Online standardized measurements of pulp and stock quality

HÅKAN KARLSSON
Product manager, Lorentzen & Wettre, Box 4, SE-16493 Kista, Sweden; hakan.karlsson@l-w.com

Keywords: Fibre morphology, pulp quality, online, brightness, CSF, SR, automation

ABSTRACT

Optimization and control of the pulp and paper making processes for cost-effective production requires more frequent monitoring of the relevant pulp and stock preparation quality parameters. A new quality monitoring system for pulping and stock preparation is developed. The new online L&W Pulp Tester is a complete wet laboratory with automatic sampling from different positions along the process chain. Repeatable tests are made automatically and frequently. True variations are monitored in real time and are used to secure product quality, save time, material and energy, and increase production. The online pulp tester consists of automatic standard and established tests for CSF, SR, brightness, color, fibre length, kink, coarseness etc. suitable for building up an automatic quality monitoring and optimization system in the mill. Samples from a liner mill with refining in several steps was investigated and showed a good potential for online measurement of pulp strength potential. A new automatic measurement of fibre coarseness is an important parameter for prediction of pulp strength potential in addition to the fibre morphology measurements. Accurate and repeatable measurements and classification of vessel cells is an important measurement for classification of hardwood pulps. Reliable data and high uptime of the system are fundamental requirements for online pulp quality analysers. Confidence is created by automatic measurements according to existing standards and established procedures. The repeatability is tested with automatic sampling from a tank to avoid manual steps in the test. A high uptime of the system is reached by automatic cleaning procedures, use of well proven components and robust design. The new online standardized tests are used for applications in all types of pulp and paper production.

As a complement to the sampled system a new fast inline fibre quality analyser (L&W Fiber Quality Transmitter) based on image analysis is recently introduced.

WHAT IS PULP QUALITY?

What is the purpose of pulp quality testing? One main purpose is to predict the final product potential from wet pulp properties. If we know the impact from the pulp properties on the final product then we can optimize and control the process for best economy. But what shall we measure to characterize pulp quality? And what technique is useful in a reliable online quality testing system?

Mechanical pulp

For mechanical pulp the measure of freeness has been used traditionally since it is sensitive to process parameters in refining and is connected to dewatering on paper machines. Regarding strength properties of mechanical pulp, Forgacs [12] showed already 1962 that measuring only freeness was not enough for characterization of pulp. He stated that at least two parameters are needed for classification of strength properties of mechanical pulp (reinforcement and bonding or total surface). Much work has been done since that time regarding pulp quality.

Automatic analysis with modern optics was early introduced in mechanical pulping. One of the absolute first successful optical devices for online process measurements was a shive analyzer with automatic sampling and sample preparation. Shives increase the probability for web brakes, linting and printability problems. The optical Shive analyzer was invented by Jan Hill at STFI 1974 [1]. The signals from two perpendicular placed detectors were multiplied. The pulse length and height resulting from passing shives were analyzed and were measures of shive length and width respectively. It was followed by a pulp quality monitor system (which became the PQM). An optical fibre fractionator was combined with the shive analyzer and a freeness tester to an automatic sampled system for monitoring of quality for mechanical pulps. Three fibre length fractions were created from three optical channels with different characteristics [4]. It is known that fiber length correlates to sheet strength like tear index and strongly influences formation. Several systems with the same concept as PQM have entered the market since then and are common in the industry today. Ferritsius[13] has summarized the quality for mechanical pulp in five steps - the five star:

- Length
- Bonding
- Shives
- Brightness
- Resin
Chemical pulp
Chemical fibres give much stronger sheets since the fibres are more slender and flexible than mechanical fibres. When image analysis technique [5] was established from 1990 an image based online fibre analyzer was developed mainly for chemical pulps, where fibre deformations and in general more accurate measurements of fibre properties were required [5, 6]. Figure 1 shows how the fibres are oriented in a plane between two glass plates with 90° angle relative to the illumination/camera axis. All parts of the deformed fibres are clearly visible for the camera with a tight measurement gap of 0.5 mm according to standard, which is a unique feature for an online system. True fibre length instead of projected fibre length and fibre deformations could now be measured. A cleaning system with automatic separation of the plates keeps the passage free. This solution has been used during the last 10 years in the L&W STFI Fibermaster online system with great success.

Figure 1. Image analysis based analyzer 1990.

Figure 2 shows the definition of shape factor. It is the ratio between projected fibre length and true fibre length measured along the fibre axis. Shape factor is commonly expressed as a percentage. A straight fibre has the shape factor equal to 100%. The more deformed fibre the lower the shape factor is.

