutes of beating in a "Valley" beater).³

²Ibid.

³ Ibid.

FIGURE 2 - Test results show the changes in "weighted fiber size average" (WA), "mean size" (Msize) as a function of beating time (in minutes).⁴

SCANNING LASER MICROSCOPE

The scanning laser microscope is a proprietary technology described in detail by E. Preikschat⁵ in, "Development of a High Performance Consistency Transmitter for the Pulp and Paper Industry".

A laser beam is focused on a very small spot at high intensity, and scanned across individual fibers. As the beam scans across individual fibers, it produces back scattered light pulses which are picked up by photo detectors. The fiber size distribution is statistically determined from the classification and counting of the length of the pulse generated as the laser beam scans across individual fibers. Several versions of the SLM were used in this investigation.

LAB-TEC 150

The LAB-TEC 150 is a laboratory version of the SLM. The instrumentation is designed for use on the laboratory bench top, see Figure 3. A pulp sample is collected, and placed in the supplied beaker. The beaker is then placed into a special holder in the apparatus, a stirrer installed, and a computer guided measuring procedure is followed. As mentioned above, this is the type of unit which was used in the original study at the University of Washington.

⁴Ibid.

⁵ Preikschat, E., "Development of a High Performance Consistency Transmitter for the Pulp and Paper Industry", Washington, D.C.

FIGURE 3 -The LAB-TEC 150 system with analyzer unit and dedicated output computer.

PAR-TEC 200

Another version of the SLM is the PAR-TEC 200, a commercial in-line process analyzer for particle size measurements (Figure 4). In this set-up, both the laser diode and the detection circuitry are contained in the probe head which can be directly inserted into a beaker, Valley beater or a pulp pipe line. To obtain optimized readings, the pulp slurry has to be in motion past the measuring point so that the instrument sees a representative distribution of the whole pulp flow. The probe is installed at an angle facing into the pulp flow to use the pulp flow to keep the probe window clean. When the pulp is in a beaker, it has to be constantly stirred using a top stirring mechanism.

FIGURE 4 -The PAR-TEC 200/250 with probe head, field unit and analyzer unit.

PAR-TEC 100

Two special PAR-TEC sensors were developed by Lasentec for measuring pulp consistency, and are referred to as model PAR-TEC 100. This instrument is essentially the same as the PAR-TEC 200, except that it is also capable of measuring both mean size and the "bulk scattering" of light, an extra measurement Lasentec developed for measuring pulp concentration, (Figure 5). "Bulk scattering" is a measure of the amount of diffuse light which is back-scattered by the pulp slurry. Both of the PAR-TEC 100 sensors contained the standard Lasentec PAR-TEC SLM instrumentation, as well as a special modification, designed to reduce the influence of flow on the measurements.

FIGURE 5 -The PAR-TEC 100 with bench top unit, dedicated computer and probe unit.

PAR-TEC MEASUREMENTS

In the standard configuration, the PAR-TECs are programmed to determine four mean size measurements. Depending on the application, any one of these measurements can be used to monitor particle sizes in a particular process. These measurements are:

1. Scanned Counts -- raw counts as they are accumulated by the PAR-TEC.
2. Spherical Equivalent (SpEq) Diameter -- a corrected distribution based on the assumption that the Scanned Counts represent a random distribution of chords of spherical particles.
3. Volume diameters (from SpEq) -- a weighing of each channel by the cube function of each radius from the spherical equivalent contribution.
4. Volume diameters (from Scanned Counts) -- a weighing of each channel by the cube function of each radius from the scanned counts distribution.

The PAR-TEC 100 and PAR-TEC 200 report the particle size distribution either as a histogram (Figure 6), by plotting the number of particles counted for each particle size channel or category, or as a line plot of counts in each channel (Figure 7). The shape and distribution of the data is described with standard statistics. The scan count mean size or "PAR-TEC mean size" was the value evaluated as a means to monitor refining development.

Sample ID :		Cycle Time	: 2.2 sec.
Date :	02/16/90	Avg Counts/Cycle :	7483
Time :	14:04:45	Averaged last 10 cycles	
Cycles :	11		
Scaling :	1.00		

Scanned Counts Mean : 46.3 microns
SDev : 39.8

FIGURE 6 - Particle size distribution displayed as histogram

Sample ID :	REFINER TEST	CF Code :	
Date :	06/05/91	Cycle Time	: 1.0 sec.
Time :	15:16:17	Avg Counts/Cycle :	8065
Cycles :	10	Averaged last 10 cycles	
Scaling :	1.00		

Scanned Counts Mean : 44.7
Standard Deviation : 41.8

FIGURE 7 - Particle size distribution displayed as a line graph

POTENTIAL ENERGY SAVINGS

Pulp and papermaking operations are among the most energy intensive of all industrial processes. One of the most energy intensive aspects of the industry is the refining operations. There are approximately 8000 paper machines in the world. Seventy-five percent are large enough to require a substantial amount of instrumentation and about 2000 of these are in the United States. There is a need for about 5 pulp quality sensors per machine. It was projected that these sensors would cost \$10,000 to \$20,000 because of the micro-miniaturization, solid state design and large production quantities. This cost would be far out weighed by the potential energy savings of 0.07 QUADS which could result from:

- (1) improved quality by better monitoring pulp quality throughout the process,
 - (2) improved production rate, due to fewer sheet breaks, downtime and off-grade products with better quality pulp,
 - (3) improved refiner control by immediate quality data.
- Normal testing procedures require off-line testing of pulp or product samples, with the inherent lag time.

EXPERIMENTAL STUDIES

LABORATORY VALLEY BEATER STUDIES

A one-pound laboratory Valley beater was used for preparing wood pulp samples for the evaluation of the SLM. For the first two studies, samples were taken for a 5-point hardwood beating curve and a 7-point softwood beating curve. Each sample was tested for Canadian standard freeness, Kajaani fiber length, bursting strength, tensile strength and tearing resistance. LAB-TEC 150 and PAR-TEC 200 measurements were both taken in a beaker at 1.2% consistency. Sufficient pulp was taken at the middle point of each curve for Bauer McNett classifications and additional testing at each classification point. The laboratory tests had to be repeated because the LAB-TEC instrument results indicated that repairs were required, as the output was skewed towards the smaller size counts, see Figure 8.

FIGURE 8 - LAB-TEC 150 RESULTS - FEBRUARY, 1990 TRIAL

During the repeat study, the PAR-TEC 200 Probe was mounted directly into the Valley beater (Figure 9). The weight was removed from the bed plate to reduce beating during the PAR-TEC measurement. Each of the mid-point samples was taken for a Bauer McNett classification. Each classification fraction was also measured with the LAB-TEC and PAR-TEC instruments and the Kajaani 100.

FIGURE 9 - PAR-TEC 200 INSTALLED IN VALLEY BEATER

A final 3-point Valley beater study was conducted on softwood pulp. Each of the 3-points were tested as before. Each Valley beater point was also fractionated and PAR-TEC measurements were compared with Canadian standard freeness, Kajaani fiber length and coarseness on those fractions. For this testing, 100 grams of pulp was removed for fractionation at each sample point. This created a very low level in the beater for the last point and the poor resulting circulation may have affected pulp strength development.

PILOT SCALE REFINING STUDIES

SINGLE PROBE STUDY

The Herty initial pilot refiner circuit, used in June 1990, is shown in Figure 10. This consisted of a 4"-10 foot section of clear PVC pipe ahead of a 16" Beloit-Jones Model 4216 Double-D refiner, with a probe port just before the refiner. On the exit side of the refiner, were three additive ports and an in-line mixer. From here, it was a straight horizontal 9 foot run through another section of 4" clear PVC pipe to the second probe position. A Fischer & Porter flow controller was used to maintain flow at 4.5 ft/sec (180 gpm). Samples are taken from the drain line following the flow controller. The PAR-TEC 200 Probe was mounted 25° from the normal, facing into the flow on the side of the 4" pipe, to avoid the effects of material stratification such as air on top and contaminants on bottom of the pipe. Refiner plates D58707002 and D58707003 were used for refining softwood pulp.

