Volume 38 http://acousticalsociety.org/

2019 International Congress on Ultrasonics

Bruges, Belgium

3-6 September 2019

Structural Acoustics and Vibration: NGW (2/4)
Presentation 1

Full wave field signal processing techniques for NDT of composites: A case study

Joost Segers
Department of Materials, Textiles and Chemical Engineering, Ghent University, Technologiepark-Zwijnaarde 46, B-9052, Zwijnaarde; Oost-Vlaanderen, Ghent, BELGIUM; joost.segers@ugent.be

Saeid Hedayatrasa
Department of Materials, Textiles and Chemical Engineering, Ghent University Technologiepark-Zwijnaarde 46, B-9052 Zwijnaarde, BELGIUM; SIM Program M3 DETECT-IV, Technologiepark-Zwijnaarde 48, B-9052 Zwijnaarde, Oost-Vlaanderen, Ghent, BELGIUM; Saeid.Hedayatrasa@ugent.be

Erik Verboven
Department of Materials, Textiles and Chemical Engineering, Ghent University, Technologiepark-Zwijnaarde 46, B-9052 Zwijnaarde, Oost-Vlaanderen, Ghent, BELGIUM; Erik.Verboven@ugent.be

Gaétan Poelman
Department of Materials, Textiles and Chemical Engineering, Ghent University, Technologiepark-Zwijnaarde 46, B-9052, Zwijnaarde, BELGIUM; SIM Program M3 DETECT-IV, Technologiepark-Zwijnaarde 48, B-9052, Zwijnaarde, BELGIUM; Gaetan.Poelmam@ugent.be

Wim Van Paepegem and Mathias Kersemans
Department of Materials, Textiles and Chemical Engineering, Ghent University, Technologiepark-Zwijnaarde 46, B-9052, Zwijnaarde, BELGIUM; Wim.VanPaepegem@ugent.be; Mathias.Kersemans@ugent.be

Non-destructive testing of composites using full wave field analysis of guided waves is illustrated for a CFRP aircraft panel with production defects. The full wave field is measured using 3D scanning laser Doppler vibrometry for broadband chirp excitation through one piezoelectric actuator. First, the A0 mode is extracted through mode filtering in the frequency-wavenumber domain. Next, the measured chirp response is converted to a narrowband burst response. At last, the local wavenumber map is constructed and evaluated. A debonding defect between stiffener and base plate is detected and confirmed by the ultrasonic C-scan time-of-flight map.

Published by the Acoustical Society of America

 https://doi.org/10.1121/2.0001067

2019 INTERNATIONAL CONGRESS ON ULTRASONICS
BRUGES, BELGIUM, 3-6 SEPT 2019

I. Introduction

Composite materials (e.g. carbon fiber reinforced polymers CFRP) are increasingly used for critical components in several industrial sectors (for example aerospace, automotive,). A major challenge is the detection of internal damages in these composites which may have occurred during manufacturing or during operational life. One possibility for damage detection in thin-walled composite structures is to analyze the elastic wave propagation (typical frequencies are on the order of 100 kHz range) measured on the surface. The elastic waves are bounded by the structure's surfaces and referred to as guided waves or Lamb waves. Many different wave actuation and sensing configurations are possible combined with advanced data processing methods. In this study, a single piezoelectric actuator is used for excitation combined with a 3D scanning laser Doppler vibrometer (SLDV) to measure the resulting full wave field.

When a guided wave interacts with a defect one or more of the following phenomena will occur [1]: wave amplification, wave attenuation, mode conversion, wavenumber change, wave reflection, etc. Which of these effects the damage will have on the elastic wave depends on the type of wave and the morphology of the defect. Different methods exist which aim at the detection of these wave-defect interactions [2]. Typically, the process of guided wave NDT comprises two steps. First, a filtering technique is used to isolate waves with specific properties e.g. one single wave mode. Next, a damage map is constructed by looking for one of the typical wave-defect interactions.

This study describes a case were guided waves are used to detect production defects in a CFRP aircraft panel with bonded stiffeners. The full field response of the component to a broadband chirp excitation is measured using 3D SLDV. First, the data is transformed to the frequency-wavenumber domain and the A0 mode is filtered out. Next, frequency filtering is performed to calculate the response of the structure to a narrowband burst excitation. At last, the local wavenumber map is calculated and used to evaluate the structural integrity of the component.