Fiber deformations like kinks are often a result of cellulose degradation and correlates to viscosity and fiber/sheet strength. Increasing shape factor and decreasing kink increase tensile stiffness and tensile index, decrease stretch and is affected by refining, bleaching and latency.

In figure 3 is shown how the shape factor together with refining energy explain Tensile index [6]. This relation has been used for online testing and estimation of pulp strength for chemical market pulp in some Scandinavian mills for many years.

A high shape factor means straight fibres and gives, in most cases, good mechanical properties to the sheet. It is well correlated to tensile strength and tensile stiffness. A gently treated laboratory pulp has quite straight fibres, whereas in a mill there are several process stages that are potential curlers of fibres, like presses, mixers etc.

Shape factor
Form Factor of a Fibre 100 x VL

Figure 2. Shape factor.

Figure 3. Softwood samples from different Scandinavian pulp mills and different sampling positions were refined and tested with respect to sheet strength and fibre properties. Tensile Index is to a great extent explained by shape factor and refining energy.

The bench top L&W Fiber Tester (2005) is a modern version of the L&W STFI Fibermaster. It is an automatic analyzer used for R&D, process optimization and manual based test of the fibre quality. It measures fibre length according to the latest standard and other important fibre properties. It includes all kind of statistics. Measurements of fiber deformations, vessel cells and shive content are unique features. It is today common in the industry. The same signals are used in the new online pulp tester. Results from the laboratory work are then completely comparable with results from the new online system. It is simply the same measurements. This philosophy is valid also for other modules in the new online pulp tester.

A mill test (figure 4) showed how Fiber morphology tests correlate well with Zero Span Tensile strength [11]. Samples were gathered at various stages of a bleaching process for a softwood line. Zero Span Tensile varied from 66.4 to 98.3N/cm. Least squares regression of Shape factor...
vs. Zero Span Tensile test yielded $R^2$ of 0.95. Multivariate analysis generated models (least square) from Length, Width, Shape and Fines vs. zero span tensile yielded $R^2$ of 0.98. The process was sampled during 48 hours.

Samples were taken from various points in the bleaching process including the pre-oxygen and several post oxygen stages and at the end of the bleaching process. The Pulmac Sheet former was used to produce six samples for the Zero Span Tensile strength. Fiber tester was set up with standard length weighted measurements.

Figure 4. Zero-span Tensile can be predicted from fibre morphology (L&W Fiber Tester) in a fibre line.

Another commonly used measure in chemical pulping is viscosity. For unrefined pulp it is strong correlation between deformations like kink and viscosity. Refining changes the deformations and as a consequence destroy the correlation to viscosity. But automatic kink measurements in the pulp mill before refining will correlate well with viscosity.

**Coarseness**

Different fibre sources can have significant different coarseness. Fibres with thick fibre walls result in an open and bulky paper with low burst and tensile strength and high tear. Fibres with thin walls collapse easier and allow more bonding between fibres resulting in low porosity and high tensile strength. Measurement of coarseness will then improve the strength estimation models. Automatic measurement of coarseness has resulted in better repeatable measurements than before. According to table 1 we are talking about coefficient of variations lower than 2 % for softwood and less than 1 % for hardwood. For market pulp production units fibre morphology including coarseness is a good basis for online quality testing and prediction of pulp strength.

Pulp quality depends on raw material, cooking, bleaching and refining. Pulp quality measurements should show the potential for optical properties, strength properties, runnability and printability of the paper. We have some experience from how NIR spectra can improve pulp quality modelling and we are testing alternatives for WRV as well. But the focus now is on burst test! Here is a concept for pulp quality testing;

- Established image based fibre testing technique (length, width, shape, kink, fines, vessel cells, shives and coarseness
- Traditional standardized measurements like CSF & SR
- Established Elrepho technology for optical properties measured on pressed and dry pads.
- Alternatives for improved measurements related to bonding
  NIR (chemical composition) or WRV or Burst strength.

**Refining**

Refining increases the strength of the sheet. This is achieved by increasing the bonding area between the fibres. The bonding area is affected by fibre collapse, split, fibre flexibility/bendability, fibre swelling, internal fibrillation, external surface fibrillation and external surface macro-fibrils. Other refining effects are generation/removal of Shape/kink, generation of fibre fractions, secondary fines and reduction of shives.

Figure 5. The spaghetti is ready when it fasten in the ceiling. Compare refined fibres with raw and cooked spaghetti respectively (flexibility and bonding).