FIGURE 10 - INITIAL REFINING CIRCUIT

Softwood Pulp

The single PAR-TEC 200 Probe available was mounted after the refiner. Pulp was disintegrated in a Black-Clawson hydropulper and transferred to a 7000-gallon chest where consistency was adjusted to 2.5%. The softwood pulp was refined in a single pass through the refiner, with no recirculation. Following the single pass, the pulp was sewered. At a flow of 4.5 ft/sec, samples were taken at 5 different power settings, ranging from 0 (no load) to 121 kWh/t. Each PAR-TEC measurement consisted of duplicate readings, taken one right after the other. A pulp sample, for other tests, was taken when the second PAR-TEC reading began. Each power setting was duplicated, for a total of 10 samples and sets of readings.

The samples taken from the drain line were tested for Canadian standard freeness, Kajaani fiber length, bursting strength, tensile strength, and tearing resistance. The PAR-TEC 200 was used to make dynamic measurements, with the probe in-line. Samples were also tested off-line, in a beaker, with the probe installed as shown in Figure 10. The two sets of measurements were taken to compare the 2 measuring configurations. The probe was checked and focus adjusted using a reference PVC solution.

For wood pulp applications, the sensor only counts pulses in 2 opposing 90° quadrants of the circular scan path, in an attempt to remove the influence of flow on the measurements. For softwood pulp, the active scanning areas of the sensor were oriented parallel to the pulp flow.

Hardwood Pulp

The refiner plates were changed to a finer bar pattern, D58707040 and D58707041. The probe was mounted with the active scanning areas across the flow for the hardwood pulp. Pulp preparation and testing was the same as for the softwood pulp, except the 5 net power readings ranged from 0 (no load) to kWh/t.

TWO PROBE STUDIES

In order to accurately monitor changes in the pulp caused by refining, two probes would be required, one before the refiner and one after the refiner. The first step in this evaluation was to install two, PAR-TEC 100 Probes, in the refining circuit in similar flow conditions, and then refine the pulp, see Figure 11, i.e. both probes were before the refiner, for this trial in June 1991.

FIGURE 11 - HERTY REFINER FLOW LOOP, REFINER AFTER ALL PROBES

With the pulp recirculating to the stock chest, the pulp was refined to 5 different freeness levels, namely 704 mL(no load), 582 mL, 479 mL, 355 mL, and 269 mL. At each freeness level, the pulp was circulated for 10 minutes, with the refiner backed out before taking PAR-TEC measurements, and sampling for freeness and handsheet strength properties. PAR-TEC measurements were taken at 3.8 ft/sec because flow loop trials indicated this to be a good flow to get repeatable results from both probes.

The results were very poor, but the laboratory results were encouraging, so another trial was conducted. For the trial in July 1991, the pulp, at 4% consistency, was refined in a recirculation mode to 4 freeness levels; 1) no-load, 2) 560 mL Canadian standard freeness, 3) 460 mL Canadian standard freeness, and 4) 346 mL Canadian standard freeness. Measurements were made, with the refiner backed out at flow rates of 2.5 and 3.8 ft/sec. Before making measurements the standard software was used to adjust the

particle size distribution curves reported by the two probes to give the same reading on unrefined pulp. The size distribution of Probe 1 is displayed in Figure 12 and the size distribution of Probe 2 is shown in Figure 13. The scaling procedure included eliminating the lowest 7 channels and the top 8, in order to concentrate on the center of the curve where the greatest number of counts are located, and adjusting individual channel counts and proportioning the results of the entire curve. The result of this adjustment is shown in Figure 14.

PAR-TEC Particle Analysis by Scanned Count : Percent Per Channel

Sample ID	: none	CF Code	: TEST
Date	: 09/30/91	Cycle Time	: 1.0 sec.
Time	: 12:32:06	Avg Counts/Cycle	: 5955
Cycles	: 10	Averaged last 10 cycles	
Scaling	: 1.00		

Scanned Counts Mean	: 57.9
Standard Deviation	: 47.6

FIGURE 12 - Probe 1 Output Before Channel Adjustments

PAR-TEC Particle Analysis by Scanned Count : Percent Per Channel

Sample ID	: CALIBRATION	CF Code	: TEST
Date	: 09/30/91	Cycle Time	: 1.0 sec.
Time	: 12:28:42	Avg Counts/Cycle	: 6093
Cycles	: 10	Averaged last 10 cycles	
Scaling	: 1.00		

Scanned Counts Mean	: 53.0
Standard Deviation	: 45.7

FIGURE 13 - Probe 2, No Scaling

PAR-TEC Particle Analysis by Scanned Count : Percent Per Channel

Sample ID	: SCALED	CF Code	: TEST
Date	: 09/30/91	Cycle Time	: 1.0 sec.
Time	: 14:35:11	Avg Counts/Cycle	: 5906
Cycles	: 10	Averaged last 10 cycles	
Scaling	: 0.95		

Scanned Counts Mean	: 53.2
Standard Deviation	: 46.9

FIGURE 14 - Probe 1 After Channel Adjustments

Readings were taken both with the corrected values and with the uncorrected values. A portion of each batch of refined pulp was stored separately for dilution to 0.2% and further testing. Pulp from each refining level was diluted to 0.2% consistency and passed through the flow loop. The refiner was removed from the flow loop for these measurements. Mean size readings on the diluted pulp were taken with no scaling factors or channel adjustments for each of the dilute pulp slurries, at 2.5 and 3.8 ft/sec, as for the refining trials. "Bulk Scattering" was measured for the 346 mL Canadian standard freeness sample and the No-Load sample, but because the values were so small (0.2 to 0.4 μ) no other "bulk scattering" readings were taken.

In the fourth refining trial, September 30 - October 1, 1991, the PAR-TEC 100 Probes were installed, one before and one after the refiner in positions 1 and 3, see Figure 15. Refining was done in a harsher one-pass mode. Refined pulp was again stored for testing at lower consistencies. Using the standard software, the general shape of the particle distribution curves reported by the probe before the refiner and the probe after the refiner were adjusted to give the same readings on the unrefined pulp. With the unrefined pulp, the same calibration factors were suitable for pulp at 3.3% and 1.0% consistency. A new focal position and calibration and scaling factor were required when the pulp was diluted to 0.6% and 0.2% consistency. At all four consistencies, PAR-TEC readings were taken with and without scaling factors. "Bulk scattering" was also measured.

Figure 15 - HERTY REFINER FLOW LOOP, REFINER BETWEEN PROBES

The final refining trial, October 22-23, 1991, was conducted at two levels of refining intensity. Refining intensity was adjusted by changing the flow rate and refiner power setting to give two refining intensities. Refined pulp was stored in separate chests for dilution and testing at lower consistencies, as described above.

FLOW LOOP STUDIES

It became apparent during the refining trials that the performance of the PAR-TEC sensors in a pulp slurry, without refining, needed to be investigated.

SINGLE PROBE STUDY

The first flow loop was designed to evaluate the influence of variables such as flow, probe position into the pulp flow, and consistency on a single PAR-TEC 200's readings without refining the pulp. This flow loop consisted of a 10 foot section of PVC pipe, a centrifugal pump and a 1500-gallon chest (and a single probe mounting.)

