Zero-Group-Velocity Lamb mode's behaviour in the vicinity of a thickness step

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Lamb modes are commonly used for nondestructive testing of thin structures that can be seen as waveguides. These modes are strongly dispersive. When two mode branches from a same symmetry (i.e., symmetric or anti-symmetric) have close cut-off frequencies, a repulsion between these two modes is observed. This results in a local minimum in the dispersion curve that corresponds to a nonpropagating Lamb mode having a zero group velocity (or ZGV) whereas its phase velocity remains finite. Because of their zero group velocity, the energy is trapped under the excitation source, offering a sharp resonance. Quality factors up to 10^4 have been measured in a 0.5 mm thick Duralumin plate [1]. This enables local measurements with high sensitivity. Laser-based ultrasonic techniques, as they are contactless, offer a very adequate tool to observe these resonances [2]. In the last decade, ZGV resonances have been observed in many different structures (e.g., plates, tubes, and ribbons). This allowed to locally determine, with a high sensitivity, various parameters such as the Poisson ratio, the sample thickness, or the adhesion between two plates [3-4].

Because of its group velocity being null, usual ZGV Lamb mode measurements are performed with pump and probe beams aligned to one location of the sample with the beams being either in the same side of the sample (reflection measurement) or on each side of it (transmission measurement). To map the spatial evolution of a sample parameter—for example its thickness—one must perform a one- or two-dimensional scan point-by-point. This requires the sample's surface to be optically reflective at the laser probe wavelength and to be orientated normally to the probe beam to ensure the detection of the acoustic signal. In order to lift this strong limitation, we investigate the possibility to detect the ZGV frequency associated with different excitation points while the detection is fixed at one location. In particular, we investigate the possibility to retrieve the ZGV frequency in the presence of a thickness step, where the nonpropagative ZGV Lamb mode can convert to propagative ones. Such mechanism would enable measurements to be performed in the far field.

The samples are millimeter thick Duralumin plates containing either a small thickness step (a few percent thickness variation), a large one (around 10%), or a thickness gradient for comparisons. Experiments are achieved all-optically. A Q-switched Nd:YAG laser (λ=1064 nm) delivers 10 ns pulses of ~10 mJ energy that generates the acoustic waves. The normal surface displacement is detected on the opposite side of the plate with an interferometer (λ=532 nm). 1D and 2D scans are performed by shifting only the pump beam and with the probe beam fixed either on the thick or the thin section of the sample. An example of a triangle exhibiting a ~8% thickness variation and the experimental setup is depicted in Fig. 1(a). The 2D spatial thickness, observed from the measurement of the ZGV resonant frequency associated with the excitation point, is presented in Fig. 1(b).

The mode conversion phenomena in the aforementioned configurations are further analyzed using numerical studies. This allows to assess the necessary conditions under which the ZGV resonance

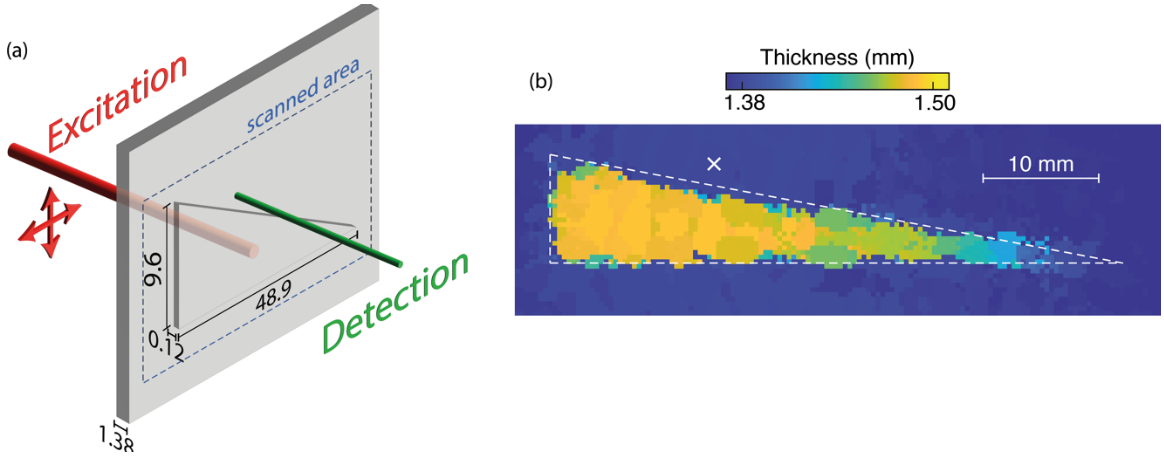

Figure 1: (a) Schematic representation of the Duralumin plate and the experimental setup. Dimensions in millimeters. **(b)** Thickness locally measured at the excitation position for a fixed probe beam located in the thinner part (white cross). The triangle limit is depicted in dashed-line.

frequency of different excitation points can be accessed from a unique detection point. Harmonic Finite Element simulations with absorbing layers are exploited for this end. Moreover, the computation of modal conversion coefficients provides quantitative information about the formation of propagative waves at the thickness step. The numerical and experimental results are in good agreement and the implications for the ZGV measurement technique are discussed.

We hope that these new results will pave the way to exploiting ZGV Lamb mode techniques in materials having a surface not favorable for interferometric laser detection, thus significantly extending this laser ultrasonic technique applicability.

References

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