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

- Steel: 10%
- Titanium: 15%
- Aluminum: 20%
- Composites: 50%
- 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
Goal of research

- 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)
Normal to YZ plane

Normal to XY plane
Goal of research

- 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?

Lamb wave

$1/\text{wavelength} = \text{wavenumber}$
What are we detecting?

Delamination
Wavenumber Domain Analysis

Sample time domain wave field

Wavenumber domain

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

Wavefield data over time

Wavefield data over frequency

FFT
Local wavenumber technique
Local wavenumber technique
Local wavenumber technique
Local wavenumber technique
Local wavenumber technique
Local wavenumber technique
Local wavenumber technique

2D FFT

k_x

k_y
Local wavenumber technique
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

Next: LWT results
Differences in frequencies: Wavenumber
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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
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

![Graph showing wavenumber vs frequency for different ply layers.](image-url)
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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