Flow was controlled with a Fischer & Porter flow controller installed after the probe and before returning the stock to the 1500-gallon chest.

TWO PROBE STUDY

The second flow loop was designed for evaluating additional parameters, using the two PAR-TEC 100 sensors.

Before the July, 1991, refiner study, a flow loop using the same piping as for the refiner study was set up, except that the refiner was not included, see Figure 11. There were two Turbulent positions, Position 1, on a vertical section of pipe, opposite the discharge of the stock supply pump impeller and Position 2, after a 90° bend in the pipe. The two Laminar positions, Positions 3 and 4, were located after a 9 foot straight section of pipe. Except for the section immediately after the pump, the piping was horizontal, and the probes were all mounted on the side of the pipe in a horizontal plane.

This flow loop was used for evaluating refined and unrefined pulp at various flow rates from 2.1 to 5.0 ft/sec, the turbulent and laminar flow positions, and consistencies from 0.2 to 4.6%.

The refined pulp from the fourth refining trial was stored for testing at several consistencies as well as for the effect of several additives on the measured values. For this trial, Probe 1, the particle size distribution curve and the reported mean size values were adjusted to match those of Probe 2 at the 4 consistencies measured namely 3.3, 1.0, 0.6 and 0.2%. As part of the calibration procedure, the lowest 7 channels and the top 8 channels were excluded from the measurement to focus the calculation on the center of the curve where the majority of the

particles were being counted. The no-load pulp was used for the calibration procedure. The same calibration factors were used for 3.3 and 1.0% consistency. Separate calibrations were required at 0.6% and 0.2% consistency. For each calibration, focus had to be adjusted to obtain the optimum focus reading at that particular consistency. Measurements were made, both with the calibration factors (scaled results) and without additional calibration or channel exclusion (not scaled results).

With the no-load pulp sample at 0.2% consistency, 1.0% alum, based on O.D. pulp, (dissolved in hot water) was added to the stock chest. Measurements were made during the 15 minutes allowed for the mixture to stabilize. Readings were taken without calibration or scaling factors, except for the last two measurements which used the factors determined for the 0.2% consistency pulp.

Dry clay was added to the chest, to achieve a concentration of 10% clay on O.D. pulp. Again, during the mixing time, measurements were made with the unscaled probes. The last two measurements, made 15 minutes after the addition of the clay, were made with the same calibration factors as used for the 0.2% consistency pulp.

Sufficient quantity of a 1.0% retention aid stock mixture (Percol 178) was added to the pulp slurry to give a concentration of 0.02% retention aid on stock. During the mixing, the unscaled probes continuously made measurements. It was noticed that the mean size value continually decreased as the mixing continued. After 15 minutes of mixing, and a final two measurements with the scaled probes, an additional 0.02% retention aid was added to the pulp slurry. Continuous readings were again performed, with the final two readings made with the scaled probes. A final addition of retention aid and measurements concluded the testing with the no-load pulp stock.

The wood pulp refined at 123 kWh/t was measured using the same factors and focus procedure as above at 1.0, 0.6 and 0.2% consistency. At all 3 consistencies, the readings were lower than the unrefined pulp. To eliminate the effect of focus adjustment, future tests were conducted without further focus adjustment. The 41 and 82 kWh/t pulp were measured at 1.0, 0.6 and 0.2% consistency. Alum, clay, and 3 levels of retention aid were added to the 0.2% 82 kWh/t pulp and measurements made as above.

NYLON FIBER STUDIES

Four samples of nylon fibers, of a known fiber length and diameter, were obtained from Microfibers, Inc, Pawtucket, R. I. These samples were of two fiber diameters, namely 19 μ and 47 μ . Each of these samples were cut to two fiber lengths, 1.27 mm and 4.57 mm. These samples were then dispersed in water at several consistencies, ranging from 0.1 to 1.0%, and measured with the PAR-TEC 200 Probes. Two component mixtures of all of these fibers were prepared, as shown in the table below. These mixtures were then measured in a beaker at 0.6% consistency.

Table 1 Nylon Fiber Mixtures								
Mixture	Component				Percentage Fiber A			
	Fiber A		Fiber B					
	Length mm	Diameter μ	Length mm	Diameter μ				
I	1.27	19	1.27	47	0	33	67	100
II	1.27	19	1.27	47	0	33	67	100
III	4.57	19	4.57	47	0	33	67	100
IV	4.57	19	4.57	47	0	33	67	100
V	1.27	19	4.57	19	0	33	67	100
VI	1.27	47	4.57	47	0	33	67	100

TMP EVALUATION

The results with conventional pulps showed that the sensor was not sensitive to changes in fibers caused by refining, especially at 4% consistency. It was decided that very little effort should be devoted to TMP applications, and this part of the project should be abandoned.

TMP SHIVES

As long as we had the sensors, we decided to perform a quick laboratory study on the response of the sensor to shives in TMP pulp.

Two samples of TMP pulp were received from Bear Island Paper Company, for an initial study of the effect of shives content on the mean size value. One sample was collected from the discharge of the secondary refiner, and the second was collected from the feed to the thickener. A Pulmac Shive Analyzer was used to determine the shive content of each of the pulps, and also to extract some of the shives from a sample of the secondary refiner pulp, for addition to the thickener feed sample.

As determined above, the pulps were diluted to 0.2% consistency before PAR-TEC measurements were made. Measurements were made of the original pulps, and combinations thereof. Measurements were also made of the thickener feed sample with the addition of natural and "synthetic" shives. The synthetic shives were samples of the 4.6 mm long, 47 μ diameter nylon fibers used above, which the sensor had been shown to be capable of sensing. The natural shives were the shives extracted with the Pulmac Shive Analyzer, for the purpose of adding them in controlled quantities to the thickener feed sample.

RESULTS AND DISCUSSION

VALLEY BEATER RESULTS

LAB-TEC 150

In the first laboratory trial series, the LAB-TEC 150 readings did not show a good correlation to Canadian standard freeness or physical strength results. It was also noticed that the particle size distribution was very skewed, towards the smaller channel counts, see Figure 8. The instrument was returned to Lasentec for servicing.

Upon receiving the instrument back from Lasentec, a second series of tests was conducted. Measurement of the particle size distribution was more typical of a hardwood or softwood pulp. Results of the second series of tests are shown in Figures 16, 17, 18 and 19. It can be seen that the results do not show an acceptable correlation between LAB-TEC 150 readings and pulp strength or freeness. Figure 18 does show a general relationship.

LAB-TEC Comparison to C. S. Freeness

Figure 16
Softwood Beating

Figure 17
Hardwood Beating

In order to gain a better scientific understanding of which changes in fiber morphology the SLM is detecting, one refined pulp sample was classified into four Bauer-McNett fractions. LAB-TEC 150 and

S22-BTL.CHT

H21-BTL.CHT

Kajaani measurements were taken and are shown in Figures 20 and 21. For the softwood pulp, there is a significant parallel relationship, although the offset varies with screen mesh. For hardwood pulp, the results were not as good. The sensor readings paralleled Kajaani readings for the middle fractions, but not the whole pulp or 100 mesh fraction.

Since the objective of the program was to establish the use of the SLM as an in-line tool for monitoring fiber development, it was decided not to pursue further test work with the LAB-TEC 150.

PAR-TEC 200

The first Valley beater trial in February 1990 with measurements made in a beaker, was inconclusive. The PAR-TEC results are shown in Figures 22, 23, 26 and 27. It can be seen that in the early stages of beating, the PAR-TEC mean size generally follows Canadian standard freeness with the softwood pulp, (Figure 22) and strength development, (Figure 24). For the hardwood pulp, there is no clear relationship, as seen in Figures 23 and 27.

