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Investigation of Higher Harmonic Lamb Waves for Facilitating Delamination Characterization

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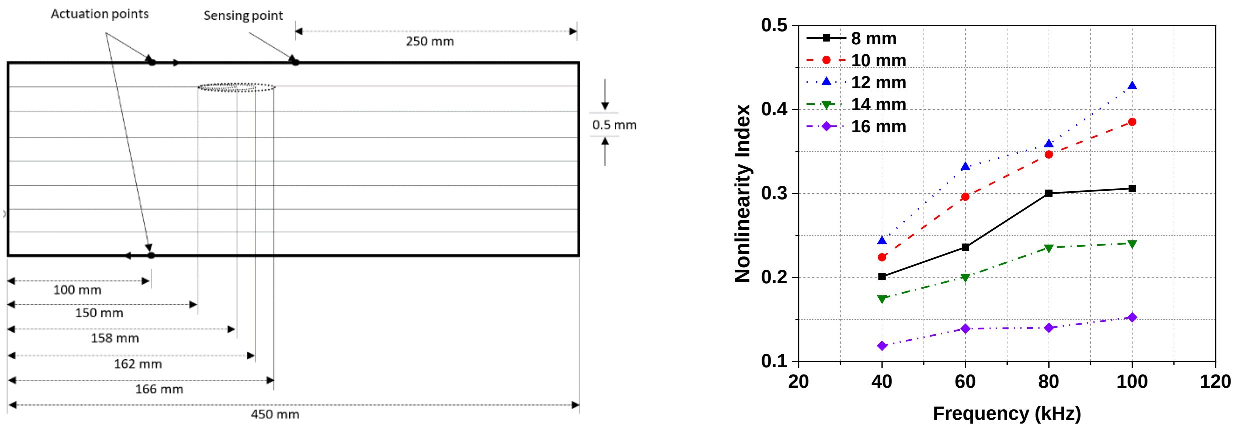
ABSTRACT

Recent advancements in manufacturing techniques have given FRP composites a wider range of applications in the aerospace, civil, and mechanical industries. However, their susceptibility to various defects necessitate frequent inspection for ensuring the safety and reliability of these structures. In this regard, the Lamb wave based Non Destructive Techniques are considered as one of the most viable methods to be employed for inspecting long composite panels, for the ability of these waves to propagate over longer distances and to scan the entire thickness. As delamination is one of the predominant mode of defect in FRP composites, many researchers have investigated the Lamb wave interactions with the delamination for facilitating the localization and characterization of delamination. Because of the improved sensitivity of the response characteristics originating from nonlinear wave-damage interactions, they have emerged as significant contenders to be employed as damage precursors, lately. The intermittent contact between the surfaces at the delamination (known to as a "breathing of the delamination") is one of the prominent mechanisms that generates such nonlinear. Previous researchers have demonstrated the generation of nonlinear harmonics from breathing of the delamination and their use in delamination identification.

We advance the state of the art in this work by systematically studying the nonlinear interaction of fundamental Lamb wave signals with delamination defect of various sizes and interlaminar location, for facilitating delamination characterization. The interrogation signal used in this regard, comprises a modulated sinusoid with central frequency varying from 40 kHz to 100 kHz in steps of 20 kHz. Commercial FEM software is used for modelling the contact at delamination interfaces and for simulating the Lamb wave propagation through the waveguide with delamination defect. Numerical results are validated by employing the in house experimental findings. It is demonstrated that the intermittently acting contact pressure between the two surfaces of delamination acts as a source of nonlinearity, resulting in generation of higher order harmonics of interrogation frequency. Further, the strength of the nonlinear wave-damage interactions is quantified using a metric called the nonlinearity index (NI), and its dependency on the interlaminar location and various width of the delamination is investigated over a range of interrogation frequencies.

The NI index is observed to vary with both the interlaminar location as well as the width of the delamination. The maximum value of NI is further influenced by the frequency of excitation signal. To infer the effect of delamination parameters on the NI, a concept of a concept of contact

energy intensity is introduced, which is largely dependent on the size and the interlaminar position of the delamination. Use of the contact energy intensity together with the phase difference between wave packets travelling through the two sub-laminates and the flexural rigidity of the two sub-laminates created at the delamination location justify the observed patterns in the nonlinearity index. The inferences provided can potentially be used for determining the interlaminar location and width of delamination employing higher harmonic Lamb wave signals generated by the breathing delamination.



(a) **(b)**

Fig: (a) Schematic representation of $[0]_8$ laminate with different size of delamination defect, (b) NI variations with central frequency of excitation, for delamination located at 1-2 interface.

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