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ON-LINE ESTIMATES OF STRENGTH

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Virtually all paper products must meet mechanical property specifications. This usually requires destructive testing that cannot be performed on the paper machine. It is possible, however, to measure other properties on-line which are also indicators of product quality or can be correlated with the strength properties. The elastic stiffnesses of paper are such properties.

The elastic stiffnesses* of any material are the ratios of stress to strain in the limit of small strain. For a material which has three mutually perpendicular symmetry planes, such as paper, nine independent elastic parameters are required to describe the three dimensional elastic response. The elastic properties of paper are very sensitive to paper machine operating variables (1) and also can be correlated with many of the usual strength tests (2).

Seven of the nine elastic properties of paper can be routinely measured nondestructively using ultrasound velocity techniques (3). The velocity of sound in a material depends upon the elastic properties and the material density. Using the appropriate propagation directions and wave polarizations, mass specific elastic properties of paper can easily be determined by measured ultrasound velocities. The square of the velocity (for a particular mode) is an elastic property divided by density, i.e., a mass specific elastic stiffness. Details of such measurements may be found elsewhere (3). At present, only three of the seven elastic stiffnesses have been measured on a moving paper web. These are the longitudinal planar stiffnesses in the machine direction, MD, and cross machine direction, CD, C_{11} and C_{22} , respectively, and the shear modulus, C_{66} . Poisson's ratio, ν_{MD-CD} , could be determined from on-machine measurements, but this has not been done yet.

Our first on-line instrument, tested about six years ago (4), used piezoelectric transducers mounted inside of wheels which rolled along the paper (see Fig. 1). The piezoelectric element in each wheel was coupled to a section of the rim of the wheel by an aluminum "button". Three such wheels were used, one serving as a transmitter and two as receivers. The receivers were positioned relative to the transmitter, with one about

20 cm away in the MD and the other about 20 cm away in the CD. All three wheels were synchronized so the buttons contacted the web at the same time. At web contact, the transmitter was excited with a burst of sine waves, so that it vibrated and created a mechanical disturbance in the paper. This disturbance propagated away from the transmitter in all directions. The MD receiver detected the longitudinal displacements of the disturbance after a time delay Δt_L . This time was corrected for nonpaper delays (determined during calibration) and the longitudinal velocity in the MD, V_{L-MD} , was calculated as the transducer separation distance divided by the corrected delay time. The value of C_{11}/ρ is $(V_{L-MD})^2$. C_{11} is the elastic stiffness which is closely related to the MD Young's modulus, E_{MD} . E_{MD} is typically 95% of C_{11} . The CD receiver detected a shear component of the initial mechanical disturbance, allowing C_{66}/ρ (or G_{MD-CD}/ρ), the specific shear stiffness, to be determined. From the two measured specific elastic stiffnesses, it is possible to predict C_{22}/ρ (approximately E_{CD}/ρ) (5).

Another instrument, developed later for application to lower basis weight sheets, has its transducers mounted in a cylindrical shell. To avoid cross-talk through the cylinder, the transducers are acoustically isolated from the shell of the cylinder. Laboratory tests with the cylinder have been made on a variety of coated and uncoated paper grades. Basis weights from about 12 g/m², to 500 g/m², at web speeds up to 650 m/min, have been studied. The cylinder device has improved the performance by using two receivers for each velocity measurement. These are spaced at different distances from the transmitter so that two delay times are determined. The velocity is then computed by finding the ratio of the difference in separation distances between receivers and transmitter to the difference in delay times. This procedure reduces the sensitivity of the measurement to the environment or to coupling variables between the transducers and the web, and eliminates the need for separate calibration to eliminate nonpaper delay times.

Figure 2 shows a typical output obtained during an extended mill trial (6,7) using a wheel type system. The NOW column is updated approximately every 40 seconds. The first two entries in this column are C_{11}/ρ and C_{66}/ρ . These were corrected for moisture content and temperature variations in the web, using moisture and temperature measurements taken from the scanning (Measurex) sensor. The third and fourth entries are the first two, respectively, multiplied by the basis weight (BW) at the location of the sensor. Next is $(C_{22}/\rho) BW$, computed as noted above. Squareness is the ratio, C_{11}/C_{22} . CD ring crush, Mullen (bursting strength), and CD STFI compressive strength are estimated from the measured values using empirical relationships established in the laboratory on samples taken from many reel turn-ups. The two columns on the right are the running reel averages and twice their standard deviations.