PAR-TEC Comparison to C. S. Freeness

Figure 22
Softwood Beating
February 1990

Figure 23
Hardwood Beating
February 1990

Figure 24
Softwood Beating
June 1990

Figure 25
Hardwood Beating
June 1990

In the second Valley beater trial in June 1990, mounting the PAR-TEC 200 Probe directly in the beater improved the results as seen in Figures 24, 25, 28 and 29. The PAR-TEC mean size results generally follow the development of the physical strength properties of burst index and tensile index, for the softwood pulp (Figure 28). The results for the hardwood pulp were again found to be less promising (Figure 29). For hardwoods, the sensor is not indicating as significant a change in particle size. This may be the instrument, or it may reflect actual fiber morphological behavior.

PAR-TEC Comparison to Pulp Strength

Figure 26
Softwood Beating
February 1990

Figure 27
Hardwood Beating
February, 1990

Figure 28
Softwood Beating
June 1990

Figure 29
Hardwood Beating
June 1990

The investigation of individual Bauer-McNett pulp fractions for one refined sample was repeated for the PAR-TEC 200, in order to gain additional understanding of which fiber elements this sensor is detecting and monitoring. The results are shown in Figures 30-33. The relationship between PAR-TEC sensor readings and C.S.F. readings, (Figures 30 and 31) is not consistent. The whole pulps and 14 or 20 mesh sample readings show a good correlation. The other fractions are less clear to interpret. Kajaani fiber length,

Bauer-McNett Classifications PAR-TEC Results

Figure 30
Softwood Pulp
February 1990

911-CLP.CHT

Figure 31
Hardwood Pulp
February 1990

H11-CLP.CHT

Figure 32
Softwood Pulp
June 1990

922-CLP.CHT

Figure 33
Hardwood Pulp
June 1990

H21-CLP.CHT

Figures 32 and 33, is reasonably good for the softwood 8, 14, 28 and 100 mesh fractions. The softwood and hardwood whole pulps and hardwood 100 mesh correlation is less clear.

The laboratory results indicated there is an overall response of the PAR-TEC instrument to changes in fiber dimensions during refining, eg. Figure 28.

Following the November, 1990 Advanced Sensors Meeting, it was decided to repeat the Valley beater tests in order to obtain a better understanding of how the PAR-TEC 200 results compare to conventional methods of monitoring refining.

The approach used was to beat softwood pulp in a Valley beater to produce a three point beater curve and to compare PAR-TEC measurements on those samples with Canadian standard freeness, tensile and tear strength. Each Valley beater point was fractionated and PAR-TEC measurements were compared on those fractions with Canadian standard freeness, Kajaani fiber length and coarseness.

Figure 34 shows very good overall correlation between Kajaani fiber length (arithmetic average) and PAR-TEC 200 mean size results as the pulp is beaten. As the mean Kajaani fiber length decreases, the PAR-TEC readings increase in a linear manner. This would indicate that as the fibers are beaten, the Kajaani detects a shortening of the average pulp fiber length, while the PAR-TEC 200 detects increased surface.

The question of what the sensor is detecting beyond fiber length is at least partially answered in Figure 35, which plots the PAR-TEC readings vs. Kajaani fiber length, and identifies the three individual levels of refining. When each of the individual Bauer-McNett fractions for each beater point is clearly identified, it can be seen that there are at least two separate relationships. At zero minutes, the Kajaani and PAR-TEC relationship is different from the correlation at either 18 or 28 minutes beating.

At zero beating, the PAR-TEC and Kajaani readings closely correlate, at each of the 8, 14, 28 and 100 mesh fractions, as seen in Figure 36. In effect, the PAR-TEC is acting as an in-line Kajaani sensor for these individual fractions, if the proper scaling or calibration factor is used. Figure 37 also shows the same excellent relationship between fiber length and PAR-TEC at 28 minutes of beating. Comparing the two figures at equal fiber length (e.g. 1.5 mm), it can be seen that there are added surfaces being detected after 28 minutes beating (mean size 70) versus at zero minutes beating (mean size 64). These added surfaces could include fibrillated fibers, which contribute to final sheet properties.

In Figure 38, it can be seen that there is a reasonable correlation between the Kajaani Coarseness results and PAR-TEC mean size, as Valley beating progressed. This indicates that as the fibers were swollen during beating, both of these measures increased.

Figures 39 and 40 show the same excellent correlation between coarseness and PAR-TEC for each Bauer-McNett fraction that was exhibited for fiber length, both for unbeaten and beaten pulp. At equal levels of coarseness the PAR-TEC is detecting more surfaces as beating proceeds, as can be seen by comparing the same level of coarseness on both graphs.

It can be seen in Figure 41 that Canadian standard freeness shows a large drop in value (727 to 320 mL) for the three beater points evaluated, and that there is a strong inverse correlation between Canadian standard freeness and mean size.

When Canadian standard freeness is used to evaluate the Bauer-McNett fractions of each Valley beater run, it is found that there is no relationship shown between the Canadian standard freeness and mean size. Figure 42 highlights this difference. This shows the large difference between the whole pulp freeness (550 mL) and the individual fractions (725 to 755 mL) at 18 minutes of beating. A similar graph was found at 28 minutes of beating to illustrate that for individual fractions, Canadian standard freeness and PAR-TEC do not correlate. These results are in line with the knowledge that Canadian standard freeness is highly dependent on fines. In-line drainage sensors do not produce the evidence of fiber development that the PAR-TEC is showing for the individual fractions, because of the great influence of fines on these devices.

It can be seen in Figure 43 that there is generally a good correlation between PAR-TEC mean size and all of the properties plotted. One sample, in all of the plots which stands out, was considered as being questionable, possibly because of the low level in the beater for the final beating point.

Figure 43
Valley Beater Study
Mean Size Strength Comparison

FLOW LOOP STUDIES

Both the PAR-TEC 100 and PAR-TEC 200 were used in flow loop studies.

PAR-TEC 200

The primary goal of the first study, with a single probe, was to determine if flow rate, consistency, and probe position had a significant influence on a single PAR-TEC 200 mean size measurement. Ideally, there should be no effect, and the PAR-TEC readings should remain constant.

Figure 44 indicates that flow rate does have an effect on a single probe output at the 1.65% to 2.61% consistencies tested. From 1.65% to 2.32% consistency, there was no effect of consistency on PAR-TEC readings. There was an effect at 2.6% consistency, as seen in Figure 45.

Figure 44

Figure 45

Consistency Effect

Figure 46

Position Effects

Figure 46 indicates probe position can have an effect. For future work, one particular position was selected. The position of 0.5 to 1 inches from wall gave the highest response readings. In a commercial application, position should only have an influence when the probe is first installed. It would have to be installed so the value which gave the best response to refining was achieved.

As testing progressed, it was found that the probe was very sensitive to focus adjustment. Part of the set-up procedure includes a display screen with peak count value. Focus adjustment is made until the maximum value is achieved. When the focus was checked after making a process adjustment, such as changing flow rate, it was often found that the focus had to be readjusted. For each of the last 14 samples, the PAR-TEC mean size was checked after the change in process variable, and again after the focus adjustment. The results are shown in Figure 47. It can be seen that there can be large changes in apparent particle size by changing the focus.

PAR-TEC 100

The previous study evaluated a single PAR-TEC 200 Probe and it was found that flow rate and consistency did effect the readings. The next study evaluated the response of two similar PAR-TEC 100 Probes to identical pulp and the process variables, flow and consistency, to determine if both probes were responding in an equal manner.

