“redefining the limits of ultrasound”

Non-Contact Ultrasonic Inspection for Continuous Feedback in Manufacturing

JEC Europe
Paris
March 12, 2013
We will explore non-contact ultrasound (NCU), the advantages of continuous inspection and applicability of NCU to composite analysis.
Significant advancements in non-contact ultrasound allow for high performance and widespread applicability

**Elements of Non-Contact Transducers***

- Transition layer and matching layers provide efficient transmission through air
- Optimized for frequencies between 50 kHz and 5 MHz
- Gas matrix piezoelectric (GMP)* composite allows for enhanced performance at frequencies between 50 kHz and 500 kHz
- High quality results achieved with many composite materials

*SUS and International Patents
Through transmission is the most applicable and robust method of non-contact analysis.
For most analyses in non-contact ultrasound, it is easiest to use the direct transmission route.

- Direct transmission route
- Thickness reflection route
- Material surface reflection route

Transmitter side surface reflection
Receiver side surface reflection
The key ultrasonic measurement through non-contact through transmission is attenuation or transmittance.

Transmittance in Material, $T_m (\text{dB})^*$

$$T_m = T_c - T_a$$

$T_c (\text{dB})$ transmission in air + material

$T_a (\text{dB})$ transmission in air column

Material Transmittance is related to material texture, $Z$, homogeneity, and other physical characteristics.
Material Velocity is often directly related to material density

### Material Velocity, $V_m$ when thickness is known

\[
V_m = \frac{d_m}{t_{am} - (t_a - t_c)}
\]

- $d_m$ material thickness
- $t_{am}$ tof in air corresponding to $d_m$
- $t_a$ tof in air
- $t_c$ tof in air + material
- $V_a$ air ultrasound velocity

\[
t_{am} = \frac{d_m}{V_a}
\]

### Material Velocity, $V_m$ when thickness is unknown

\[
V_m = \frac{d_m}{t_{am} - (t_a - t_c)}
\]

\[
d_m = V_a \times t_{am}
\]

\[
t_{am} = t_a - \left( \frac{t_1 + t_2}{2} \right)
\]

- $t_1$ round trip tof from transducer 1 to materials surface
- $t_2$ round trip tof from transducer 2 to material surface

### Material Velocity Equivalent, $V_e$ when thickness is known

\[
V_e = \frac{d_m}{\delta_t}
\]

- $\delta_t = t_a - t_c$

*Indirectly proportional to $V_m$

Easy to measure, does not require air/gas velocity
Closing the loop on a manufacturing process allows for instant feedback and process control.

- Can make adjustments during process to remain within control limits
- Enables continuous process improvement
- Provides further product information and creates opportunity for product improvement
- Allows for 100% inspection of manufactured product
  - Identify regions of defective material
  - Certification of sold product
Non-Contact Ultrasound can measure key material properties in many composite materials

- **Prepreg**: Carbon Fiber, Glass Fiber, etc...
- **CFRP & GFRP**
- **Honeycomb Sandwich structures**
  - Nomex core and aluminum core with composite & Al skins
- **Carbon-Carbon composites**
  - Autoclave oven fixtures
  - Disk Brakes (aircraft and automobile)
- **Foam Core sandwich structures**
Using a bench-top C-Scan system, we can characterize various composite materials.

**System Features**

- Tone-burst pulser up to 375V, with frequency range from 50 kHz to 1 MHz
- 4-channel receiver up to 84 dB gain
- Software features:
  - Cross-sectional profiles for quantitative analysis
  - Absolute transmittance and reflectance measurements
  - Palette selection for easy accept-reject limits
  - Parametric correlation of acoustic vs. material characteristics
  - Statistical Quality Control
  - Numerous features for detailed localized region analysis
  - X-Y Scanning capability can be provided at customer request (various sizes available)
The below composite section demonstrates bonded and disbonded regions detected by NCU

_C-Scan and Line Scan Images of CFRP-GFRP Cylindrical composite section (19mm thick)_

1. Complete disbond across top region of part
2. Well-bonded area on left side with disbonded region on right
3. Well-bonded area on left side with disbonded region on right
Delamination can be detected within foam core structures.