All of the work described thus far has been carried out by The Institute of Paper Chemistry, in part sponsored by the Fourdrinier Kraft Board Group of the American Paper Institute. The technology described has been licensed to two instrument manufacturers, AccuRay and Measurex. Both companies have prototypes and are negotiating with customers. I will discuss them in alphabetical order.

The AccuRay device uses the roll approach with a transmitter and two receivers. The transducers may be oriented to measure either shear or longitudinal waves in the paper. That is, C_{66}/ρ and C_{22}/ρ are measured. C_{11}/ρ can be determined from the two measured values.

*We avoid the use of elastic "constant", because for paper these parameters are seldom constant because of their extreme sensitivity to machine variables.

Figure 3 shows the sensor mounted on a corrugating medium machine during a mill test.

The Measurex system, shown in Fig. 4, apparently measures E_{MD} and E_{CD} . This device has been tested in several mills, as outlined in Fig. 5, including linerboard, multiwall sack, specialty kraft, and newsprint grades. Fig. 6 shows CD profiles of MD tensile strength for weights of linerboard. The agreement between the laboratory results and the predictions from on-machine measurements is good. The decrease in mechanical properties at the edges of the profile is commonly observed, even though the basis weight and moisture profiles may be flat. Figure 7 is a plot of CD tensile, as measured in the laboratory, versus CD tensile as estimated from on-machine measurements. Figure 8 is a similar graph showing laboratory MD STFI compressive strength vs. values estimated from on-machine measurements. Figure 9 shows end of reel data for bursting strength in a newsprint grade. Note the change in Mullen with time (or reel number), and the good agreement between lab and on-machine estimates.

All of the systems discussed so far are capable of continuously monitoring product quality in real time. The operators can immediately determine when product quality fluctuates. At the same time, the effects of changes made on the machine on mechanical integrity can be rapidly monitored (6). In this way the paper machine can be "fine-tuned" to give optimum product quality at the lowest possible cost.

The next step will be to use the sensor in automatic process control. For this purpose the basic measured parameters, the elastic properties, should be used to control setpoints. An important question to ask is, "What should be controlled on the machine?". You know the old papermaker said "Paper is made in the beater.", but the old papermaker was not completely right. Today's grades, whether commodity or specialty grade, require careful adjustment of the machine. In addition to refining, paper machine variables which should be considered include jet-to-wire speed differentials, wet pressing pressure levels, wet straining, and drying restraints. Of course, we cannot neglect furnish variables, yield or bleaching levels, HW to SW ratios, etc. We are now in a position, however, to monitor the impact of these process variables on sheet properties and to provide real time input for process control.

If more than one elastic parameter is measured on the machine, it should be possible to separate the effects of some of the papermaking variables. Measurements of in-plane shear stiffness, C_{66} or G_{MD-CD} , are sensitive to changes in density due to refining or wet pressing. They are less sensitive to those factors which affect directionality, such as jet-to-wire speed differentials, wet straining, and drying restraints. C_{11} and C_{22} are sensitive to all of the above machine variables. C_{33} , on the other hand, is independent of fiber orientation effects, but is extremely sensitive to wet straining (or draws), and is considerably more sensitive to refining than either C_{11} , C_{22} , or C_{66} . Thus the three measurements, C_{11} , C_{66} , and C_{33} would allow three of the machine variables, viz., refining, fiber orientation, and wet straining (assuming other variables are not changing) to be monitored separately.

It is conceivable that these three paper machine variables could be controlled automatically. However, CD control of mechanical properties on the machine will be considerably more difficult than for the MD case. Remember that CD profiles of mechanical properties can vary even though basis weight and moisture content are constant across the web. Since CD variations are primarily caused by local changes in fiber orientation and

nonuniform CD shrinkage, it will be a challenge to control them. Bell-shaped profiles, like those in Fig. 6, might be flattened by a spreader roll that resisted the normal CD shrinkage near the edges.

As on-machine measurements of elastic properties become more widespread and our experience grows, there will be more emphasis on their use as inputs for control purposes. Prior to that time, they will find immediate application as product quality monitors. Ultimately, these devices will lead to increases in machine productivity, more efficient use of raw materials and energy, and better product uniformity.

