**Efficient finite element simulation of ultrasonic defect responses in arbitrarily complex materials and geometries**

**Paul D. Wilcox1**

1University of Bristol

Bristol, UK

p.wilcox@bristol.ac.uk

ABSTRACT

In ultrasonic NDE, there is increasing demand for ultra-realistic 3D simulations from large populations of defects to provide training data for machine learning and test data for inspection qualification. However, despite massive advances in computational power, direct numerical simulation of ultrasound using finite elements remains extremely computationally expensive. This paper proposes a methodology for significantly reducing this computational burden, which can be implemented in a standard, explicit time-marching finite element code.

The general steps for simulations in a pulse-echo configuration are as follows. First the incident wavefield from a transducer is simulated in a modelling domain that covers the complete geometry in the absence of defects. This is termed the main-domain model and is only executed once. A region enclosing potential defects is defined, and time histories of the transmitted displacement field are recorded at nodes in the immediate vicinity of this boundary. A separate, smaller modelling domain surrounded with a suitable absorbing layer is defined which encloses this region. This is termed a sub-domain model and a model of the defect of interest is introduced into this. The displacement histories from the boundary nodes in the main-domain are converted to time-domain forcing functions and applied to the equivalent nodes in the sub-domain; this is a numerical implementation of the Kirchhoff–Helmholtz integral which recreates the incident field on the defect. In the absence of a defect, it follows from the definition of the Kirchhoff–Helmholtz integral that the displacement field will be completely contained within the boundary nodes. However, if a defect is present, the scattered wavefield passes through the boundary nodes to be eventually dissipated in the absorbing layer. A complete description of the scattered displacement wavefield is therefore provided by the displacement on the boundary nodes of the sub-domain, which can again be converted into equivalent time-domain forcing functions. Reciprocity between the transducer forcing function and the boundary node responses in the main-domain model is then exploited, which allows the measured response from the defect at the transducer to be computed without executing a further model of the main-domain.

Therefore, the method allows the response from any defect in a region to be simulated using only the sub-domain model. Because the main-domain includes the complete geometry, the effects of reflections from structural features on both the incident and scattered fields are implicitly included. First-order scattering effects are captured with identical accuracy to that of a numerical model that directly modelled a defect in the main-domain. Higher-order scattering effects (i.e. multiple interactions of waves with the defect) are not captured because the coupling between domains is one-way. In contrast to previous approaches, the method does not require knowledge of analytical Green’s functions, which means that both domains can include arbitrarily complex geometrical features, anisotropy, and inhomogeneities. Extensions to pitch-catch and array inspections will be demonstrated and some limitations discussed.

**Keywords:** finite element, ultrasound, simulation