

On-line measurement of strength and elastic properties of a running paper web

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PAPER MAKERS HAVE LONG DESIRED to measure strength properties of paper on the paper machine. Measuring tensile stiffness index (TSI) to date has only been possible off-line.

The benefits of an on-line strength sensor are obvious. A continuous, real-time display of TSI allows an operator to adjust the paper machine to optimum strength, cost, and quality parameters. Less off-quality production, faster grade changes, optimized furnish and refining, and improved process visibility are possible.

ULTRASONIC TESTING OF STRENGTH AND ELASTIC PROPERTIES

Ultrasonic testing of strength and elastic properties of paper has been in commercial use as a laboratory method for several years. It has overwhelming acceptance and has realized rapid growth as a testing method for use to optimize the papermaking process and verify quality to customers.

TSI is the ratio of stress to strain when the strain is sufficiently small that the sample returns to its original length after strain removal. TSI is a fundamentally important property of paper. It has therefore found increasing acceptance as a measure of the strength properties of paper. The strong correlation established in practice has allowed many mills to reduce traditional destructive testing because TSI can give the same results.

By measuring the velocity of ultrasound propagating in-plane through a paper sheet, the following algorithm can determine TSI:

$$TSI = v^2 C \quad (1)$$

where

TSI = tensile stiffness index, kNm/g

v = ultrasonic velocity, km/s

C = dimensionless constant related to Poisson's ratio for the material.

Measuring the velocity of the ultrasound in several sheet directions determines the TSI in all in-plane directions of the sheet.

DEVELOPMENT OF ON-LINE ULTRASONIC SENSORS

Several different techniques are already available that apply the ultrasonic testing method to an on-line sensor. They provide mixed results. The main problem has been transmission and reception of a repeatable ultrasonic signal in the moving paper web in the physically and acoustically harsh paper machine environment. Another problem is that many previous ultrasonic sensors have signal generation methods that can damage the paper.

METHOD

The method used here is unique compared with earlier concepts because it does not depend on a well-defined pulse signal. Instead, it measures only the propagation velocity of a continuous wide-band ultrasonic signal in the paper web. An

ABSTRACT

Measuring paper strength and elastic properties optimizes the papermaking process. A new method for such measurement on the paper machine uses a continuous stochastic ultrasonic signal instead of the traditional, well-defined pulse and uses advanced digital signal processing to give tensile stiffness index. This paper describes background of the method and experiences and applications from two mill installations.

Application:

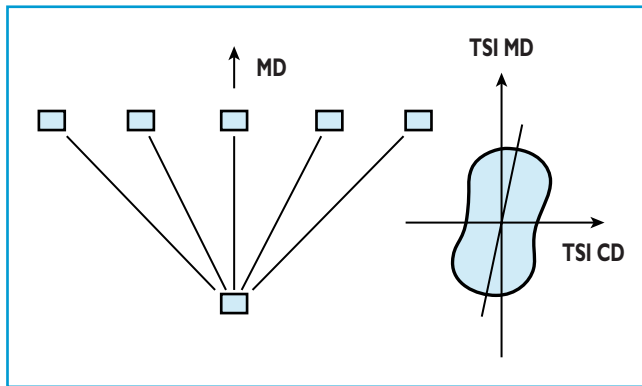
An ultrasound unit uses a continuous stochastic signal to give tensile stiffness index of paper on the paper machine.

important criteria is that it must be an ultrasonic signal with sufficient energy to overcome the low signal-to-noise ratio experienced in the paper machine.

Signal generation, detection, and processing

With a pulse signal, a very high amplitude is necessary to overcome machine noise. Total energy will be low and create measuring difficulties. The method in this application is a wide-band continuous signal that allows a signal with sufficient energy to remain in the paper web and therefore provide a useable measurement.

Two passive transmitters generate the source signal. The signal has a spectrum of 0–100 kHz. It is completely stochastic—completely random. Frequencies below 35 kHz are filtered out because of the surrounding machine noise. Frequencies above 70 kHz are also filtered out since the paper web dampens sound within a very short distance from the passive transmitters. A frequency band of 35–70 kHz therefore remains for use for repeatable propagation velocity measurements.