References

1. Fleischman, E. H., G. A. Baum, and C. C. Habeger, Tappi 65(10):115(1982).
2. Baum, G. A. "Paper testing and end use performance", Paper, March 19, 1984.
3. Mann, R. W., G. A. Baum, and C. C. Habeger, Tappi 62(8):115(1979).
4. Baum, G. A., and C. C. Habeger, Tappi 63(7):63(1980).
5. Baum, G. A., D. G. Brennan, and C. C. Habeger, Tappi 64(8):97(1981).
6. Habeger, C. C., and G. A. Baum, Tappi 69(6):106(1986).
7. Baum, G. A., and C. C. Habeger, "On-line Measurement of Paper Mechanical Properties", Project 2692-4 Progress Report One. Fourdrinier Kraft Board Group, The American Paper Institute, May 15, 1985.

Acknowledgements

We are indebted to AccuRay Corporation for providing Fig. 3 and to Measurex Corporation for providing Figs. 4-9.

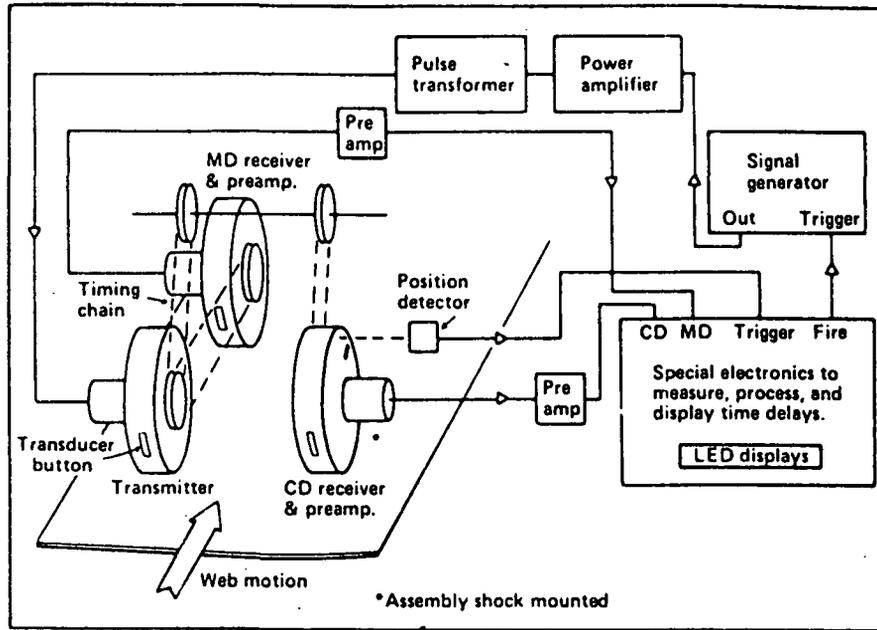


Figure 1. Schematic of the first on-line ultrasonic velocity gage.