The two sensors were installed and tested in a single flow loop in which pulp was circulated. Figures 48 and 49 show the influence of flow rate and consistency on mean size. These figures show that both flow rate and consistency have an effect over the range of flows and consistencies measured. Figure 45 shows the results from Probe 1 when it is mounted in position 1 (turbulent). Figure 49 shows the results from Probe 2 when it is mounted in position 3 (turbulent - see Figure 11).

Scaled Results
P1M5CONS.DRW

Scaled Results
P2M5CONS.DRW

There would be only one horizontal line, if flow rate and consistency had no effect on the output. The purpose of using two probes, is to eliminate this effect. Figure 50 combines the results of Figures 48 and 49 by subtracting the mean size value from Probe 2, position 3, from the mean size value of Probe 1, position 1, to produce a delta mean size result, at each of the different flows and consistencies tested. This is measuring the differences between the two signals, which should be zero. It can be seen that the only place where the difference is zero is with conditions used for calibration. At all other consistencies and flow rates the signals did not zero out.

From these three figures, it can be seen that at 3% and 4% consistency, there is an influence of flow and consistency on the mean size and delta mean size results. At any given flow rate, the mean size value can change due to a change in consistency. This change is not constant with probe. It can be seen that changing the consistency from 3 to 4%, the mean size value from Probe 1 decreased (Figure 48), while it increased for Probe 2 (Figure 49). These results indicate that using a two probe system has not eliminated the effect of these process variables, flow and consistency.

With any one probe, the signals are reproducible. The measurements taken at the beginning of the flow tests and at the beginning of the corresponding refiner tests were both taken at the same consistency and flow rate, and it was seen that the results are the same.

BULK SCATTERING

Figures 51 and 52, plot the "bulk scattering" results from the probes. The effect of flow rate on "bulk scattering" is less than the effect on mean size, (Figures 48 and 49). However, it can be seen that there is a significant effect of consistency on "bulk scattering".

Figure 51
Effect of Flow and Consistency
on "Bulk Scattering"

Figure 52
Effect of Flow and Consistency
on "Bulk Scattering"

Figure 53 combines the results of Figures 51 and 52 by subtracting the Probe 2 results from the Probe 1 results, to produce a delta "bulk scattering" result. It can be seen that the lines are nearly horizontal, indicating that there is very little influence of flow rate on the delta "bulk scattering" results. None of the difference points zero out, but the lines are more horizontal than the delta mean size results. The lack of a zero point is due to a difference in the calibration program from the mean size calibration. The 4% "bulk scattering" results were repeatable.

Figure 53
Effect of Flow and Consistency
Probe Differences (P1-P2)

EFFECT OF ADDITIVES

For this trial, alum, clay and retention aid were added to the no-load sample and the sample refined at 87 kWh/t specific energy. The addition of alum, clay and retention aid all had an effect on the PAR-TEC mean size results. Probe readings were taken with the probes both scaled and not scaled as above. The not scaled results were much more sensitive to slurry changes due to additives and are plotted in Figure 54. Figures 55-60 show how the particle size distribution changes in both shape and location with the addition of additives. The addition of alum had almost no effect on the mean size of the no-load sample, for either Probe 1 or 2. However, the refined sample showed an increase in mean size for both probes (Figure 54). The biggest change in results occurs with Probe 2. This is probably due to the flocculation of the small particles with the alum. The influence was greatest for Probe 2 because there was more time for the flocs to re-form after the pump than at probe position 1. Possibly much of the flocculation which was measured by Probe 1 was the result of flocs which had not broken down in the pump.

Figure 54
Effect of Additives

NSADD1.DRW

The addition of clay caused a large decrease (Figure 57) in the mean particle size. It also caused a great flattening out of the particle size distribution, with a large increase in the smaller particle size counts, as seen in Figure 57.

The retention aid results (Figures 58-60) were similar to the alum results, but the results are more pronounced. The retention aid used was PERCOL 178, an ultra-high-molecular-weight, cationic, polyacrylamide-based copolymer. The retention aid has a great influence on the small particles in the slurry.

Change In Particle Size Distribution with Additives

Figure 55 No-Load

Figure 56 Alum Added

Figure 57 Clay Addition

Figure 58 First Retention Aid Addition

Figure 59 Second Retention Aid Addition

Figure 60 Third Retention Aid Addition

The influence of the addition of retention aid is visible at both probe positions, and on both pulp samples. As with the alum, the mean size results were larger at Probe 2 than at Probe 1, indicating floc re-formation as the stock moves through the pipe away from the pump. A large increase in mean size occurs immediately after retention aid addition, and the value then decreases with time. This effect is seen to differing degrees at both Probe 1 and Probe 2. For the concentrations used and the time allowed, the final mean size of any time sequence is always greater than that of the previous sequence. There was probably never enough retention aid added to saturate the system. This may indicate that the retention aid is more effective at capturing the fine clay particles in the presence of the refined pulp. One final point is that the unrefined pulp requires more retention aid to achieve the same mean size as the refined pulp. For each addition of retention aid, the mean size of the unrefined pulp gets closer to the mean size of the refined pulp. This may indicate at which point there would be no further change in mean size and therefore the system is saturated and additional retention aid has no further effect.

DISK REFINING RESULTS

The first study in June 1990 compared the in-line PAR-TEC 200 results to Canadian standard freeness, Kajaani fiber length and pulp strength properties. PAR-TEC 200 measurements were made both in-line and with the probe used in a beaker.

Figures 61 and 62 show the relation between in-line and beaker sample PAR-TEC sensor readings and C.S.F. The PAR-TEC readings do

PAR-TEC Comparison to C. S. Freeness

not show the same refining response sensitivity as does freeness, although the trends are uniform. Note also, that the in-line readings for softwood pulp refining are lower than beaker sample readings (Figure 61), while for the hardwood pulp samples the in-line readings are higher (Figure 62). This lack of consistency between in-line and beaker samples lead to the first flow loop study mentioned above.

Figures 63 and 64 compare the PAR-TEC readings with pulp strength development. For the softwood pulp refining in Figure 63, it can be seen that there is a correlation between in-line PAR-TEC results and strength development.

The hardwood results show that with the refiner plates chosen, there was very little strength development (Figure 64) for the energy applied. The results are not as consistent as with the softwood pulp but there does appear to be some correlation between strength development and PAR-TEC results.

PAR-TEC Comparison to Pulp Strength

After the second laboratory study showed that the PAR-TEC probe is sensitive to pulp changes caused by refining (Figure 43), additional pilot scale refining trials were conducted. During the second study, June 1991, two PAR-TEC 100 units were installed before the 12" Sprout-Waldron Twin-Flo refiner in positions 1 and 3 as shown in Figure 11. The pulp was refined in a re-circulation mode. Once the desired pulp freeness was achieved, the refiner was backed out and the PAR-TEC measurements made. The PAR-TEC results were poor.

The objective of the trial in July 1991 was to show that the responses of the probes correlate to different levels of disc refining energy input. Both probes were asked to measure the same pulp in order to determine if equal responses were occurring. All refining was performed at 4% consistency in a recirculation mode. Measurements were made at 4% and 0.2% consistency and at flow rates of 2.5 and 3.8 ft/sec.

Considering that both probes were measuring the same pulp (both probes were before the refiner, and the refiner was backed out during measurements), there was a significant difference between the two probes, see Figure 65. Except for the first refining point, Probe 1 measured no significant change in mean size with increased refining. Probe 2 measured a continual change for each refining value, except that the values decreased as refining progressed, which is the opposite from the laboratory tests.

Figure 66 shows that there are no significant changes in mean size due to refining when the pulp is measured at 4% consistency.