1. Continuous stochastic ultrasonic signal generated and received by multiple receivers

A reference microphone close to the passive transmitters and an array of measurement microphones—receivers—a specific distance from the transmitters determine the propagation velocity of the generated ultrasonic signal. The distance of the microphones from the paper web is critical for measurement repeatability since the velocity of ultrasound is much lower in air than in paper. The distance must therefore be as small and stable as possible. The measuring head has laser distance meters to control this parameter.

As noted, the generated signal is completely stochastic. The only variable is propagation time of the ultrasound in the paper between the transmitter and the receivers. Cross correlating the signals at the transmitter and receiver microphones creates a new function that reaches a maximum at a particular time. This time defines the time-of-flight of the generated signal between the transmitter and receiver and allows calculation of the ultrasound velocity in the paper web.

Instrument design

Figure 1 shows the parts of the sensor:

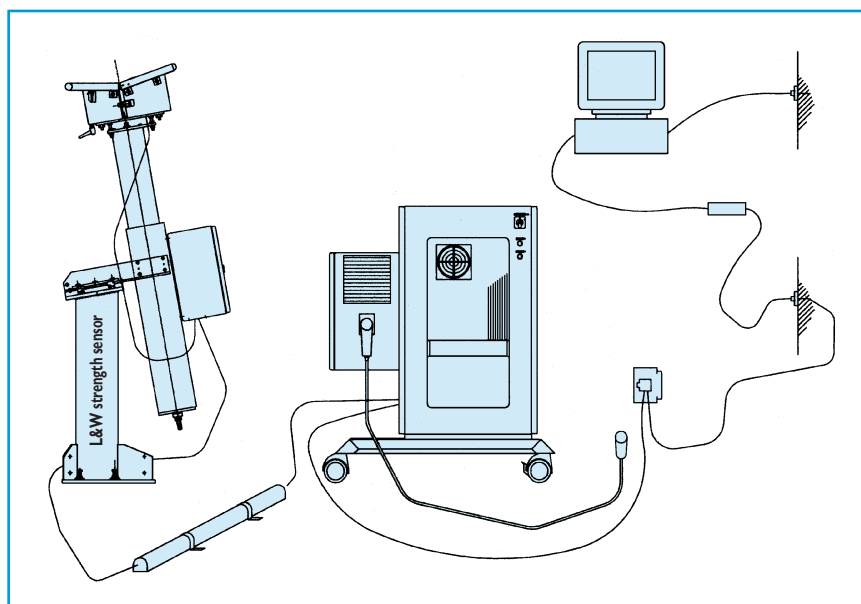
- Two passive transmitters made of industrial diamonds
- Reference microphone in direct conjunction with the passive transmitters for the generated noise signal
- Array of five receiver microphones 150 mm from the reference microphone (The array allows velocity measurements over ± 45 degrees of the paper web's machine direction.).

Using the five measured ultrasound velocities from the different angles, the transmitter measurement, and powerful digital signal processors gives the following key TSI values:

- TSI in machine direction (MD) relates to runnability problems on the paper machine and in printing presses including baggy edges, wrinkles, and breaks.
- TSI in cross direction (CD) relates to strength properties such as short-span compression test (SCT) and ring crush test (RCT), bending stiffness, shrinkage, and hygroexpansion across the machine.
- Tensile stiffness orientation (TSO) angle relates to dimensional stability for control of headbox balance.
- TSI MD/CD ratio relates to sheet squareness.
- TSI geometric mean has use with TSI ratio to optimize refining.

MILL EXPERIENCES

The systems installed on two paper machines have the parts of Fig. 2:



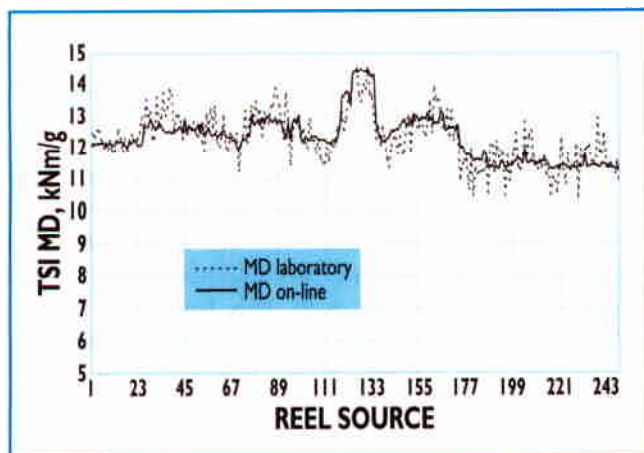
2. On-line strength sensor

- Measuring head mounted on a pneumatic stand
- Environmentally-hardened processing cabinet located near the paper machine
- Computer for presentation of the results in the machine tender's control room.

