Composite characterization using laser Doppler vibrometry and multi-frequency wavenumber analysis

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Motivation

Composite Solutions Applied Throughout the 787

- Carbon laminate
- Carbon sandwich
- Fiberglass
- Aluminum
- Aluminum/steel/titanium pylons

- Composites 50%
- Titanium 15%
- Aluminum 20%
- Steel 10%
- Other 5%
Motivation

Barely Visible Damage (BVD)
IM7/8552(1D) 15 x 15 2G-PLY

[(0/45/-45/90)]
Motivation

Low velocity impact

Ply layers

Carbon fiber composite
• 26 ply carbon fiber panel 15”x15”, quasi-isotropic layup ([0/45/-45/90]_3/0)_s

• Damaged using a static point load of 1511 lbf until failure, then scanned using a traditional nondestructive evaluation technique (ultrasonic immersion tank scanning)
Data was collected from a Scanning Laser Doppler Vibrometer (SLDV) while acoustic waves were excited in the panel with a contact transducer.

Goal: to correlate the SLDV data to the size and depth of the delaminations in the composite.
What are we detecting?
What are we detecting?

1/wavelength = wavenumber

Lamb wave
What are we detecting?

Delamination
Any relationship between wavenumber and location is lost.
Local wavenumber technique

Wavefield data over time

Time

$X (mm)$

$Y (mm)$
Local wavenumber technique

Wavefield data over time

FFT

Wavefield data over frequency
Local wavenumber technique

FFT

Wavefield data over frequency
Local wavenumber technique
Local wavenumber technique
Local wavenumber technique

2D FFT

2D FFT

k_x k_y
Local wavenumber technique
Local wavenumber technique
Local wavenumber technique

2D FFT

$X$ $Y$

$k_x$ $k_y$
Local wavenumber technique

Next: Window size
Window size
Window size
Window size
Dechirp process

Data recorded using chirp excitation

Chirp Excitation Signal

Desired single frequency signals

\[ u(x, y, t) = \mathcal{F}^{-1}\left[ \frac{\mathcal{F}(R_c(x, y, t))}{\mathcal{F}(S_c(x, y, t))} \ast \mathcal{F}(S_d(x, y, t)) \right] \]

Single frequency excitation data

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Differences in frequencies: Wavefields

- 200kHz
- 300kHz
- 400kHz
- 500kHz

Next: LWT results
Differences in frequencies: Wavenumber

Next: Dispersion curves
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Frequency

Wavenumber

Ply 1
Ply 2
Ply 3
Ply 4

Next: Curve correlation
Multi-frequency wavenumber-ply correlation

\[ k(x, y, f_1) \]

\[ k(x, y, f_2) \]

\[ k(x, y, f_3) \]

\[ k(x, y, f_4) \]
Multi-frequency wavenumber-ply correlation
Multi-frequency wavenumber-ply correlation
Multi-frequency wavenumber-ply correlation

\[ \text{Ply}(x, y) \approx \text{Ply}_2 \]
Ply correlation results

- Correlation frequency range: 300kHz-400kHz in 5kHz steps
- 10mm window
- 0.3mm spatial resolution
- 20MHz sampling rate
Ply correlation results
Sources of error: standard deviation
Sources of error: dispersion curves
Conclusions

• The local wavenumber technique is capable of very accurate determination of the shape and size of interlamina damage in composite panels, especially when considering multiple frequencies.

• Using multi-frequency wavenumber-ply correlation can determine the depth location of damage in many instances, but struggles with deeper and smaller delaminations.

• Future research will be conducted to improve this methodology using wave domain filtering, better dispersion curve generation, and more robust correlation methods.
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