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Accurate velocity measurement through Green's Function Reconstruction from diffused fields

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ABSTRACT

Manufacturing processes of metal such as forging and rolling influence the crystal orientation distribution of materials, and by extension many of their macroscopic properties. To overcome the limitations posed by several state-of-the-art texture characterisation methods, Imperial College's Non-Destructive Evaluation (NDE) group has developed an ultrasonic wave speed approach to quantitatively determine crystallographic texture, which was validated using an immersion setup. However, this immersion technique could only accurately measure the wave speeds of raw material plates with parallel flat surfaces. This restrains its applicability on real-world components that tend to have a more complex geometry near the end of the manufacturing process, and whose texture is more critical for real applications. Therefore, this paper proposes the use of Green's Function (GF) reconstruction from diffused ultrasonic fields for accurate velocity measurements on samples with arbitrarily shaped geometries. The GF reconstruction, demonstrated in the early 2000s, entails utilising the ensemble average of the cross-correlation of responses at two specific locations within diffused fields to effectively reconstruct the heterogeneous GF which contains the same information as a localised excitation and reception between two points.

The diffused fields recorded at the two locations can be generated either by deterministic sources or by random noise. The accuracy of reconstruction can be improved with more averages over different source locations and by increasing the duration of diffused fields used for the reconstruction process. This approach was initially demonstrated using phased arrays on a flat geometric sample, with the primary objective of acquiring velocity values at different angles with a high degree of accuracy. The obtained results are calibrated against conventional coherent velocity measurements, revealing a commendable agreement within an angular range of normal incidence to 55°. Subsequently, the proposed measurement method is applied to samples with curved geometry, thereby utilising laser vibrometers that are better suited as surface receivers for such shapes and eliminating the requirement for a couplant. However, because lasers exhibit lower sensitivity than piezoelectric elements in detecting vibrations, further modifications such as simultaneous excitation of sources to increase the signal-to-noise ratio and a signal processing technique termed one-bit normalisation, more commonly used in seismology, to account for energy dissipation of diffused fields had to be implemented to overcome this challenge. These modifications resulted in the measured velocities exhibiting good agreement with the ground truth, affirming the feasibility of attaining accurate velocity measurements on samples with curved geometries. With the use of lasers, this method has the capabilities of performing localised point to point wave speed measurements, which cannot be achieved with conventional methods. Furthermore, the non-contact nature of lasers extends the applicability of the proposed method to more challenging environments such as manufacturing processes, thereby paving the way for the potential of in-line material characterisation of manufactured components and other applications.

Keywords: Ultrasonics, Diffused fields, Green's functions, Velocity measurement