New Developments in Online Pulp Quality Measurements

Uniya Rakesh & Nigel Farrand

Metso Automation India Pvt. Ltd

1st Floor, DLF Building #10, Tower A, Cyber City, DLF City, Phase II, Gurgaon-122 002 (Haryana) INDIA

ABSTRACT

With developments in imaging technology, new and improved measurements are now available that permit the previously tedious laboratory analysis of fiber morphology to be performed with precision, automatically and online. While online fiber length and shive analysis are well established, the new image based measurement of the Metso Pulp Analyzer (Metso MAP) analyzer also allows for measuring other characteristics of the fiber such as width, curliness, kinks and amount of fine elements. Hardwood/softwood blend ratio, optical coarseness, external fibrillation, number of vessel cell elements or other particles and amount of detached fibrils can also be measured.

Background

Automatic optical fiber measurements date back to 1983, when the first automatic fiber length analyzer, the *FS100* was developed. This measurement, further refined in the later *FS200* from Metso, allowed for a quick characterization of fiber length and soon replaced the existing, tedious laboratory method in fiber length analysis to become the basis of the first standardized method, TAPPI T271.

Later, with the development of digital camera systems, the scope of measurement was broadened to measure other characteristics such as width, curliness, kinks and amount of fine elements with the *Metso Fiber Image Lab* laboratory analyzer. Also hardwood/softwood blend ratio, optical coarseness, external fibrillation, number of vessel cell elements or other particles and amount of detached fibrils could be measured by utilizing the ever increasing resolution of camera systems and increasing computing capacity. These new fiber morphology measurements are now available online, incorporated in the new Metso MAP Analyzer and combined with modern statistical methods, to provide a wealth of information on dynamic pulp qualities formally seen as only a snapshot through a laboratory microscope.

Fiber Morphology

The relation between various fiber characteristics and sheet properties is a widely researched field. In general, the literature agrees on correlation with fiber length and strength properties [Cowan 1995, Retulainen 1996], fiber width and zero-span tensile strength, elongation and tensile energy absorption as well as curl and breaking energy [Wathen 2006] to name a few. In a practical situation however laboratory methods are too slow and infrequent to have a great impact on real-time control of the papermaking process.

The morphological properties of a fiber cannot be considered as independent variables because applying mechanical treatment will always affect several properties simultaneously. Furthermore, the effect of the fiber properties with respect to desired sheet properties may be contradictory for instance decreasing tensile strength caused by decreasing fiber length may be compensated by increasing fiber flexibility and bonding area. Because of this, it is not enough to monitor single quantities, which is where the multiple fiber measurements of the new analyzer now enable not only analysis but also online process control. Additionally, statistical methods for extracting the useful information from numerous available fiber quality measurements have been further developed.

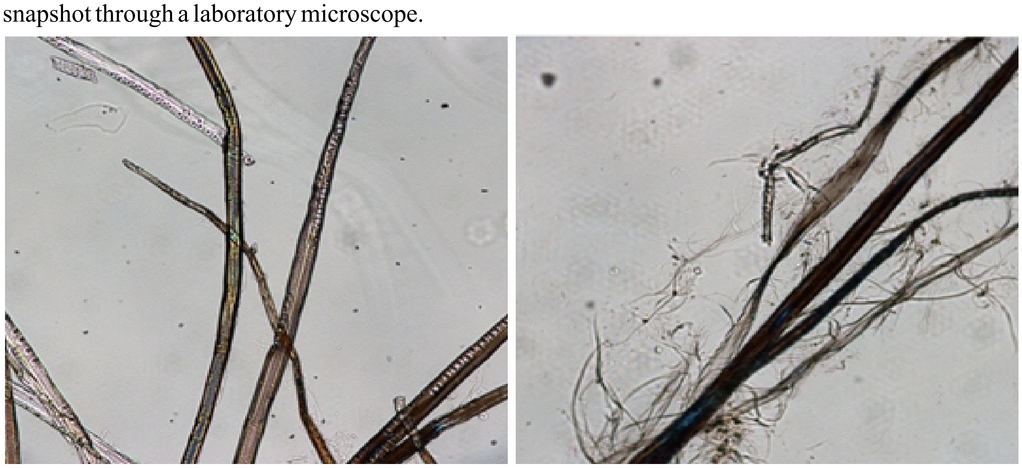

Figure 1: A microscopic image of less fibrillated and well fibrillated kraft fibers. Photograph: University of Oulu, Laboratory of Fiber and Particle Engineering

Fibrillation Measurement

External fibrillation (hereafter referred as fibrillation) refers to external delamination of fiber material primarily from the secondary S2 layer of the fiber wall. Figure 1 illustrates external fibrillation in a microscopic image.