Figure 67 shows the actual responses when the measurements are made at 0.2% consistency. Figure 68 shows the actual responses normalized by correcting the initial offset of Probe 2 values from Probe 1 values. There is a much greater change in mean size value at 0.2% measurement consistency than at 4% consistency. At 2.5 ft/sec, the change is about 5μ , and at 3.8 ft/sec the change is 4.4μ . This is approximately 10 times the response at 4% measurement consistency. These results are of a similar magnitude to the responses (6μ) measured earlier in the laboratory when the pulp was beater refined to a similar Canadian standard freeness range, and measured at 0.6% consistency. It can also be seen that the PAR-TEC mean size for both probes increases with increasing refining.

Figure 67
Refining Evaluation
0.2% Consistency

R024ALL.DRW

Figure 68
Refining Evaluation
Mean Size vs C. S. F.

Probe 1 Mean Size Values Normalized
R2CSVRMD.DRW

FIGURES 67 & 68

This figure shows that there is an influence of flow rate over the two flows tested. It can be seen that the 3.8 ft/sec results have a better linear correlation to Canadian standard freeness than the 2.5 ft/sec results. For this section, we will use both PAR-TEC results measured at 3.8 ft/sec to compare the various other methods of monitoring refining.

Figure 69 shows the actual probe response to refining on "bulk scattering" normalized by subtracting the initial offset of Probe 2 values from Probe 1 values. The results are significantly different from the mean size response. Here, the effect of flow rate is less, but the probes respond to refining in a different manner. Both probes produce increasing "bulk scattering" results with increases in refining. Probe 1 has about twice the rate of increase of Probe 2. At 0.2% consistency, not illustrated, the "bulk scattering" results were very low, i.e. 0.2 to 0.4, over the entire refining range, for both probes, and this was much less than the effect seen at the higher consistency.

Figure 69
Refining Evaluation
"Bulk Scattering" vs C.S.F.

Probe 1 "Bulk Scattering" Values Normalized
Sept 30 - Oct 1, 1991

R4BALL.DRW

Figure 70
16" Refiner Study
Strength Comparison

Figure 71
Strength Comparison
Canadian Standard Freeness

Figure 70 is plotted as a summary of the relation between mean size and the various strength results. This shows that there is a good correlation between apparent density and mean size. It can be seen in Figure 70 that there is a very good correlation between Tensile Index and mean size. Figure 71 is a comparison of Canadian standard freeness to strength results. This figure indicates that this relationship is at least as good as the correlation between Tensile Index and Canadian standard freeness. However, with Tear Index, the correlation to Canadian standard freeness is better than the correlation to mean size. Similar results to the tensile results are seen with Wet Breaking Length.

Figure 72 shows that there is some correlation between Kajaani Arithmetic Average Fiber Length and PAR-TEC mean size.

Figure 73 is plotted as a summary of the relation between "bulk scattering" and the various strength results. There is a good correlation between all of the strength results and "bulk scattering". There appears to be scatter in the results, but this is due to the fact that the two probes were each responding to refining in a different manner, as was seen in Figure 69.

It was shown in Figures 51 and 52, that consistency has a major influence on the "bulk scattering" results. In this study, the pulp was all measured at the same consistency, so the influence of

Figure 73
Strength Comparison
 "Bulk Scattering"

consistency on the readings was negated. If both probes can be manufactured and calibrated to give identical results at the same consistency, then these results could become the basis for a monitor which could measure refining development at commercial refining consistencies.

The refining circuit was set up on September 30, 1991, with two PAR-TEC 100 Probes, one located before the refiner and one after the refiner. See Figure 15. For this study, the bleached softwood pulp was prepared at 3.3% consistency and refined in a single pass mode. The PAR-TEC mean size reading of both probes were made to match on the unrefined pulp before refining began. Refined pulp from each of the four refining energy levels was stored in different chests for further testing.

At 3.3% consistency, the PAR-TEC mean size remained constant at all three levels of refining, whether the probes were using the scaling factors or not. For example see Figure 74, the bottom two lines. Probe 1 should have remained constant, because it was measuring the feed stock to the refiner. But Probe 2, which was after the refiner should have been measuring a change in the fiber size due to the refining, if the sensor was able to do that at this consistency. It does not appear that it is possible. At the lower consistencies, the pulp was diluted to the appropriate concentration and measurements were made by both probes on the same pulp in a flow loop, without the refiner.

In Figure 74 it can be seen that the mean size increased for the first three data points, but decreased when the freeness dropped to 260 mL. The same results were obtained but are not presented when the non-scaled values are plotted. The non-scaled values contain the results of the particle size analysis over the entire measurement range, with none of the values eliminated or adjusted. Figure 74 may be showing that the small particles are having an influence on the overall mean size sooner than indicated in the earlier trials.

Figure 74
Refining Results
Mean Size vs C.S.F.

Figure 75 shows the results of measuring "bulk scattering" at several different consistencies. It can be seen that as consistency decreases, so does "bulk scattering." At 0.6% and 1.0%, there is a slight increase in value as refining progresses, but not as much as at 3.3%. In the flow loop, both probes are measuring the same pulp, but in the refining loop, at 3.3% consistency, Probe 1 is measuring the pulp as it comes out of the stock chest, before it is refined, and Probe 2 measures it after the refiner. Except for the first Probe 1 value, the bulk scattering results remain relatively constant as the refining trial progresses. It can be seen that for Probe 2, after the refiner, there is the same constant increase of bulk scattering with increasing refining from 4.3 to 5.0 as seen in previous trials.

FIGURE 75
Refining Results
Bulk Scattering vs C. S. F.

Canadian standard freeness shows a uniform, constant drop in value as refining progresses, in Figure 76.

Sept. 30 - Oct 1, 1991
NSCB9CF.DRW

Figure 76
Refining Results
C. S. F. vs Net Specific Energy

In Figure 77, the last value for each probe is circled, and excluded from the regressions which compare the mean size results to various strength properties. As was seen in Figure 74 the results from the highest refining level are lower than expected. It can be seen that there is a fair correlation between mean size and the strength properties plotted for the first three refining levels.

Sept. 30 - Oct. 1, 1991
CSFVKWS.DRW

Figure 77
Strength Comparison
PAR-TEC Mean Size

Figure 78 shows that "bulk scattering" correlates to the strength properties plotted.

Figure 78
Strength Comparison
"Bulk Scattering"

The results of the previous trial were inconclusive, so the trial was run again on October 22-23, 1991. The pulp was refined in a single pass mode with each net specific energy loading achieved in a high and low intensity manner.

The results were very similar to the previous trial. At 4% consistency, there is very little change in PAR-TEC mean size as refining energy input increases, for both the high intensity (low flow) and low intensity (high flow) refining modes (see Figure 79). There appears to be at least as much change in mean size before the refiner (unrefined pulp) as after the refiner. Both of these results indicate that at 4% consistency, the PAR-TEC sensor is not sensitive to changes in fiber size due to refining. When the measuring consistency was reduced to 0.2%, refining had a greater influence on the mean size value. This affect appears to be a combination effect, an increase in mean size at the beginning of refining and then a decrease as refining progresses (see Figure 80).

"Bulk scattering" results, again showed an increase with increased refining (see Figure 81). The Probe 1 results were measured before the refiner and are nearly horizontal. The Probe 2 results do show the typical 0.5 to 1.0 unit increase in refining over the entire refining range.

SYNTHETIC FIBER RESULTS

EFFECT OF CONSISTENCY

Four different nylon fibers were measured at a range of consistencies. The nylon fibers used were of two different diameters, namely 19 and 47 μ . Each fiber diameter was present in two lengths, 1.27 and 4.57 mm. As consistency increased, the mean size tended to decrease, Figure 82. These results confirm that the sensor is sensitive to consistency. Careful dilution is going to be required to get meaningful and repeatable results of the sample before measurement.