Obviously bonding is rather complex. If we try to find one measure that correlate well with bonding one idea is to use the traditional measures. CSF or SR are widely used everywhere mainly for pulp drainage. The paper maker will always use these methods although they are mainly influenced by the fines. R&D people often use WRV as a measure of development of bonding. It is also used for measuring potential for pressing (bonded water).

Best measure of bonding might be strength tests on sheet for example z-direction tests. The problem here is to find the best compromise between accuracy of prediction models and a reliable
system. We make a sheet/pad in the system to measure coarseness and true consistency. When we have a dry pad it is not a big step to put it in our standard burst tester and make a burst test. The burst tests so far are made off-line with automatically made sheets from the system described below.

The curve in figure 6 represents measurements of Burst index and beating degree before refining and after each of three refiners in the stock preparation for liner. Beating degree was measured as SR in L&W Pulp Tester in an offline test. The pulp pads used for automatic weight tests in L&W Pulp Tester were collected and tested in a standard L&W Burst Tester. The three first samples were tested twice and the fourth sample were tested 20 times. The averages were plotted in the figure. The result is a beating curve, which describes the pulp potential. The coefficient of variation for SR was 3%. If these tests can be performed automatically online this curve can be displayed quite accurately and constitute a solid base for optimization of energy, quality and production. This type of information is not possible to achieve in real time with normal laboratory instruments.

Vessel cells
Certain types of Vessel Cells can cause linting problems, deposits on creeping blades and on coating blades and picking in the print room.

Classification of vessel cells can hopefully help to identify the problem and help to improve the processes. Vessel cells are often collapsed because of the thin cell wall. With the tight measurement gap in the measurement cell they are mostly oriented so that they are seen by the camera from the flat side. This makes it easier to identify them and monitor how they are distributed with respect to width and length. Acasia seems from limited investigations to have more of big vessel cells than eucalyptus when comparing corresponding plots. Detection of vessel cells is built on detection and classification of objects wider than the fibres. Several selection parameters are used to get best possible selection. Basically a width limit is defined. Everything up to this limit is defined as fibres. Everything above this limit is analyzed more in detail for classifying. The selection criteria can easily be fine-tuned by the user. This is done by using an overview of saved images from measurements. It is possible to use the images and together with the measured properties for each image to adjust the selection parameters for optimal precision in the detection. The calibration is actually done by comparing with manual recognition of the actual objects. Number of vessel cells per gram, vessel area, number of vessel cells per 100,000 fibres and length/width distributions are reported.

In an example with refining effect on vessel cells (see figure 7) was shown how the refining reduced the amount of big vessel cells. Smaller cut cells increased consequently.

A second method to reduce the amount of vessel cells is with hydrocyclons. A good measurement of the vessel cells is needed for evaluation of these possibilities.

The fibre analyzer has recently been used for measurements of smaller shives that normally are detected with older optical instruments. New definition of shives can be developed based on the images. From tests of shive measurements we can see a need for improved definitions of what we mean with shives. Vessel cells, shives and other objects can be measured selectively with, in principle, the same parameters but with different settings.

Figure 6. Test along a refining line before, between and after the refining.

Figure 7. Blue curve is unrefined eucalyptus pulp. The red curve is laboratory refined pulp. The x-axis show the area of the vessel cells in mm².
A NEW GENERATION ONLINE SYSTEM FOR STANDARDIZED PULP QUALITY MONITORING

One way to measure pulp quality covering both chemical and mechanical pulps is a 6-star approach;

- Fibre length and deformations (Shape/Curl, kink)
- Cross section properties (Width, Coarseness)
- Bonding; (CSF/SR, Burst, (WRV, optical))
- Chemical composition (soft-sensor from NIR spectra)
- Optical properties (Brightness, Whiteness, Colour, Fluorescence, Estimated Residual Ink)
- Cleanliness (Vessel Cells, Shives)

This concept is substantiated in the online automatic laboratory for testing of pulp – L&W Pulp Tester (figure 8). A central unit is fed from samplers distributed in the mill. A sample preparation unit adjust the consistency of the sample and distribute pulp samples to different included modules. Wet samples are fed to standard tests for freeness (CSF/SR), fibre morphology (length, width, shape, kink, fines, vessel cells, shives) and to a sheet former and dry sheets are then analyzed with respect to optical properties (Brightness, whiteness, fluorescence, color and Erik), NIR spectra and Burst strength.

A separate shive analyser is available for better statistics in this measure.

Standard CSF/SRare automatic versions of the laboratory standard equipment measured with correct consistency and temperature compensation. Since CSF and SR are well-established methods a lot of process experience relates to these measurement values. It has shown to be difficult to model the measurements mathematically from other non-standard measuring devices. Frequent calibration work is avoided by using the standards.