Fibrillation is promoted by mechanical treatments in refiner stages, where shear forces from rotating refiner segments detach thread like fibrils from the fiber body. Fibrillation is desirable for a papermaker, as it rapidly increases the specific surface area of the fiber. The inter-fiber bonding area increases with increasing surface area, which has positive impact on sheet strength. Besides strength, the fibrillation may also affect sheet structure and optical properties. By suitable choice of refiner parameters (segment geometry, segment gap, refining load, throughput) it is possible to increase surface fibrillation while preserving fiber length and fiber strength.

The microscopic method for measuring fibrillation in laboratory is slow and non-standard. Different methods such as light microscopy, electron microscopy (SEM) and confocal laser microscopy have been utilized, with different methods for extracting qualitative result from images. Metso Fiber Image Lab was the first commercial device in market capable to measure fibrillation index automatically from a digital image. Metso Fiber Image Lab has two cameras, one with lower and another one with higher magnification, fiber length was measured from the first and fibrillation from the second higher resolution image.

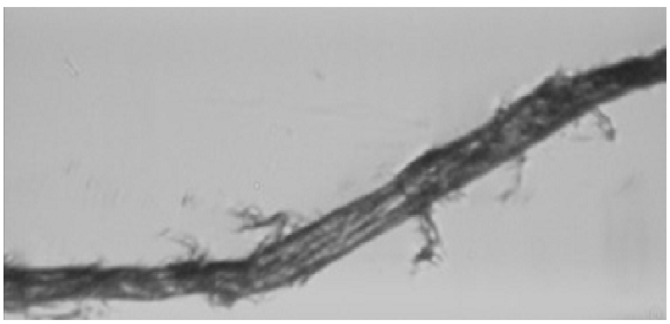

Figure 2: A fibrillated softwood kraft fiber in a kajaani FiberLab™ image. In this device a highly enlarged image is taken from the middle part of a fiber, one by one. Fibrillation index is calculated as the ratio of fibril area and the fiber trunk area.

With improved high definition cameras, a redesigned optical system and newly designed measurement cell, Metso MAP can now measure length, width and fibrillation from a series of high-definition images of several fibers at the same time. This brings an effective fiber length, width and other conventional measurements together with fibrillation and loose fibril measurements in a single high definition optical system capable of continuous online use. Figure 3 illustrates the caption of a digital image with well fibrillated fiber, acquired with Metso High Definition fiber module in a Metso MAP analyzer.

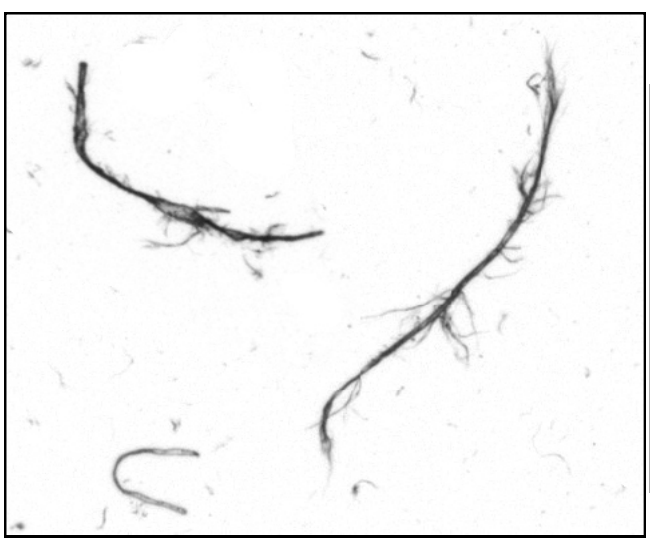

Figure 3: A caption from Metso High Definition Fiber Module™ image, showing several well fibrillated softwood Kraft fibers.