FIBER DIMENSIONS

Single Fibers

The simplest case was investigated, that of measuring a single, stationary fiber. A single fiber was held stationary in front of the probe and measured. The nylon fiber with a nominal diameter of $19\text{ }\mu$, was measured to have a mean size of $69\text{ }\mu$. The nylon fiber with a mean size of $47\text{ }\mu$, showed a mean size of $82\text{ }\mu$. The single fiber measurements are plotted with the slurry results on Figure 82. The thinner fiber results are about the same as the results obtained when the same diameter fiber is measured in a slurry at low consistency. The thicker single fiber results are lower than the slurry results. This may be due to differences in the way the light is reflected off the fibers in the wet or dry state.

The plot of these measurements produced counts in several channels, not in one as would have been expected (Figure 83). There is a smoothing algorithm built into the software to eliminate extraneous data points, which spread the values over a range of 5 adjacent channels. The mean size increased as the axis of the fiber moved away from the normal to the scan.

FIGURE 83

Date : 05/20/92
Time : 15:04:41

M.Cycle Time: 1.0 sec.
Averaged last 1 cycles

PAR-TEC #1

ID : N1-sampA

Scanned Counts Mean	: 82.5
Standard Deviation	: 13.2
Skewness	: 2.2
Kurtosis	: 3.2
Coeff. of Variance	: 15.9
Avg Counts/Cycle	: 71

Fiber Mixtures Effect of Fiber Length

On the plot of mixtures of fibers of equal diameter (Figure 84), it can be seen that the mean size results are basically the same for both sets of fibers with the same diameter. A series of two component fiber mixtures were made at a concentration of 0.6%, using each combination of the different fibers. When the fibers of the same diameter were mixed, the mean size measurement remained the same, irrespective of the proportion of long or short fibers. The conclusion is that mean size does not seem to be related to fiber length.

Figure 84
Equal Diameter Nylon Fiber Mixtures
Mean Size vs Fiber Length

Nylvis.drw

Fiber Mixtures Effect of Fiber Diameters

On the plot of mixtures of fibers of different fiber diameters (Figure 85), the mean size results are plotted against the large diameter fraction of each mixture. When fibers of different fiber diameters were mixed, the mean size increased as the proportion of the thick fiber in the mixture increased. For all the combinations which included the long fibers, cases II, III and IV, the mean size increased approximately in the same proportion to the percentage of thick fiber in the mixture. Case I, with only short fibers, showed a different response, possibly due to greater influence of the larger count of thin fibers in a given weight than the count of thick fibers in the same weight. An unusual and unexplained result is that a

Figure 85
Nylon Fiber Mixtures
Mean Size vs Fiber Diameter

Nylvt.drw

plot of the mixture's particle size distribution does not show two peaks representing each of the individual fiber diameters as would be expected (Figure 86). A partial explanation may be the smoothing algorithm described in the discussion of the single fiber measurements.

These results, which relate to fiber diameter, compare to the results obtained earlier with regard to Kajaani fiber length and coarseness (Figures 34 and 35). Refining appeared to produce shorter, coarser fibers. It would appear that the PAR-TEC results are giving a direct measure of increased fiber diameter while the fiber is still in the wet state as refining progresses. Increasing coarseness would come about as the fiber increases in diameter, due to such factors as fiber swelling, increased surface area from the presence of fibrils, and decreases in length. This corresponds to decreasing Kajaani fiber length and increasing PAR-TEC mean size results.

ALTERNATIVE ANALYSIS

It was suggested that there might be some alternative way to analyze the results, which may give a closer relationship to pulp strength development than mean size, assuming that the instrument is working properly. Mean size appears to correlate to strength results for some of the trials, but not all of them. The present algorithm calculates a mean size value from the particle size distribution data. This value appears to be generally related to tensile index. However, there might be some alternative way to manipulate the data, to produce some other parameter --X-- or --X2--, which has a consistent, improved relationship to strength. This may also help to explain why some of the mean size results do not correlate to strength development.

RATIOS

One approach, suggested by Lasentec, was to make a ratio of the part of the curve which rises steeply before the peak and the part of the curve which falls steeply after the peak. Changes in this ratio would be more sensitive to changes in refining than the mean size. A similar approach was used by Mr. R. Bareiss with initially successful results. He evaluated the results of one beater run and found the ratios of counts in certain channels demonstrated a

correlation to beating time (Figure 87). If beating time is replaced with a strength property, such as tensile index, a good relationship is also found (Figure 88). The channels that were ratioed were based on a similar analysis on nylon fibers. However, the analysis using these channels was not successful on other sets of data. Other ratios of various channel combinations were also unsuccessful.

FIGURE 87
Ratio vs Time

Figure 88
Data Analysis
Channel Count Ratios

JAN 1992
 $Avg1 = (22+25+31+37)/4$
 $Avg2 = (53+63+75+88)/4$

Each bar on the channel size histogram, for example Figure 6, represents the measure of a given number of particles that the probe has seen in front of it, if the instrument is working properly. In order to compare several histograms, each channel can be plotted in a single group. For example, in Figure 89, channel 75 has been plotted at four refining levels. This technique can be repeated for each channel output. This figure shows the effect of four refining levels, on the individual channels. Now it can be seen whether a particular channel increases or decreases with beating.

Figure 89
16" Refiner Softwood Study
Particle Size Distribution Variation

This plot shows a tendency for channels in the range of 53 to 105 μ to decrease with increased energy input. Channels 92 to 15 μ tend to increase with beating. For this particular study, it does seem to confirm that as refining progresses, the particle size distribution does shift to larger values. However, when other data was analyzed in a similar manner, the results were inconclusive.

Other methods of channel manipulation have also been unsuccessful.

IPST INVESTIGATION ⁶

The Institute of Paper Science and Technology was given the individual channel results from the trials listed below, both laboratory and in-line, and asked to see if they could find a better way to interpret the results.

Valley Beater Study - June, 1990
 Valley Beater Study - March, 1991
 16" Refining Study - July, 1991
 Nylon Fiber Lab Study - January, 1992
 - Consistency
 - Fiber Mixtures

⁶ Waterhouse, J. G. Brodeur, P. H., and Esworthy, C, "IPST Data Analysis of the Herty Foundation Experiments Using the Lasentec PAR-TEC Particle Size Analyzer, Project 3765, Institute of Paper Science and Technology, Atlanta, GA, July, 1992.

Rather than just trying to manipulate the data by making ratios as shown above, IPST searched for a mathematical equation which would consistently fit the data. If information from the equation could be used to predict strength development, this equation could give a better understanding of the PAR-TEC readings. Using a program called "PeakFit", from Jandel Scientific an exponentially modified Gaussian (EMG) could be successfully used to model the data (Figure 90).

FIGURE 90

Jul 8, 1992 10:51 AM

35 Active X-Y Points

X: Mean: 130.56571429 SD: 196.90388659

Y: Mean: 2.8507477515 SD: 3.1657879646

File Source: BEAT2.WK1

Curve-Fit Std Error= 0.280035075 r2= 0.992865821

Curve-Fit Coefficients

Peak#	Type	Area	Ctr	Wid	Dist
1	ExpGauss	750.84816	19.295549	10.18685	54.024709

Measured Values

Peak#	Type	PkAmpl	PkCtr	Wid@HM	Area	%Area
1	ExpGauss	9.6508741	34.501747	60.831594	748.47003	100

The PeakFit form of the EMG function is

$$f(x) = \frac{a_0}{2a_3} \exp \left[\frac{a_2^2}{2a_3^2} + \frac{a_1 - x}{a_3} \right] \left[\operatorname{erf} \left(\frac{x - a_1}{\sqrt{2}a_2} - \frac{a_2}{\sqrt{2}a_3} \right) + 1 \right]$$

where

a_0 = Peak area
 a_1 = Gaussian peak center
 a_2 = Gaussian peak width
 a_3 = Gaussian distortion

When IPST evaluated the results to determine the best way to proceed, they observed some irregularities in the plotted data. The plots, especially of the in-line data, appeared to be comprised of at least two sets of data, a bimodal fit (Figure 91). This data was collected with the PAR-TEC 100, which had been modified for measuring pulp consistency. It would therefore appear that there could be something in the way these instruments collect the channel counts which could produce a bimodal output.