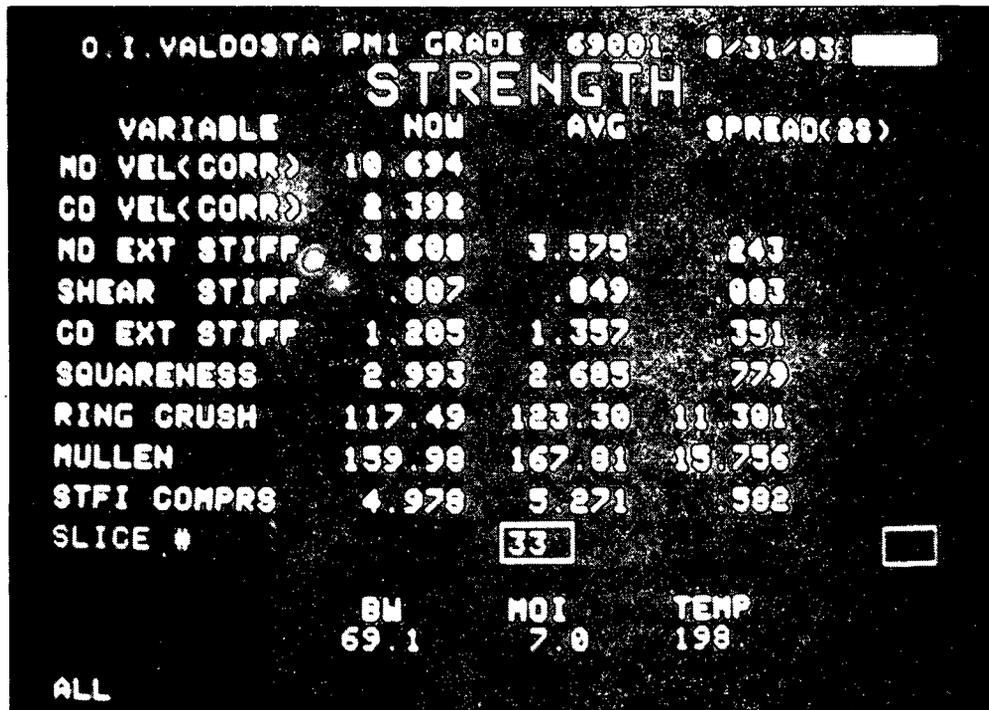


Figure 2. CRT display for IPC field trials.

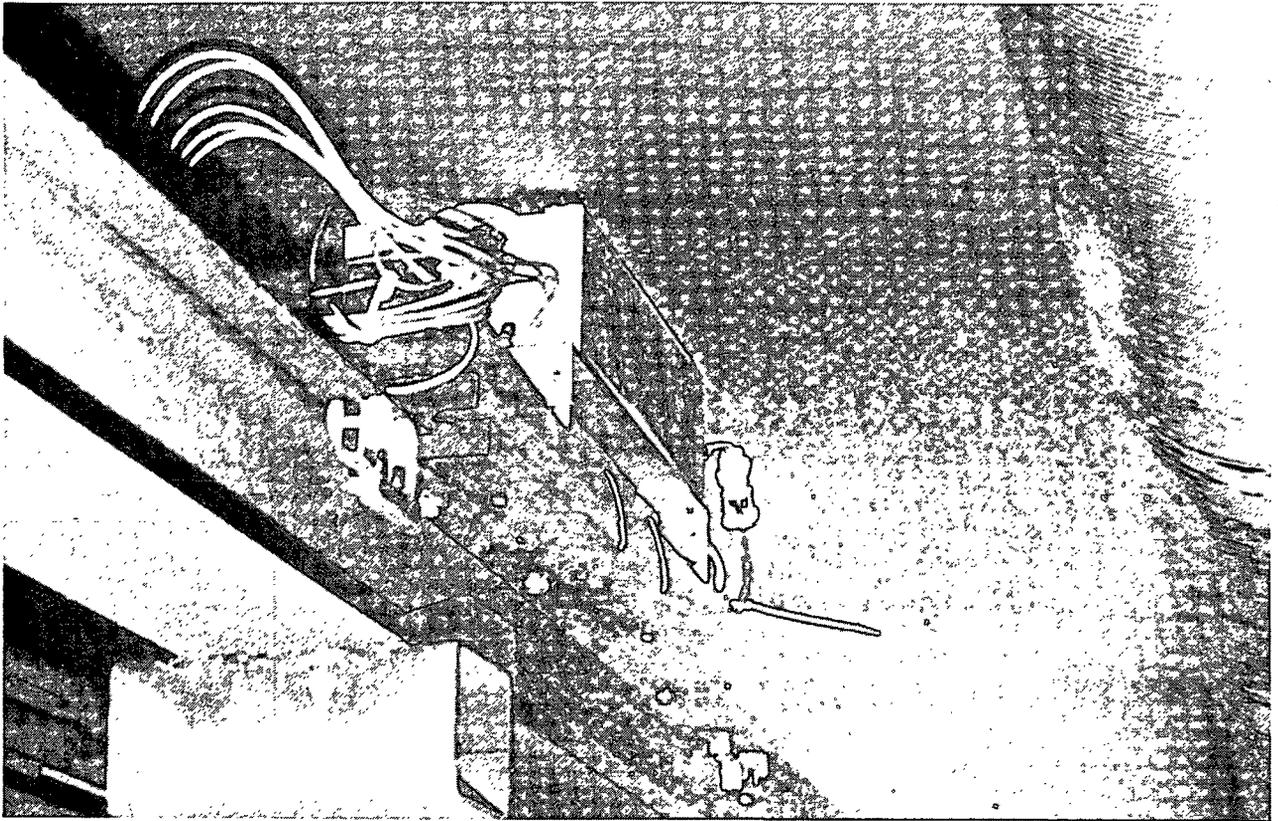


Figure 3. AccuRay prototype during field trials.