The performance of the Metso Fiber Imaging Module™ has been validated by the University of Oulu, Laboratory of Fiber and Particle Technology. This study and subsequent mill trials haveindicated that the Metso Fiber Imaging Module fibrillation measurement is repeatable and logical with respect to existing technology and qualitative validation by microscopy.

Estimating Sheet Properties With Multiple Fiber Measurements

With the vast amount data available from the Metso MAP analyzer, new challenges in data interpretation and handling arose. When studying correlations between analyzer results and laboratory measurements such as sheet tear and tensile, it is important to identify the relevant variables. In a simple case, correlation analysis can be used in order to find out simple relations. If one is able to have two completely identical pulp samples with the average fiber length being the only differing variable, a simple correlation analysis would be enough to analyze the effect of changing fiber length. However, it is impossible for instance to change only the fiber length in a refiner without affecting other fiber qualities as well. Therefore it is misleading to draw conclusions on the effect of fiber length alone, when other qualities such as curl, flexibility, fines and external fibrillation are changing simultaneously.

Multilinear regression is not sufficient method to extract meaningful data, as it does not allow redundant input variables and assumes noiseless data. Metso Data Modeler™ is a software tool, designed specifically for multidimensional data analysis and modeling. The modeling calculation is based on principal component analysis (PCA), a mathematical tool where the model is created by reducing the data to few prime components where many variables describe the same property (cross correlation). This allows for reducing the dimension of the data and removing systematic noise while preserving the variables that have significant variance with respect to the modeled quantity.

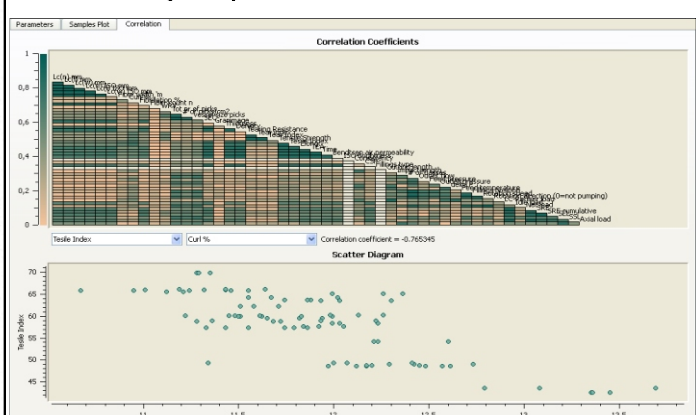

Figure 4: A correlation matrix in a typical data analysis situation. The number of variables makes the simple regression methods insufficient. Screen capture from Metso Data Modeler™

When interpreting the models, it is worth noting that the strong model cofactors do not necessarily describe the causality. Therefore, it is advisable to include only those variables in the analysis that can be expected to have causal relation with the modelled output. Furthermore, as the model cofactors indicate the gross effect of the modelled variables with all their cross correlations, caution is needed when drawing conclusions on the cofactor values. For instance, in the following case study, the fiber length had negative cofactor and fibrillation had positive cofactor in the tensile strength estimate. This does not indicate that fiber length and tensile strength would have negative correlation, which is contradictory to literature. Instead, it can be interpreted that fiber length may be sacrificed and yet better tensile strength obtained, if more fibrillation can be promoted.

Case study

Modeling Tensile Strength in A TMP Plant

Traditionally, thermomechanical pulp (TMP) refiners are operated to produce pulp with certain freeness and in some cases average fiber length. The freeness measurement is a direct measurement of free water removal, or free flow of water during the filtration of the pulp sample. This free water removal is affected by the hydrodynamic resistance of the pulp, which makes the freeness measurement an indirect measurement of aggregate surface area in the pulp. Therefore it is affected by the fiber size, fines fraction and the external fibrillation of fibers. If these factors change, freeness may remain stable even though the tensile strength in pulp laboratory handsheet changes.