II. Specimen and Experiment

The specimen under investigation is a CFRP vertical fin rip panel used in Airbus A320 family aircrafts (see Figure *1*). The part consists out of a flat plate with serrated outer contour and three stiffeners. All material properties as well as the composite layup are assumed to be unknown. The part was scrapped by the manufacturer after C-scan inspection.

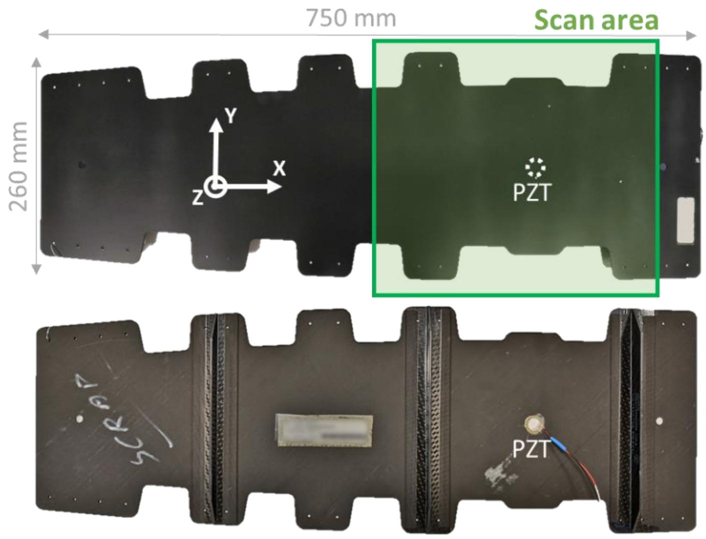

Figure 1: CFRP vertical fin panel with production defect.

A piezoelectric (PZT) bending disc (type EPZ-20MS64W from Ekulit) is bonded to the back surface with salol. In guided wave NDT, often an excitation frequency is chosen in order to excite an elastic wave field with specific properties e.g. one single wave mode, low dispersion wave, etc. This procedure relies on the prior calculation of the material's wave dispersion curves and requires all material properties to be known. In this case the material properties are unknown and therefore a broadband linear chirp excitation from 20 to 300 kHz is used. The linear chirp signal has a length of 8 ms and is amplified using a voltage amplifier (Falco System WMA-300) to a peak-to-peak voltage of 100 V. The out-of-plane and in-plane velocity response of the surface is recorded with an infrared 3D SLDV (Polytec PSV-500 3D Xtra) at a sampling frequency of 1.25 MS/s. Because the stiffeners reflect and attenuate the waves excited by the PZT actuator, only the area marked in Figure *1* is scanned. However, note that an identical testing procedure can be followed to test the complete part by attaching an actuator in between each stiffener pair. A total of 17930 scan points are distributed uniformly over the scan area. For each point, 20 averages are made to increase the signal-to-noise ratio of the measurement.

III. Measurement processing

III.1 Mode filtering

In order to get an idea of the excited waves in the component, the measured wave field of all three velocity components (Vel_X, Vel_Y and Vel_Z) is transformed from the space-time domain to the wavenumber-frequency domain using 3D fast Fourier transformation (FFT). Figure *2* shows the resulting maps for three specific cases. From these maps, three first order wave modes can be identified: the antisymmetric (A0), symmetric (S0) and shear horizontal (SH0) mode. The frequency-wavenumber curves for each mode are indicated on the figure. Note that the A0 mode shows dominant out-of-plane surface vibrations (Vel_Z) while the S0 and SH0 modes show respectively dominant and only in-plane surface vibrations (Vel_X and Vel_Y).

Different mode curves are expected at the stiffeners because of the difference in the local material thickness. However, the stiffeners only cover a small part of the scan area which results in the frequency-wavenumber maps being dominated by the mode curves of the base plate.

