Using Ultrasonic Elastic Modulus and Stiffness Data

As paper companies struggle to remain profitable, a flat economy puts big pressures on mills to continuously find ways to lower costs. Manufacturers are being forced to look at both traditional and non-traditional ways of running their operations profitably today. Traditional ultrasonic test instruments, notably L&W's TSO, have been used for years with a limited focus on fiber orientation.

Taking a non-traditional approach, SoniSys has developed ultrasonic instruments that measure not only tensile stiffness orientation, but also MD, CD, and ZD elastic modulus and stiffness. It has been suggested by researchers which include Charles Green and Gary Baum that elastic modulus can be a key factor in developing predictors for other properties and that models for predicting paper properties should include (specific) elastic modulus.

The data from the SoniSys OPUS 3-D can be valuable throughout the mill. Ultrasonic testing can be more sensitive and has better repeatability than some destructive test methods so subtle process changes can be detected that might have previously gone unseen. This could also lead to discoveries in areas of fiber and fiber refining; starch and additives usage; and could be used to find opportunities to save energy without compromising the quality of the final product, especially in the drying and calendering sections. Three-dimensional modulus data is also very valuable in pre-engineering packaging solutions using modeling software.

Below you will find excerpts from various published literature describing many ways that modulus and stiffness values may be used in the paper industry today.

From http://ipst.gatech.edu/testing_services/paper_physical_testing/lectures/ME Physical Properties of Paper Lecture 05: Ultrasonics.pdf:

Papermaking Processes vs. Paper Elastic Stiffness Properties

Elastic Stiffness Constants	Refining Level	MD/CD Anisotropy Ratio	Wet Pressing Level	MD Wet Straining Level	Restrained Drying
	From Low To High	From Low To High	From Low To High	From Low To High	From Full Restraint To CD only
MD:C11	↑	↑	↑	↑	0
CD:C22	↑	↓	↑	↓	↓
ZD:C33	↑	0	↑	↓	0
MD-CD:C66		↓	↑	0	
MD-ZD:C55		↑	↑	↓	
CD-ZD:C44		↓	↑	↓	

Prediction of End Use Performance Using Elastic Parameters

Property	Elastic Parameters
MD Tensile Strength	C_{11}
CD Tensile Strength	C_{22}
ZD Tensile Strength	C_{33}
MD/CD Tensile Ratio	C_{11}/C_{22}
MD Bending Stiffness	$C_{11}T^3$ (T=Thickness)
CD Bending Stiffness	$C_{22}T^3$ (T=Thickness)
Internal Bond Strength	C_{33}
Bursting Strength	$C_{11}+C_{22}$

From Vol 77, No 1, Tappi Journal, by John Waterhouse, "Ultrasonic testing of Paper and Paperboard: Principles and Applications":

"using the relationship: $C_{55}/\rho = \text{constant } ((C_{11}/\rho \times C_{33}/\rho))^{1/2}$, where ρ=density, we have:

$$\text{MD Compressive Strength} = \text{constant} \times ((C_{11}/\rho)^{3/4} \times (C_{33}/\rho)^{1/4}$$

$$\text{CD Compressive Strength} = \text{constant} \times ((C_{22}/\rho)^{3/4} \times (C_{33}/\rho)^{1/4}$$

$$\text{MD/CD Compressive Strength Ratio} = ((C_{11}/\rho) \times (C_{22}/\rho))^{3/4}$$ "

From PTN112 ELASTIC MODULUS PREDICTION AND UTILIZATION by Charles Green, © 1998-2001 techman@papercurl.com & http://www.PaperCurl.com :

Effects of wet straining and shrinkage on ES

Treatment	% change in		
	ESmd (C_{11})	EScd (C_{22})	ESz (C_{33})
1% wet strain	10	-10	-20
1% shrinkage MD	-10		
1% shrinkage CD		-10	

Summary of effects on paper elastic modulus (in percent change)

Fiber orientation (MD/CD 2.0 +/- 0.4)	+/- 10 MD -/+ 10 CD
Drying shrinkage (MD or CD)	-10%/1%shrinkage
Wet strain (1% MD)	+10 MD -10 CD -20 ZD
Sheet density (0.6 to 0.8) (1.6-3.3 MD/CD modulus ratio)	+10
Furnish additives: +2% starch +5% filler +2% moisture	 +10 -9 -10
Bonding (600 to 400 CSF)	+
Formation(+300% COV)	-45
Recycling (100% recycle estimate)	-15 to -25

Summary of what affects fiber elastic modulus (in percent)

Wood Variations	
softwood	+/- 14
hardwood	+/- 21
combined	+/- 25
Recycling	-15 to -25