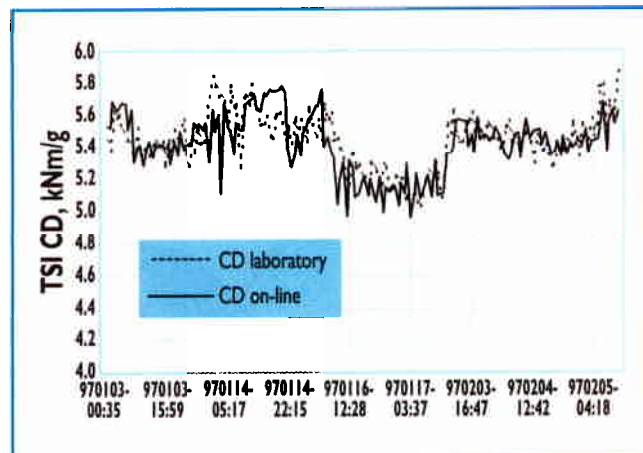
At both mills, the sensor installation is at the roll before the reel. The roll acts as a "holder" to enable the sensor to be located very close to the web with minimum risk.

APPLICATIONS

With continuous knowledge of the TSI of the product being produced, the papermaker has a new way to optimize the process. Instead of pro-



3. Point-by-point comparison of on-line TSI MD with laboratory TSI



4. Point-by-point comparison of on-line TSI CD with laboratory TSI

ducing "heavy" product to ensure meeting customer strength specifications for example, product can be produced at a lower basis weight.

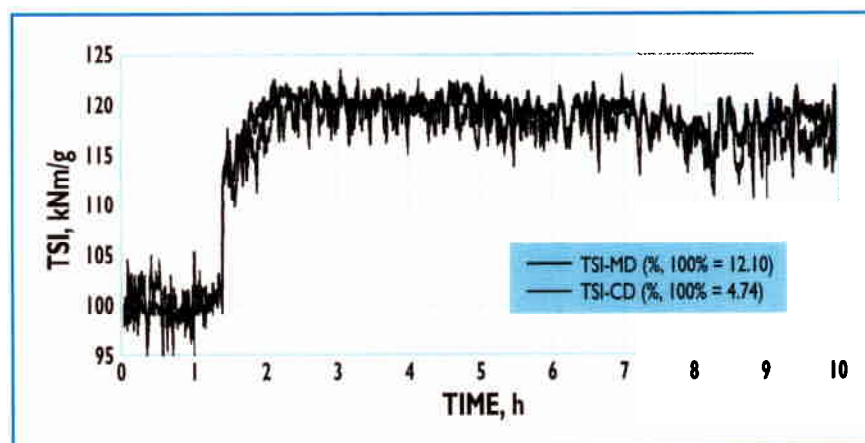
Changes in refining or furnish often control strength and stiffness. Optimization of these parameters can save significant money. Minimizing refining reduces energy consumption and can increase production for dryer-limited machines. Optimization of fiber mix by maximizing less expensive furnish is also possible.

The signal processing of the ultrasound signal is very demanding. The sensor measures in very short sequences totaling 250 ms. The cross correlation between the transmitter and receiver signals takes approximately 6 s. The different TSI/TSO values are updated on the operator's display every 6 s. The TSI results from the on-line sensor are very reproducible compared with a laboratory ultrasonic tester in a lab environment as Fig. 3 shows.