Optical properties are measured from a completely dry pressed sheet. Almost all facilities from the laboratory standard instruments are included.

The pulp strength can sometimes change due to chemical composition change without measurable changes in the geometrical fibre properties. One way to detect such effects is by using NIR-spectra. Models are then developed with multivariate data analysis methods. This require considerable modelling work. Another way may be to measure WRV or sheet strength to get complementary information of the bonding for modelling of sheet properties.

BASIC REQUIREMENTS FOR ONLINE ANALYZERS

For an online pulp quality analyzer the reliability is very important. Reliability is the ability of a device or system to perform a required function under stated conditions for a specified period of time. Required function is reached if people can trust in measured data. This is reached if measured properties are close to international standards and need less calibration. Since calibration of online units has been regarded as a major problem we have used methods close to or exactly following the standards in order to increase the reliability of data.
It is also an advantage if known engineering scales are used for the measured parameters.

The sensors also have to be stable and have good repeatability. Repeatability tests are standard procedures for acceptance of new instruments.

<table>
<thead>
<tr>
<th>Table 1. Typical examples of repeatability in L&amp;W Pulp Tester</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Length (mm)</td>
</tr>
<tr>
<td>Width (µm)</td>
</tr>
<tr>
<td>Shape</td>
</tr>
<tr>
<td>Fines (µg/m)</td>
</tr>
<tr>
<td>Coarseness</td>
</tr>
<tr>
<td>Kinks (1/mm)</td>
</tr>
<tr>
<td>Vessels cells/g</td>
</tr>
<tr>
<td>Brightness (ISO)</td>
</tr>
<tr>
<td>CSF (TM)</td>
</tr>
<tr>
<td>SR</td>
</tr>
</tbody>
</table>

Table 1 shows results from repeatability test of the fibre morphology measurements. These tests were made with automatic feed of samples from a tank to the fibre morphology analyzer. As can be seen these instruments have impressive repeatability. A new signal here for automated testing is coarseness. Also the repeatability of coarseness must be considered very good. The coefficient of variation for fines can be seen as high but observe that it is a percentage of a very small amount of fines.

Most commonly the repeatability of signals measuring on the same sample is used. Samples have been taken from a stirred tank with pulp at 3% consistency with our standard sampler. This is the repeatability for one analyzer. The difference between units could be regarded as twice these numbers. The different analyzers can be calibrated against a common pulp reference. Only synthetic fibres are not enough for the accuracy level we are talking about. Observe that the reference pulps are not better specified than the reference analyzer used for this pulp!

As can be noticed from the table all coefficients of variations are low. Coarseness is better than what is often reached with manual tests. For vessel cells the variations are commonly slightly higher due to worse statistics. Fewer vessel cells than fibres are commonly counted. If we count 900 vessel cells the statistical caused standard deviation will dominate the error and is about 3 %.

The experience from the past is that the reliability of complex online sensors and analyzers is critical for acceptance of the new instruments. The data must be available when needed and this has to be reached with limited maintenance work and costs. You have to use good and tested components. Advanced automatic cleaning systems are a must. A critical device for high uptime is the sampling.

![Figure 11. Pneumatically driven piston with robust design and sharp cutting edge goes into the process.](image)

The robust and simple samplers are designed with a cutting edge, which prevent the sampler to jam. The sampler sticks into the pipe in order not to measure pipe edge effects. The sample is diluted directly at the sampling point and transported at low consistency in separate tubes to the tester.

The measurement frequency is very limited with manual tests as illustrated in table 2. They generate more of historical data. An automatic system measures frequently and with a system based on 6 samplers complete data can be reported every 30 minutes. Single point measurements can report every 5 minute. With the inline fibre quality transmitter data can be reported every minute and even faster than that.

<table>
<thead>
<tr>
<th>Table 2. Measurement frequency of pulp quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handsheets</td>
</tr>
<tr>
<td>Other manual wet tests</td>
</tr>
<tr>
<td>Online automatic laboratory</td>
</tr>
<tr>
<td>Inline transmitter</td>
</tr>
</tbody>
</table>

Important are;
PERFORMANCE AND CONTROL POTENTIAL

In the paper “Experiences with computer control, based on sensors for pulp quality, of a two stage TMP plant” Johansson et al reports already 1980 about the control potential with online measurement of pulp quality. Measurements were made of shives, fibre length and freeness after latency and after screening. The cycle time for the sampling was 7.5 minutes. The control reduced variations longer than 5 hours period time over the whole test period. Best trimmed controller reduced variations down to 2 hours period time. This corresponds to a time constant of a chest of 20 minutes. This could be close to what is to be estimated for the latency chest. The reduction of variance in mean fibre length was 78 %. These results were presented 1980. They showed that it is possible to decrease variations by controlling the process. It is still a potential for fast and reliable sensors. The control will never be better than the sensors.