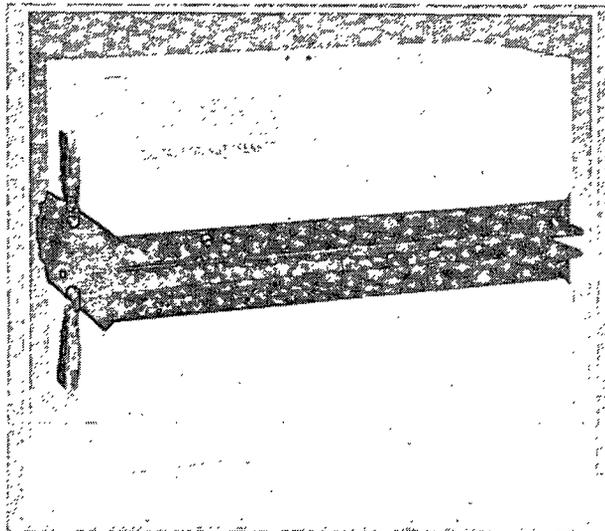


Figure 4. Measurix digital strength sensor.

DIGITAL STRENGTH SENSOR INSTALLATIONS

CUSTOMER	LOCATION	PRODUCTS	MEASUREMENTS
1. Longview Fibre	Longview, WA	26-33# Linerboard (127-161 GSM) 50-75# Multi-Wall Bag (81-122 GSM) 50-65# Guming Paper (81-106 GSM) 21# Specialty Kraft (103 GSM)	Mullen, MD & CD Tensile, MD & CD STFI
2. U.S. Confidential	Confidential	26-61# Linerboard (127-298 GSM)	Mullen, MD & CD Tensile, MD & CD STFI
3. Consolidated Bathurst	Shawinigan, QUE	30# Newsprint (48 GSM)	Mullen, MD & CD Tensile, MD & CD TEA
4. Consolidated Bathurst	Shawinigan, QUE	30# Newsprint (48 GSM)	Mullen, MD & CD Tensile, MD & CD TEA

Figure 5. Measurex field trials.