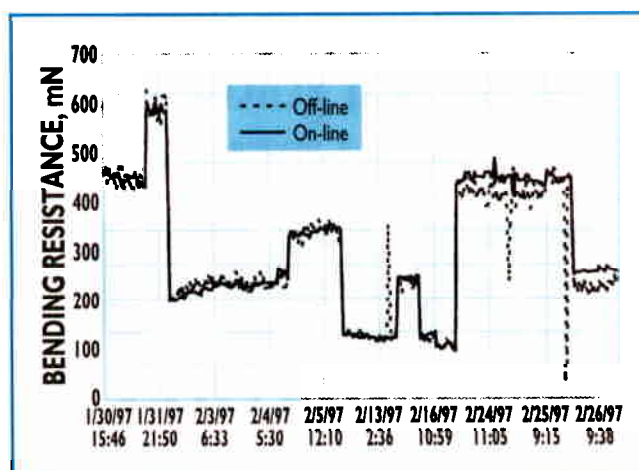
At one mill, the TSI values from the on-line sensor automatically combine with the moisture information from a gauging system scanner using the moisture content in the paper web at the same position as the ultrasonic sensor. This combination allows recalculation of the on-line TSI levels to the levels obtained in the laboratory after conditioning. This avoids a difference in this critical measurement as Fig. 4 shows.

PRACTICAL USES

Many applications for the on-line sensor and the information it provides are possible. The typical "real time" signal from the on-line sensor is very useful to optimize a paper machine. For example, the rapid feedback from the sensor at a grade change enables the papermaker to define the proper strength level for the grade being produced quickly as Fig. 5 shows. A resulting benefit can be

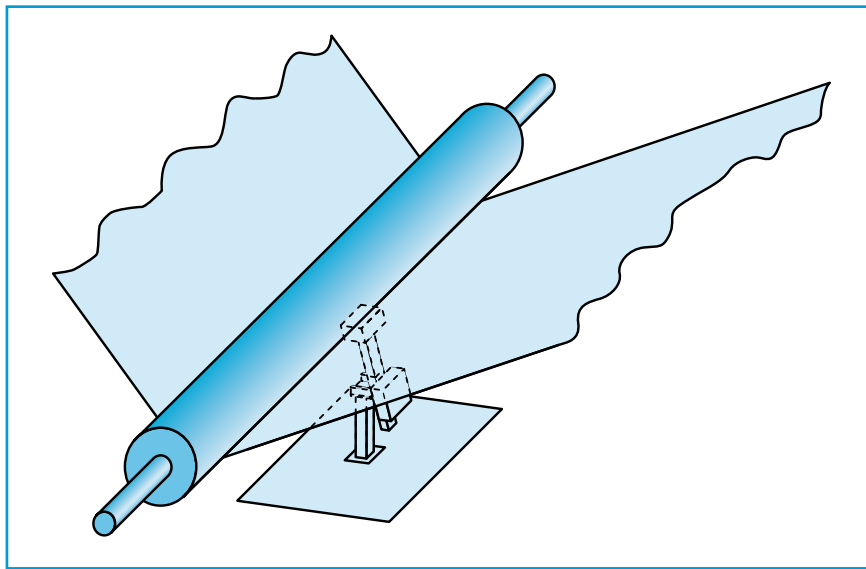


5. On-line TSI measures continuously during grade changes to provide valuable information



6. Point-by-point comparison of bending force calculated from the on-line sensor and laboratory bending force (The few excursions represent retests of out-of-sequence paper.)

the elimination of basis weight "overshooting." This would save considerable fiber.



7. On-line strength sensor with three measuring sensors

The main benefit experienced with the on-line strength sensor has been measurement of the directionality and strength and elasticity of a paper web. This has allowed optimization of the strength levels in a sheet with production of paper closer to a customer's specifications over a long period. Following are some examples of applications:

- TSI MD/CD ratio with the TSI geometric mean allows the papermaker to optimize refining in balance with the paper machine's capability to produce the proper sheet properties.
- TSI CD can be calculated into correlated bending stiffness—L & W bending resistance or Taber stiffness as Fig. 6 shows—or compression strength—RCT or SCT with basis weight and caliper information.
- TSI MD measurements have shown greater variations in the machine direction of the sheet than previously noticed with regular laboratory testing. This creates a new approach to produce more consistent quality in a paper and therefore a more optimized papermaking process.

Both installations are single position sensors. Since the total strength profile of a particular machine and grade is stable across the machine, one position is sufficient. A three-position system is available for those machines requiring significant headbox adjustments as Fig. 7 shows.

SUMMARY

This paper describes a new method for measuring paper strength and elastic properties during production on the paper machine. The system is very reliable and useful for a papermaker. Mill locations using the sensor have provided significant information. The strength sensor provides a clear picture of the machine adjustments necessary to optimize strength properties of a final product. **TJ**

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