Ultrasonic Instruments for Non-Destructive Testing

OPUS 3-D

3-Dimensional Ultrasonic System

OPUS 3-D combines In-Plane, Out-of-Plane, and Polar Diagrams in one easy to use non-destructive ultrasonic test instrument. OPUS 3-D provides a method of evaluating mechanical properties such as Tensile Stiffness, Young's Modulus, and Poisson Ratios of materials like papers, plastics, composites and thin films.

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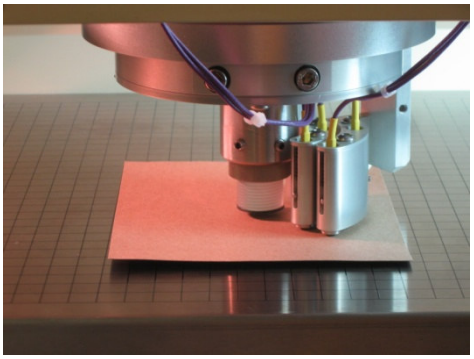
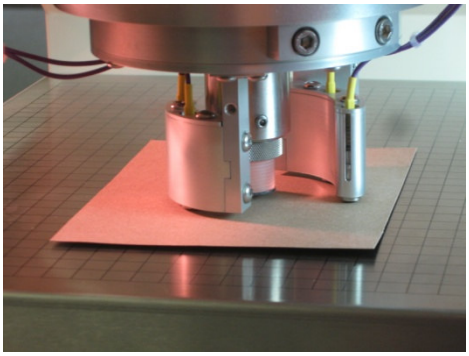
SCOPE

OPUS 3-D integrates in-plane and out-of-plane ultrasonic sensors together with soft-platen caliper in a unique, user-friendly instrument. It is designed for non-destructive tests on flat, flexible materials, even those that have increased moisture levels. Such materials include paper, tissue, board, plastic film, composite materials and gypsum. OPUS 3-D provides a number of measurements based on the principles of ultrasonic wave propagation and detection. Measurements include Soft-Platen Thickness (at 50kPa); MD-, CD-, and Z-Direction Specific Stiffness, Elastic (Tensile) Stiffness, and Young's Modulus. These measurements provide valuable data that can be used in Pre-Engineering and Product Development, Process and Quality Control, and Performance Prediction.

FUNCTION

In-plane Testing





Two pairs of transducers are used for the propagation and detection of Lamb (or plate) waves in the plane of the sample. One pair is used for the propagation of longitudinal waves and one pair for shear waves. Each pair comprises a transmitter and a receiver. Longitudinal and shear transmitters are mounted on the outer rotating arm, longitudinal and shear receivers are mounted on the inner rotating arm. The rotating arm arrangement allows velocity measurements at any angle with respect to machine direction and provides easy determination of the stiffness orientation angle (SOA), also referred to as a Polar Diagram. Moreover, the use of longitudinal and shear transducers enables the determination of four elastic stiffness constants, from which engineering constants such as the Young's Modulus and Poisson Ratios can be determined for the x-y plane. The detection method relies on the robust near-far detection approach to gather measurements insensitive to mechanical and electrical transducer properties, low and high frequency noise, and ultrasound propagation differences between different paper grades.

Out-of-Plane Testing

Two identical piezoelectric ceramic transducers are mounted vertically to send and receive longitudinal waves in the thickness direction of paper. These transducers are terminated by plastic delay lines to prevent the transmitted ultrasonic pulse between the transducers from being corrupted by reflected pulses. Thin neoprene tips are applied to the delay lines to optimize acoustic coupling with the test sample. Thickness measurements are required to calculate the sound velocity so a thickness gauge is integrated to the top transducer assembly. The top transducer is fitted with a dead weight. Since the fibrous structure of most materials is pressure-sensitive, Out of Plane (OP) velocity measurements and thickness are typically made at the TAPPI standard load of 50kPa (TAPPI Test Method T 411 and T 551).

The top transducer is raised and the sample is inserted in the gap. The transducer is lowered at a controlled rate and the test material is squeezed between the two transducer assemblies. The measurement is made after a fixed amount of time to allow for the neoprene and sample coupling to stabilize.

How to Use the Data

Advances in ultrasonic instrumentation have enabled growth in the number of applications, the types of materials tested, and the replacement of time-consuming destructive testing. Applications include areas such as:

- Manufacturing process
- Product failure properties
- Additive assessments
- Product characterization
- Product modeling and development

In-plane and out-of-plane elastic parameters have been shown to correlate with failure tests such as:

- MD, CD, and ZD Tensile Strength
- MD and CD Compressive Strength
- MD and CD Bending Stiffness
- Internal Bond Strength
- Bursting Strength

The polar diagrams have long been used as a significant tool that relates the headbox design and maintenance with problems associated with curl and wrap. Process changes such as furnish, refining, forming, wet pressing, drying, and calendaring have been observed with respect to a change in the elastic stiffness properties in one or more directions of the material under test (Fleischman et al., 1982; Berger and Baum, 1985). Habeger and Whitsitt indicated that the ZD stiffness is important in modeling the in-plane compressive strength of paperboard, and, in a 1987 TAPPI Journal article, Whittsitt and Baum stated that ZD longitudinal stiffness (Ez) correlates with the retention of medium compressive strength during corrugation.