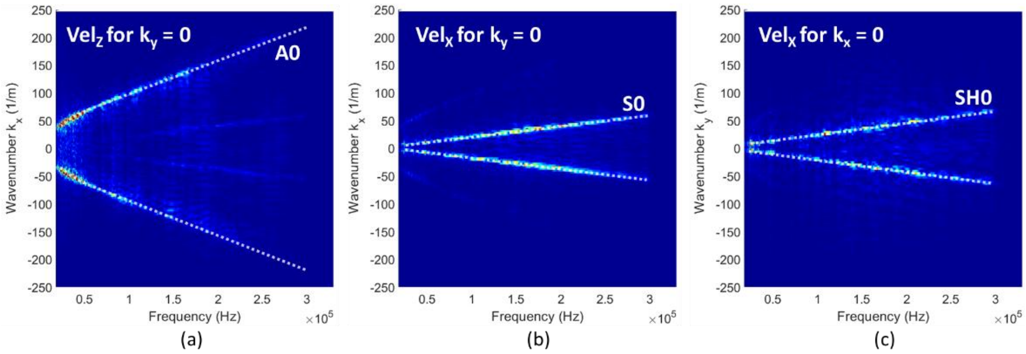

Figure 2: Frequency-wavenumber plots with indicated mode curves of the A0, S0 and SH0 waves: (a) Out-of-plane velocity component versus wavenumber in x-direction for $k_y = 0$. (b) In-plane horizontal velocity component versus wavenumber in x-direction for $k_y = 0$. (c) In-plane horizontal velocity component versus wavenumber in y-direction for $k_x = 0$.

In order to allow for local wavenumber estimation (see Section 0), the wave field must be filtered so that it only contains one mode. This mode filtering is in general performed in the frequency-wavenumber domain by constructing a mode-pass filter around the desired mode curve [3]. Care must be taken not to remove the specific mode at defected regions or structural add-ons (e.g. stiffeners) because these regions are typically related to a specific high or low local wavenumber.
In this case, the wave field is filtered so it only contains the A0 mode. Instead of using the method described above, the complete wave field is kept expect for the S0 and SH0 modes. First, a Hanning windowed mode-pass filter (with 3dB bandwidth of 100 1/m) is built around the S0 and SH0 mode curves. Next, the wavenumber-frequency domain Vel_Z data is multiplied by the inverse of this filter. Finally, the space-time domain data of the filtered wave field is obtained using inverse 3D FFT. This procedure is possible because the in-plane velocity components allowed for the precise identification of the S0 and SH0 mode curves (see Figure *2* (b,c)). Following this procedure considerably reduces the risk on A0 mode removal in defected and add-on regions.

III.2 Frequency filtering

The second step is the transformation of the broadband chirp response to a narrowband burst response. Using the method described by Dziedziech et al. [4], the A0 mode wave field is filtered in frequency domain such that it corresponds to the case of a 5 cycle Gaussian burst excitation with center frequency 200 kHz. The center frequency of the burst is preferably as high as possible. The higher the excitation frequency, the higher the wavenumber of the A0 mode and the better its interaction will be with small damages. However, the excitation of the out-of-plane waves (Vel_Z) by the PZT actuator strongly decreases for frequencies in excess of 200 kHz (see Figure *2*(a)). As such, a center frequency of 200 kHz is chosen. Figure *3* shows snapshots in time of the resulting wave field.

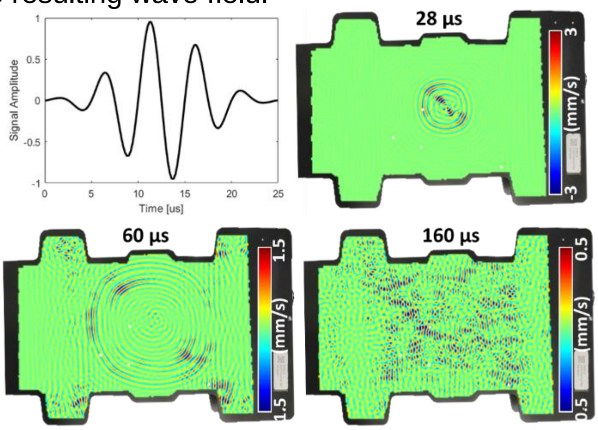

Figure 3: Snapshots of frequency and mode filtered wave field:
A0 mode for 5 cycle Gaussian burst excitation centered at 200 kHz.