FIGURE 91

Jul 13, 1992 10:23 AM

36 Active X-Y Points

X: Mean: 146.60555556 SD: 216.62259339

Y: Mean: 2.677775 SD: 2.2062471679

File Source: CHANMAR1.WK1

Curve-Fit Std Error= 0.161540449 r2= 0.995711117

Curve-Fit Coefficients

Peak#	Type	Area	Ctr	Wid	Dist
1	ExpGauss	899.7596	17.705746	13.122534	110.00201
2	ExpGauss	157.77017	59.16549	6.4939613	108.71661

Measured Values

Peak#	Type	PkAmpl	PkCtr	Wid@HM	Area	%Area
1	ExpGauss	6.3426399	40.141547	107.58735	893.56811	85.003106
2	ExpGauss	1.2563601	72.292637	91.998349	157.65007	14.996894
Total					1051.2182	100

One of the parameters which define the EMG equations which fit the nylon fiber data is the Gaussian Peak Center, a_1 . It can be seen in Figure 92 that this parameter is influenced by consistency.

FIGURE 92

FIGURE 3 Variation of Gaussian Peak for a Single EMG with Consistency - Nylon Fibers.

The Gaussian Peak Center (Figure 93) is more influenced by fiber length than mean size, but less than the Gaussian distortion parameter, a_3 , (Figure 94). These last two sets of results indicate that neither parameter is any better suited to measuring nylon fiber diameter than mean size.

Figure 93
Nylon Fibers
EMG Parameter, A1

Nylvgp1.drw

Figure 94
Nylon Fibers
EMG Parameter, A3

Nylva31.drw

The parameter, a_3 , is very successful in relating changes in the fiber size distribution to increases in fiber strength for a number of the data sets. Figure 95 shows the results from the softwood refining trials in July 1991, where a_3 is plotted against apparent density. Figure 96 plots the same data against tensile index.

July 1991
MST1791.DRW

July 1991
A3T1791.DRW

TMP EVALUATION

The results with conventional pulps showed that the sensor was not sensitive to changes in fibers caused by refining, especially at 4% consistency. It was decided that very little effort should be devoted to TMP applications, and this part of the project should be abandoned.

TMP SHIVES

As long as we had the sensors, we decided to perform a quick laboratory study on the response of the sensor to shives in TMP pulp.

Two samples of TMP pulp were received from Bear Island Paper Company, for an initial study of the effect of shives content on the mean size value. One sample was collected from the discharge of the secondary refiner, and the second was collected from the feed to the thickener. As determined above, the pulps were diluted to 0.2% consistency before PAR-TEC measurements were made.

Using a Pulmac Shive Analyzer, with a 6 cut (150 μ) screen, the shives content of the pulps was determined. The unscreened, as received, secondary refiner discharge pulp had 1.0% shives and a PAR-TEC mean size of 37 μ . After the latency was removed, the shives content was reduced to 0.4%, and the mean size was 36 μ . The thickener feed was found to contain 0.2% shives, with a mean size of 32.2 μ .

On the plot of mixtures of two TMP pulps, Figure 97, mean size is plotted against the proportion of as received, unscreened secondary refiner discharge pulp in each mixture. It can be seen that when the proportion high shives content pulp (as received secondary refiner discharge pulp) and the low shives content pulp (thickener feed), are mixed, that there is a good correlation between the percentage secondary refiner discharge pulp and the mean size.

Synthetic shives, or nylon fibers with a fiber length of 4.6 mm and a diameter of 47μ , were added to the thickener feed sample. It can be seen in Figure 98 that as the percentage of nylon fibers in the slurry increased, the mean size increased in a nearly linear manner, up to 50% nylon fibers.

Shives were removed from the latency relaxed pulp with the Pulmac Shive Analyzer for the addition of known quantities of shives to the thickener feed sample. The results of adding 1 to 8% shives to the thickener feed is shown in Figure 99. It can be seen that there is a slight increase in mean size as shive content increases. This test was repeated several times with similar same results.

The sensor showed good sensitivity to the addition of nylon fibers or the mixing of slurries with two different mean sizes, but it was not able to pickup the addition of actual shives to the pulp slurry. The retained shives collected may have been too large to be seen by the sensor, or there may have been a few very large shives in the sample, which accounted for most of the weight and these were not counted often enough to have a major influence the final result.

Figure 99
Shive Analysis
Addition of Shives

1993
SHVADD9.DRW

CONCLUSIONS

1. The LASENTEC Scanning Laser microscope is sensitive to changes in the particle size of pulp slurries. The changes in value can be due to changes in fiber dimensions caused by refining, but can also be due changing consistency and flow rate. PAR-TEC mean size does not appear to consistently correlate directly to conventional measures of refining. From the work with synthetic fibers, it appears that the PAR-TEC Probe results are related to fiber diameter. The manner in which refining is performed has an influence on how pulp strength is developed. The fibers can be cut, swollen or fibrillated, any of which will have a different effect on the fiber dimensions, and therefore have different effects on the PAR-TEC mean size measurements.

PAR-TEC measurements of wood pulp beaten in the Valley beater or refined in a pilot scale refiner in a recirculation mode correlated to conventional refining measures. The PAR-TEC measurements increased with increasing levels of refining. These results were not reproducible on pulp refined in a single pass mode. On single pass refined pulp, the PAR-TEC measurements tended to show an increase initially, and then decrease as energy input into the pulp is further increased. The PAR-TEC readings varied significantly with measurements of different Bauer-McNett pulp fractions. These results indicate that the sensor responds to different fiber morphologies and dimensions.

- 2) The sensor is sensitive to pulp slurry consistency. Changes in slurry consistency produce changes in the PAR-TEC results. The effects of refining on the pulp were not noticeable on the pulp
- 3) The sensor is sensitive to the quantities of free, fine particles in the slurry. As clay particles were added to the slurry or were bound up with a retention aid, the measured mean size of the slurry decreased and increased respectively. The instrument could be useful in monitoring changes in fine particle distributions related to fines and filler retention at or around the headbox.
- 4) At refining consistencies of 3-5%, the sensor is insensitive to changes in the pulp slurry due to refining. The instrument did not respond to changes in the pulp until the slurry was diluted to 0.2%.

In order for the instruments to be useful in measuring fiber development during refining, the following must be done:

1. A calibration system be developed to standardize the instrument on pulp slurries.
 2. Two instruments must be shown to give identical responses to pulp over a range of consistencies and pulp characteristics.
 3. Establish that the output from the sensor correlates to pulp strength as measured by conventional refining measures.
- 5). At a constant 4% consistency, there was a very slight but significant increase in "bulk scattering", which related to handsheet strength properties. However, consistency had a greater effect on the "bulk scattering" result than refining. "Bulk scattering" results may be a useful in-line measurement at actual refining consistencies if it can be shown that a two probe system can be used to eliminate the effect of consistency on the readings. A more powerful light source and/or detection method may be needed to make the refining response more pronounced.

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**DATE
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10/13/94

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