LINERBOARD

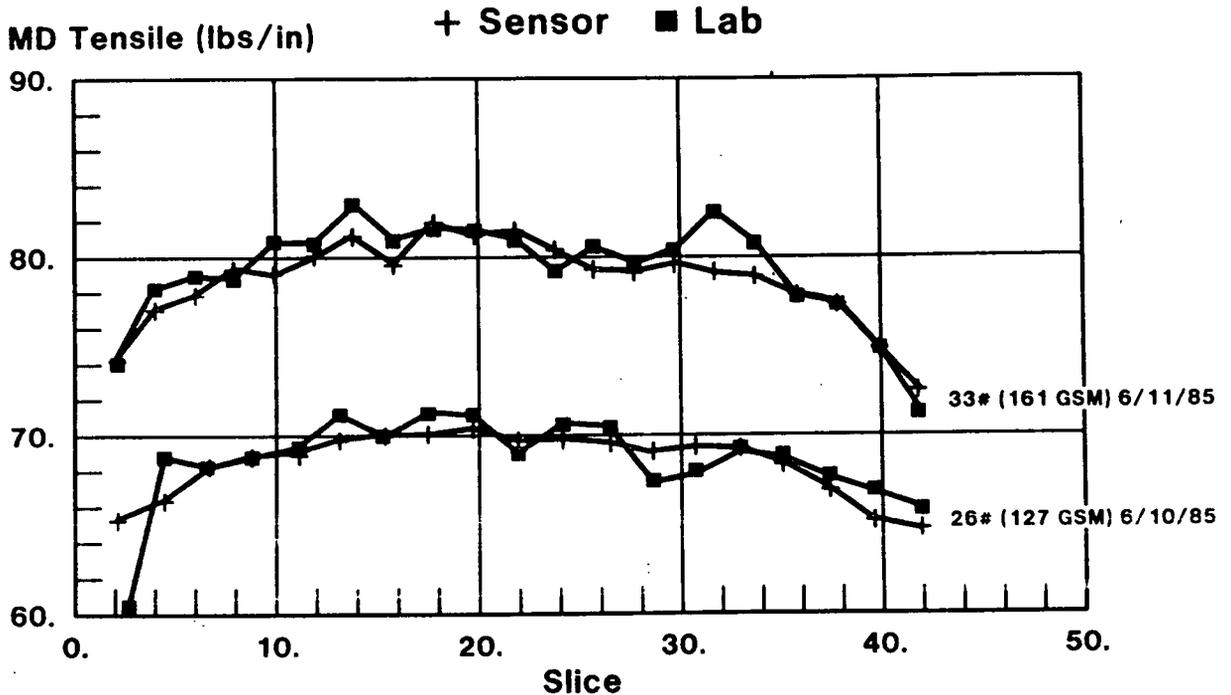


Figure 6. Linerboard CD profiles.

26&33# LINERBOARD, JUNE '85

Lab CD Tensile

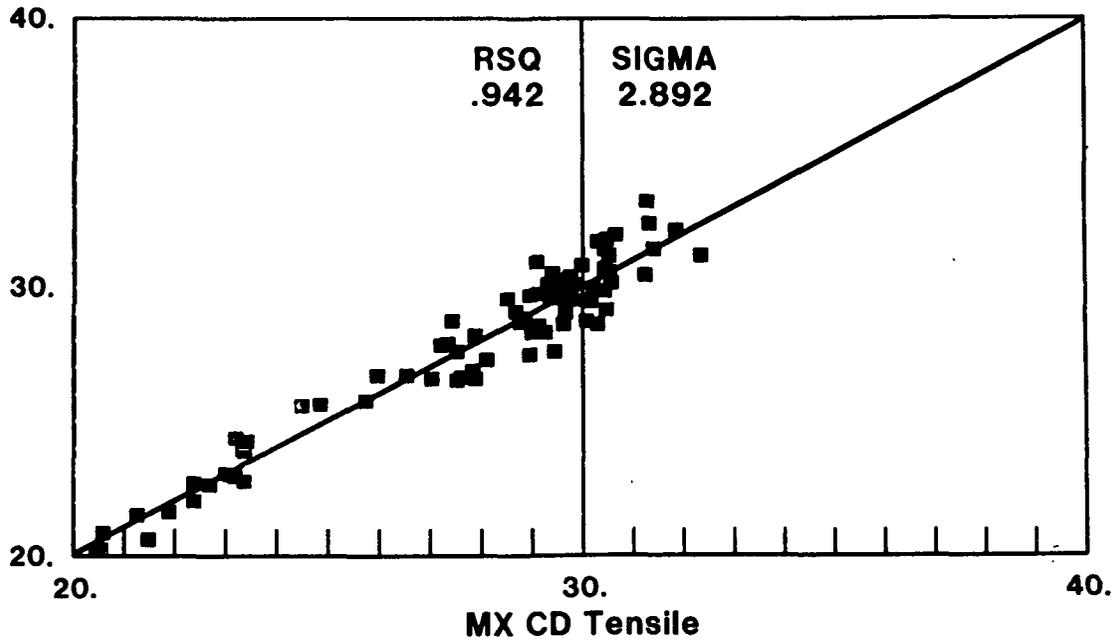


Figure 7. Comparison of laboratory measurements and on-machine estimates of CD tensile strength.