C-Scan and Line Scan Images of GFRP Foam Core Sandwich Composites

Areas of disbond between foam core and GFRP Skin
Delamination between layers for carbon-carbon plates can easily be detected using NCU

*Carbon-Carbon Plates for Oven Fixtures (~10mm thick)*
NCU can depict areas of delamination between layers of carbon-carbon disc brakes

**Carbon-Carbon Aircraft Disk Brakes**

- Blue regions depict disbond or delamination between layers
- Red areas indicate high quality bonding between layers
- Non-uniformity of bond quality between layers
The wetness or porosity of carbon fiber prepreg can be directly correlated to ultrasonic signal amplitude in non-contact analysis.

**C-Scan and Line Scan Images of two Carbon Fiber Prepreg Samples of Varying Resin Content**

**Higher Resin Content**

**Lower Resin Content**

Subtle resin content differences demonstrate significant variation in ultrasonic amplitude level - can detect <1% change.
The relationship between the desired material property and ultrasonic amplitude can be formulated using statistical analysis on experimental results.

**Graphical Representation of Material Property vs. Ultrasonic Transmissivity**

**Correlation Function**

- Transmissivity is expected to decrease as porosity increases or bond quality decreases.
  - Low porosity (drier material) and disbonded layers will have high attenuation and low transmissivity.
A multi-channel non-contact array can continuously analyze parts or web-lines in the downstream direction.

**Representation of Multi-Channel Array for Continuous Inspection**

- **Transmitter**
- **Receiver**
- **Pulser**
- **Test Material**
- **Transmission of Ultrasound through Material**
- **Direction of Travel**
- **Customizable multi-channel Receiver Arrays**

The transducer array can be arranged in a brick pattern for continuous cross-web coverage.
Application of non-contact ultrasound provides a safe and reliable method of continuous inspection.
A multi-channel non-contact array can continuously analyze parts or web-lines in the downstream direction.

**Representation of Multi-Channel Linear Array for Continuous Inspection**

Linear array pattern allows increased modularity across the web-line or test material.
Our 4-channel array pair is fully modular and can be used with mechanism for alignment in rotational axes

- 4-channel receiver array, can be built at frequencies between 50 kHz and 1 MHz
- Fully modular to allow for addition of increased number of channels
- Receiver alignment mechanism allows for adjustment in two axes of rotation
  - Alignment mechanism can be mounted to fixture across production line
At each channel we can continuously record the peak-to-peak amplitude across the product.
Plotting the peak-to-peak values over time, we can continuously monitor materials and products via user-friendly software.

**Continuous Line Scans of Material**

- Continuous line scan for up to 32 or more channels simultaneously
- Adjustable upper and lower control limits
- Alarm output if readings reach limits
- Y-axis units can be converted to distance or other desired units
- Y-axis units can be converted via a correlation function to directly measure desired material property

*Designed and Produced by The Ultran Group*
Non-Contact Ultrasound provides a safe and reliable method of measuring material properties during production

**Non-Contact Ultrasound**

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<th>Non-Contact Improvements</th>
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<tr>
<td>• High performance between 50 kHz and 5 MHz</td>
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<td>• Capable of measuring properties of many composite materials</td>
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<td>• Very high signal to noise ratios obtained</td>
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<th>Correlation of NCU to Material of Interest</th>
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<td>• It is relatively simple to correlate NCU data with material properties</td>
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<td>– For Example: Change in porosity, delamination, air gap, etc...</td>
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**Continuous Inspection**

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<th>Improve Process and Product</th>
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<tr>
<td>• Obtain data earlier during manufacturing process</td>
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<td>• Improve process with immediate feedback</td>
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<td>• Can improve product performance with better knowledge of manufacturing process, gaining competitive advantage</td>
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<th>Waste Reduction</th>
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<td>• Locate specific areas with defects or poor performance</td>
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<td>– Create product maps and product certifications</td>
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<td>• Eliminate destructive tests and need to discard untested product</td>
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**Close the Loop**

| Multi-channel non-contact ultrasonic analysis is readily available |
| – Products can be customized with relative ease for numerous applications |
| • NCU is robust, reliable, and relatively low cost |
| • Ultrasound is one of the safest technologies for inspection |
Questions?