Recently, a refining study was conducted on the effects of primary refining in a TMP plant. The study investigated the influence of refining energy on fiber properties, with a focus on fiber fibrillation. The main objective of the study was modeling and validating the tensile strength of the pulp based on the freeness and fiber measurements obtained from a Metso MAP online analyzer.

The samples were collected after the first stage refiner at approximately 7% consistency using automatic sampling devices. Refining energy step tests were executed by altering the segment gap and refining consistency with a total of 40 samples collected during one day to establish the model calibration data set. All variables from the analyzer were recorded during these bump tests, as well as the laboratory hand-sheet tensile strength.

The tensile model was accomplished using the Metso Data Modeler™ software program. The study indicated an extremely strong correlation between tensile strength and key measurements from the Metso MAP analyzer. The fibrillation measurement was one of the key co-factors in the model.

After the model co-factors were calculated, the model output calculation was implemented in "softsensor" software. This software is able to record process data and various analyzer and sensor data over a Modbus TCP/IP connection into one data table. Once the model, calculated with Metso Data Modeler, is brought to the softsensor it is able to calculate and transfer the modeled output to mill automation system. In this case, the model output (tensile strength estimate) was calculated using the Metso MAP™ measurement data and transferred into the mill DCS system.

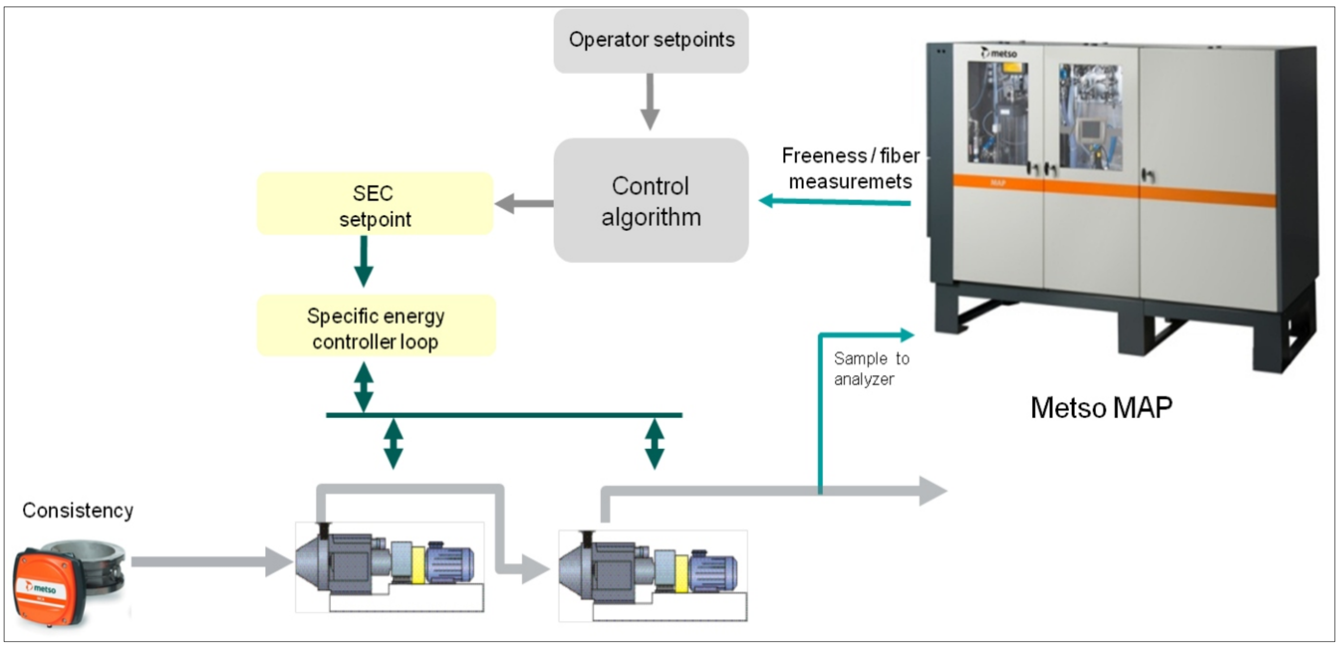

Figure 5. Metso MAP in refiner control

The accuracy and longevity of the model was verified by three separate validation bump tests at two months, four and nine months after the model was taken in use.