III.3 Damage detection using local wavenumber estimation

For each scan point, the local wavenumber of the filtered wave field is estimated using the method described by Flynn et al. [3]. The resulting local wavenumber map is shown in Figure 4 (a). At the two vertical stiffeners, a lower wavenumber is expected due to the increased material thickness. As can be seen on the figure, the wavenumber at the stiffeners is indeed lower compared to the wavenumber of the plate material. Especially at the middle of the stiffeners, a strong reduction in wavenumber is noticeable caused by the large increase in thickness (see Figure *1*). However, part of the left stiffener's area shows an abnormally high wavenumber. This high wavenumber area indicates a debonding defect between stiffener and base plate. Ultrasound inspection (C-scan centered at 5 MHz) is performed to validate the defect (see Figure 4 (b)). The highest wavenumber area corresponds to a low time-of-flight (TOF) indicating a shallow damage.

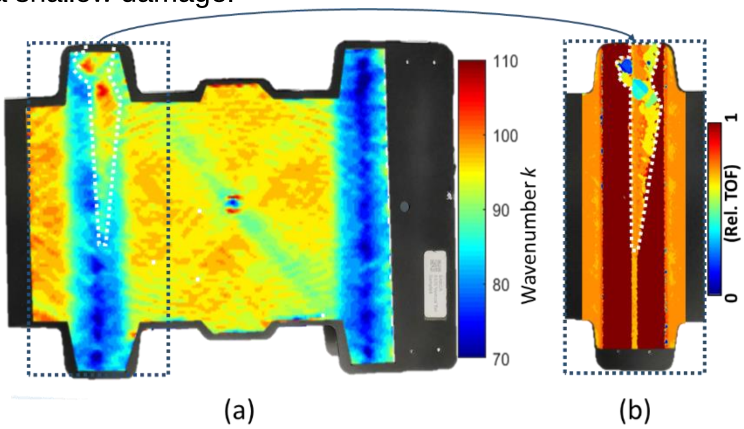

Figure 4: (a) Local wavenumber map, (b) Ultrasonic C-scan at 5 MHz relative time-of-flight (TOF)

IV. Conclusions

A CFRP aircraft panel with stiffeners and unknown material properties is inspected for damages using full wave field guided wave analysis. A broadband chirp excitation is used to introduce the vibrations and the component's response is measured using 3D infrared scanning laser Doppler vibrometry.

With the aim to perform local wavenumber estimation, mode and frequency filtering of the broadband response is performed. The resulting filtered wave field contains the A0 mode as it would be travelling after burst excitation centered at 200 kHz. Abnormalities are found at a specific area of a stiffener in the local wavenumber map. Using ultrasonic C-scan, it is confirmed that there is indeed a debonding defect at this region.

Acknowledgements.

Joost Segers is a PhD fellow of the Research Foundation-Flanders (FWO, Grant no. 1148018N). The authors further acknowledge FWO (through grants G066618N and 12T5418N) and the SBO project DETECT-IV (Grant no. 160455), which fits in the SIM research program MacroModelMat (M3) coordinated by Siemens (Siemens PLM software, Belgium) and funded by SIM (Strategic Initiative Materials in Flanders) and VLAIO (Flemish government agency Flanders Innovation & Entrepreneurship).

References

1. Munian, R.K., D.R. Mahapatra, and S. Gopalakrishnan, *Lamb wave interaction with composite delamination.* Composite Structures, 2018. **206**: p. 484-498.
2. Ostachowicz, W., M. Radzieński, and P. Kudela, *50th Anniversary Article: Comparison Studies of Full Wavefield Signal Processing for Crack Detection.* Strain, 2014. **50**(4): p. 275-291.
3. Flynn, E.B., et al., *Structural imaging through local wavenumber estimation of guided waves.* NDT & E International, 2013. **59**: p. 1-10.
4. Dziedziech, K., et al., *Efficient swept sine chirp excitation in the non-linear vibro-acoustic wave modulation technique used for damage detection.* Structural Health Monitoring, 2017. **17**(3): p. 565-576.