Mode filtering in the frequency wavenumber domain for damage detection using local wavenumber estimation

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Abstract:

The increasing use of composites in industry requires new techniques to quickly and inexpensively image and quantify areas of delamination damage. This can prove to be expensive and time consuming using current methods such as ultrasonic imaging or x-ray based techniques. Local wave number spectroscopy allows the effective thickness of a material to be estimated enabling the depth and shape of delamination defects to be approximated [1]. To apply local wavenumber spectroscopy full wavefied data must be gathered which can be achieved using a variety of techniques such as air coupled ultrasound, a laser vibrometer or a pulsing laser with a fixed sensor [1,2]. As Lamb waves are dispersive the frequency thickness product at a given wavenumber differs for different modes. Despite some previous work relying on the measurement set up to predominantly filter out any symmetric modes by only measuring the out of plane displacement component [3] other measurement techniques, such as those using 3D scanning laser vibrometers, are reliant on mode filtering.

This work presents the development of a mode filter in the frequency wavenumber domain using a tapered cosine window to separate the fundamental symmetric (S_0) and anti-symmetric (A_0) Lamb wave modes. To validate the effectiveness of the filter a model of a 3mm thick aluminium plate with a scan area of 88mm by 27.6mm was created using the local interaction simulation approach (LISA). A sine wave pulse at 330kHz was modelled in the plate. Points in the scanning area were sampled every 0.2mm. The full field data $u(x, y, t)$ was windowed using the tapered cosine window to minimise aliasing and ripple in the frequency domain. A snapshot of the wavefield in time is given in Figure 1.

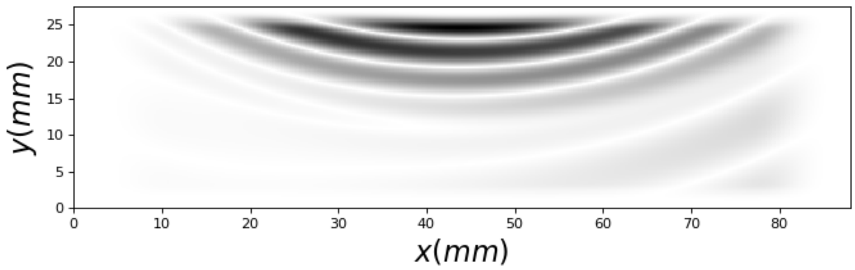

Figure 1. Wave field at $3.12 \times 10^{-5} sec$

A three dimensional fast Fourier transform (FFT) was then applied to the full field data converting it to the wavenumber frequency domain, $U(k_x, k_y, f)$. Theoretical dispersion curves were calculated using the Rayleigh-Lamb equation. Figure 2 (a) shows a cross section of the 3D FFT of the full wave field data sliced in the direction of prominent wave propagation, $k_x = 0$ along with dispersion curves for the fundamental Lamb wave modes. Figure 2 (b) shows a slice in the wavenumber domain at a frequency of $f = 1MHz$. The shape shows the wave to be propagation predominantly in the y direction

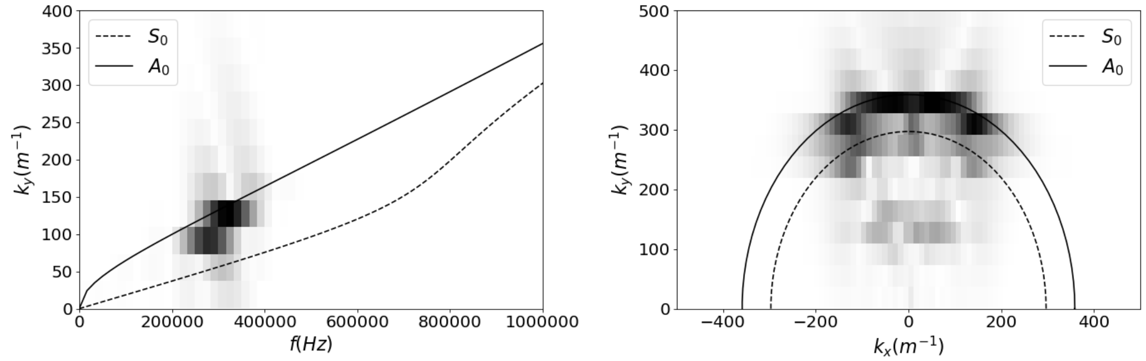

Figure 2. (a) Cross section of $U(k_x, k_y, f)$ at $k_x = 0$ (b) Cross section of $U(k_x, k_y, f)$ at $f = 1MHz$

A tapered cosine bandpass filter was then applied to each $U(k_x, k_y)$ slice at a given frequency. The position of the bandpass filter was determined using the Rayleigh-Lamb dispersion equation. Figure 3 shows a snapshot in time of the filtered wave field.

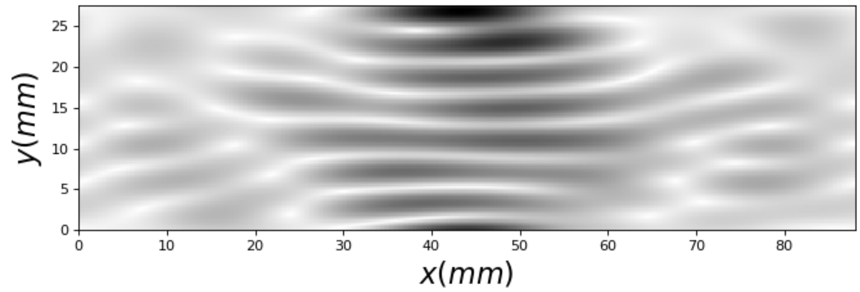

Figure 3. (a) A_0 mode at $3.12 \times 10^{-5} sec$

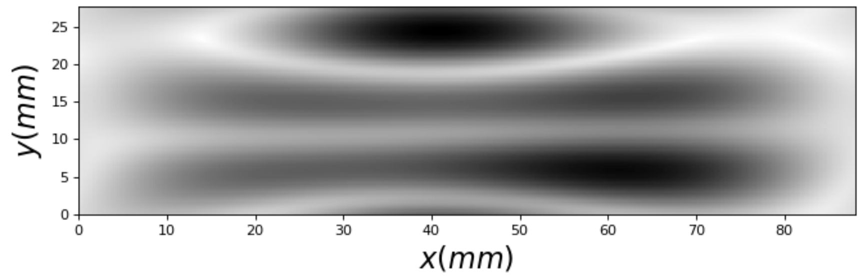

Figure 3. (b) S_0 mode at $3.12 \times 10^{-5} sec$

Despite limited wavenumber resolution due to the low number of samples wave mode filtering was shown to be possible but included significant aliasing obstructing features at the edges and producing reflections. Application of the window in the wavenumber – wavenumber domain does not only ensure symmetry in that domain but also increases the ease with which directional filtering may be applied in the future

References

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