These findings support the idea proposed by Baum in 1987 that the measurement of elastic stiffness could serve as the basis for real-time control of the manufacturing process and could be used to optimize the end-use performance of products.

SoniSys OPUS 3-D Complete Test Results

File Name:	P14 2-2 CIR3_3D_20100610_152246.txt
Specimen ID:	P14 2-2 CIR3
Test Description:	OPUS3D-0001
Test Date:	Thursday, June 10, 2010
Test Time:	3:22:46 PM
ZD Loading Pressure:	50.0 kPa
Test Repetition(s):	3
Grammage:	207.0 g/m^2

	Min	Mean	Max	StDv	%COV	Units
Soft-platen Thickness	256.8	259.5	260.8	2.3	0.9	um
Soft-platen Density(rho)	793.7	797.9	806.2	7.2	0.9	kg/m^3
C33/rho:ZD Long Spec. Stiff	0.1700	0.1729	0.1747	0.0026	1.5	(km/s)^2
C33: ZD Long Elastic Stiff	0.1370	0.1379	0.1387	0.0009	0.6	GPa
ZD Young's Modulus	0.1370	0.1379	0.1387	0.0009	0.6	GPa
ZD Velocity	0.4123	0.4158	0.4180	0.0031	0.8	km/s
Q11/rho: MD Long Spec. Stiff	13.281	13.645	14.096	0.414	3.0	(km/s)^2
Q11: MD Long Elastic Stiff	10.541	10.889	11.364	0.426	3.9	GPa
MD Young's Modulus	10.098	10.385	10.703	0.304	2.9	GPa
MD Long Velocity	3.644	3.694	3.754	0.056	1.5	km/s
Q22/rho: CD Long Spec. Stiff	4.946	5.135	5.274	0.170	3.3	(km/s)^2
Q22: CD Long Elastic Stiff	3.987	4.096	4.186	0.101	2.5	GPa
CD Young's Modulus	3.755	3.908	4.010	0.135	3.5	GPa
CD Long Velocity	2.224	2.266	2.296	0.038	1.7	km/s
Q66/rho: CD Shear Spec. Stiff	2.846	2.860	2.881	0.019	0.7	(km/s)^2
Q66: CD Shear Elastic Stiff	2.259	2.282	2.301	0.021	0.9	GPa
MD-CD Shear Modulus	2.259	2.282	2.301	0.021	0.9	GPa
CD Shear Velocity	1.687	1.691	1.697	0.005	0.3	km/s
Q12/rho: 45 Shear Spec. Stiff	1.634	1.788	2.013	0.199	11.2	(km/s)^2
Q12: 45 Shear Elastic Stiff	1.297	1.427	1.623	0.172	12.1	GPa
45 Shear Velocity	1.687	1.724	1.744	0.032	1.9	km/s
MD-CD Poisson's Ratio	0.120	0.131	0.143	0.011	8.6	
CD-MD Poisson's Ratio	0.315	0.349	0.407	0.050	14.4	
MD-CD Stiffness Ratio	2.518	2.661	2.850	0.171	6.4	

A sample report of OPUS 3-D Complete Test Results

OPUS 3-D

3-Dimensional Ultrasonic System

Instrument Specifications

- Size: Depth=20”, Height= 22”, Width=12”
- Weight= 70 lbs
- Required Voltage: 100-240 ac, 2.0 A, 50/60 Hz
- Single-Board Computer: 650MHz CPU w/ 512M RAM using Windows XP Embedded
- Operator interface: 256 color touch screen monitor
- Data Ports: (2) USB for Memory Stick and Printer (both included), (1) LAN, (2) Serial
- Generates Excel compatible data files for data analysis
- USB Printer and Memory Stick
- Calibration Shim Set

In-Plane Specifications

- Test area diameter: 75 mm (50mm effective area)
- Minimum specimen area diameter: 100mm
- Thickness: for Paper: 20 – 2000µm, and up to 10000µm (0.4 in.) for composites and plastics
- Bender-type bimorph transducer (4)
  - Spring-loaded contacting blades
    - Length: 5 mm
    - Width: 0.65
  - Operating frequency: 100 kHz
- Testing Modes:
  - MD and CD Longitudinal
  - 45-degree and CD shear
  - Longitudinal Polar diagram at 9, 11.25, 18, 22.5, or 45 degree increments

Out-of-Plane Specifications

- Test area diameter**:** 19mm
- Minimum specimen area diameter: 25mm
- Thickness: for Paper: 20 – 2000µm, and up to 10000µm (0.4 in.) for composites and plastics
- Loading pressure 50kPa ± 2kPa
- Piezoelectric ceramic transducer assemblies (2)
  - Removable soft-platen terminated plastic delay lines
    - Length: 15 mm
    - Rubber disc thickness: 0.76 mm (0.030 inch)*
  - Operating frequency: 1 MHz *
- Testing Mode:
  - ZD Longitudinal

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