The online system with distributed samplers has a cycle time down to 5 minutes depending on the pulp. If the system uses 6 samplers the total cycle time will be 30 minutes. If control actions are based on at least 2 measurements, process variations with cycle times above an hour can be controlled and reduced. If only one sampler is used the control will be faster. But to control the fastest possible variations in one measurement position the inline fiber quality transmitter is a cost effective alternative. This transmitter dilutes the pulp continuously in the pipe. Images from the fibers are taken continuously and 2-3 complete fiber property measurements are generated every minute. The process can be monitored with respect to faster variations than is possible with any other fiber analyzer.

With a fast sensor the classical possibility to shift the average of a quality parameter to better economy after reduction of variations can be utilized.

AN INLINE SENSOR FOR FIBRE ANALYSIS

To put a fiber analyzer direct in the pulp line as an inline transmitter has so far been a completely utopia. But it is now a reality. It is now possible to monitor in real time what happens with the fibres in the process. This has been possible from a recent invention by Ola Johansson from InovoCell [8]. Fibre length, width, shape, area, fines etc. are measured for each object detected from a camera-based sensor placed directly on the process pipe. All types of statistics are calculated from this raw data. Refining is a very fast process. It is a question of seconds for the pulp to pass through a refiner. The response in fiber properties after a step change comes instantly. Grade changes in the stock preparation area will benefit from this fast transmitter. With the inline transmitter the process can be stabilized on target.

The transmitter is mounted in the process through a valve. The transmitter is dismountable through this valve without stopping the process for easy maintenance. The pulp is diluted directly at the inlet in the pipe. The diluted fibers are fed through a channel and through a measurement gap. The suspension is illuminated from one side of the gap and a camera on the other side takes images of the flowing fibers. The suspension is then fed back into the process. The dilution is controlled from the camera to keep the optimal consistency in the measurement gap.

A cleaning cycle keeps the measurement channel and gap clean. A control panel close to the transmitter includes pc, plc and valves for control of the transmitter. A small unit with few mechanical parts gives low cost and high reliability.

The direct measured signals or calculated estimations of sheet properties are transmitted to the DCS system for monitoring and control. It conforms to ISO standard for fibre length and other L&W fibre tester properties.

Figure 11. Pulse response; Refining energy and optical fines from L&W Fiber Quality Transmitter vs time Pulse width is 8 minutes

A unique technique for modeling of hand sheet properties from fiber properties shows promising correlations to known measurements like Tensile Index and CSF. The technique is based on a virtual hand sheet and engineering tools for calculation of mechanical constructions. In mechanical refining the return on investment can be calculated from
energy reduction alone and changes of traditional quality targets. Quality monitoring is needed for process optimization.

**INTEGRATED PULP AND PAPER QUALITY MONITORING AND CONTROL**

With automatic pulp quality testing the data can be integrated in the DCS and QCS systems for monitoring together with other process data and for control purposes. Measurements of final paper quality in an at-line profiler is very common today. It will be as common with online pulp quality data integrated in these systems. This type of system monitoring process data in real time gives an excellent possibility for optimization of the process.

**CONCLUSIONS**

L&W Pulp Tester is an online automatic wet lab for pulp quality and stock preparation. It operates according to standards for established properties and it uses the latest optical technique as well. It is designed to cover pulp quality for different pulps and it combines different techniques in order to get a solid base for modeling of sheet properties, which are difficult to measure directly in this kind of systems. Unique features are:

- Process consistency based on weight
- Coarseness
- Standard CSF, SR
- Standard Brightness, Colouretc
- Standard fibre length
- Conform to L&W single instruments and profiler (Autoline)

L&W Fiber Quality Transmitter is a new inline fibre quality analyzer. Unique features are:

- The only inline sensor for fibre quality
- Fastest sensor for fibre quality
- Simple system

**REFERENCES**

1. Hill, J. “Method and device for examining pulp for the presence of shives” US patent 4,037,966 filed May 12 1976
8. Johansson, O., Jackson, M., and Wild N.W. “Three steps to improved TMP operating efficiency, 2007 International Mechanical Pulping Conference, Minneapolis, USA