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Exploring Nonlinear Guided Wave Mixing for Structural Health Monitoring in Pipe Structures

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ABSTRACT

It is well-known that the linear features of ultrasonic guided wave propagation, such as wave speed, attenuation, and scattering, are sensitive to elastic properties and material defects. Likewise, nonlinear guided waves are highly sensitive to microstructural imperfections related to material nonlinearity, such as dislocation structures, slip, precipitation, and microcracks. Guided wave mixing, which is a nonlinear phenomenon associated with mutual wave interaction, is a promising method for material state awareness and is a potential tool for early detection of material degradation. The mutual wave interaction generates secondary waves at combinational harmonics (e.g., at the sum and difference frequencies). Wave mixing has the advantage that the generated secondary waves propagate at frequencies designed to be far from nonlinearities inherent to the measurement system, such as transducers and coupling media. Much research has investigated wave mixing in bulk media and plate-like structures to assess material degradation. However, there is limited knowledge of guided wave mixing in pipe structures, which form the essential components of many industrial structures. Given the valuable information that the secondary waves can provide for the structural health monitoring of these fundamental components, this study aims to explore the generation of secondary waves through wave mixing in pipe structures with weak nonlinearity. As the random selection of the primary wave types, directions, and frequencies is unlikely to be productive, a physics-based selection methodology is followed. The guided wave types investigated propagate along the axis of the pipe, are axisymmetric, and either longitudinal or torsional in nature. Flexural modes are not considered. The directions are either co-directional or counter-propagating. Frequencies into the MHz range are considered. To enhance the mixing process, the two primary waves and the secondary waves (that together are known as a wave triplet) are required to be internally resonant, meaning that

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they are synchronized and that nonzero power flows to the secondary waves. The dispersion curve database is used to select internally resonant wave triplets. Advantages of co-directional and counter-propagating waves are compared. A few special cases of interest are described.

Keywords: Nonlinear guided wave, Wave mixing in pipe structures, Cumulative second harmonics

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