Figure 6. shows the original data used to build the model and 3 subsequent data sets used to validate the model was still tracking the tensile strength of the pulp.

The coefficient of determination for the model with respect to the nine month follow-up period was 0,90 with the root mean square of prediction 2 Nm/g (Figure 7). This indicates longevity in the model, very important when considering the usability of the model in a process control application.

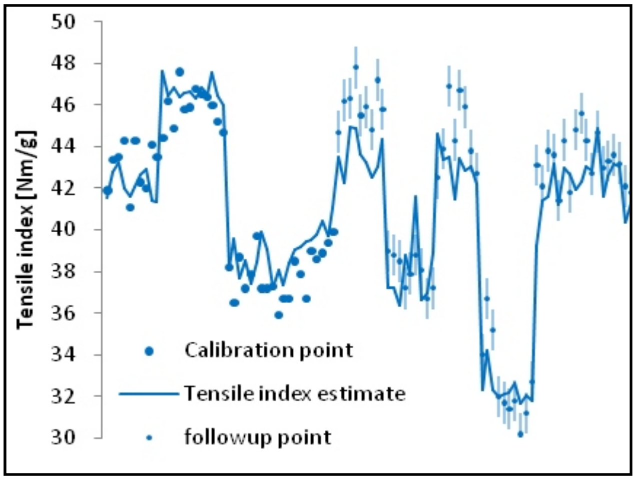

Figure 6: Tensile index estimate and calibration and validation data points. The validation period after the calibration is approximately 9 months. The accuracy of laboratory follow-up was considered as +/- 1 unit.

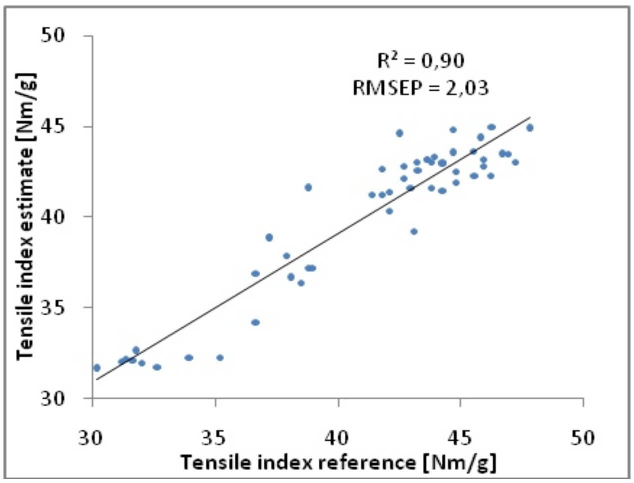

Figure 7: Model output (tensile index estimate) and laboratory reference from the nine-month follow up period. No drifting of the model could be observed during the follow up.

Conclusion

As a conclusion, it can be said that the new online fiber measurement provide numerous possibilities for process analysis, troubleshooting and control applications. The advances offered by this technology make it possible to augment specific laboratory tests with real-time measurements for process control and provide useful data for analytical purposes. When able to continuously monitor the quality parameters that are important to a specific mill, machine or grade, processes can be managed in more accurate manner. This will create benefits in form of reduced variation in quality and process parameters together with more efficient use of fiber resources.

Referenes

Cowan, WF (1995): Explaining handsheet tensile and tear in terms of fiber-quality numbers. TAPPI J 78(1): 101-106.

Jolliffe, I (1986) Springer Series In Analysis: Principal Component Analysis. New York, USA. Springer -Verlag New York Inc. p. 271. ISBN 0-387-96269-7

Laitinen, O (2012): Analyssi of the external fibrillation with Metso image analysis tools. University of Oulu, internal report.

Retulainen, E (1996) Fibre properties as control variables in papermaking? Part 1. Fibre properties of key importance in the network.

Paperi ja Puu 78(4): 187-194.

Wathén, R (2006): Studies on fiber strength and its effect on paper properties. Dissertation