26&33# LINERBOARD, JUNE '85

Lab MD STFI

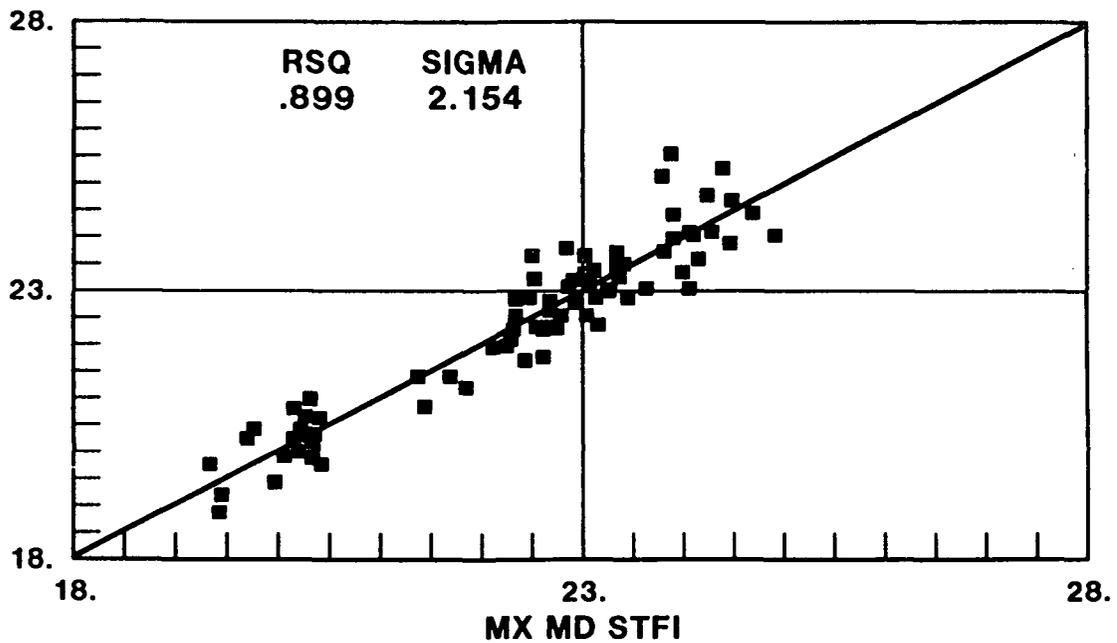


Figure 8. Comparison of laboratory measurements and on-machine estimates of STFI compressive strength in the MD.

30# (48 GSM) NEWSPRINT, SCAN AVG. NOV '85-JAN '85

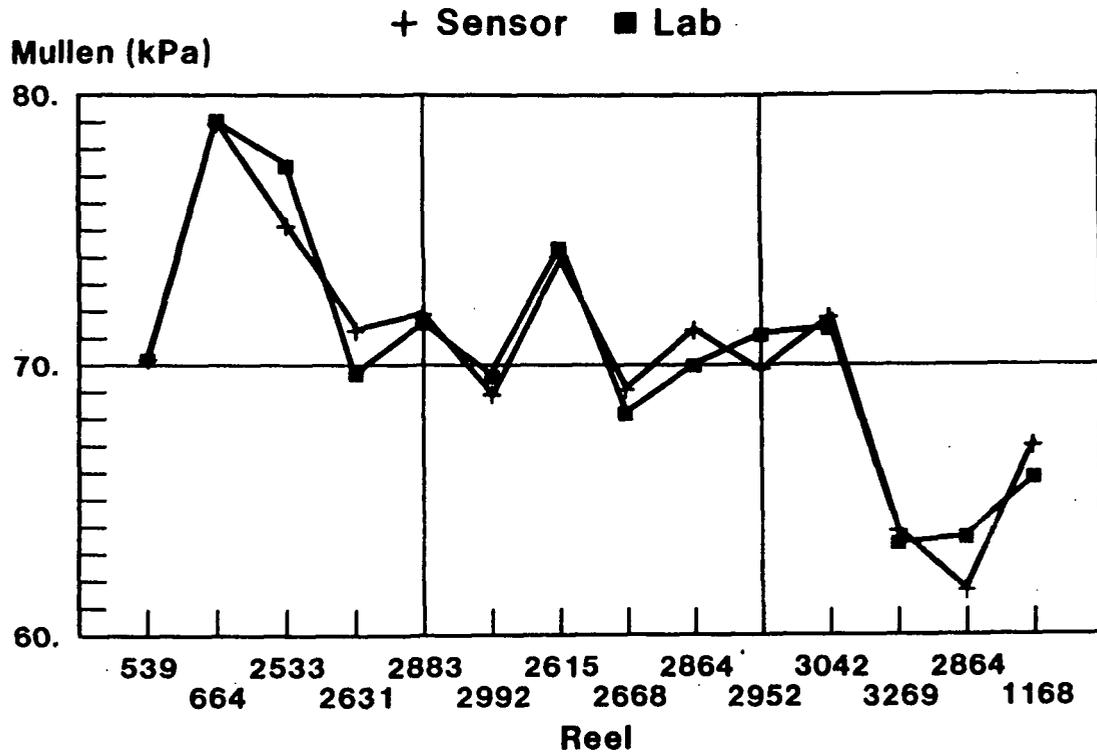


Figure 9. Changes in bursting strength plotted against reel number. Laboratory measurements compared with on-machine estimates.