Mechanical Engineering Doctoral Defense

Fast Forward and Inverse Wave Propagation Method for Tomographic Imaging of Defects in Solids

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abstract

Aging-related damage and failure in structures, such as fatigue cracking, corrosion, and delamination, are critical for structural integrity. Most engineering structures have embedded defects such as voids, cracks, inclusions from manufacturing. The properties and locations of embedded defects are generally unknown and hard to detect in complex engineering structures. Therefore, early detection of damage is beneficial for prognosis and risk management of aging infrastructure system.

Non-destructive testing (NDT) and structural health monitoring (SHM) are widely used for this purpose. Different types of NDT techniques have been proposed for the damage detection, such as optical image, ultrasound wave, thermography, eddy current, and microwave. The focus in this study is on the wave-based detection method, which is grouped into two major categories: feature-based damage detection and model-assisted damage detection. Both damage detection approaches have their own pros and cons. Feature-based damage detection is usually very fast and doesn't involve in the solution of the physical model. The key idea is the dimension reduction of signals to achieve efficient damage detection. The disadvantage is that the loss of information due to the feature extraction can induce significant uncertainties and reduces the resolution. The resolution of the feature-based approach highly depends on the sensing path density. Model-assisted damage detection is on the opposite side. Model-assisted damage detection has the ability for high resolution imaging with limited number of sensing paths since the entire signal histories are used for damage identification. Model-based methods are time-consuming due to the requirement for the inverse wave propagation solution, which is especially true for the large 3D structures.

The motivation of the proposed method is to develop efficient and accurate model-based damage imaging technique with limited data. The special focus is on the efficiency of the damage imaging algorithm as it is the major bottleneck of the model-assisted approach. The computational efficiency is achieved by two complimentary components. First, a fast forward wave propagation solver is developed, which is verified with the classical Finite Element(FEM) solution and the speed is 10-20 times faster. Next, efficient inverse wave propagation algorithms is proposed. Classical gradient-based optimization algorithms usually require finite difference method for gradient calculation, which is prohibitively expensive for large degree of freedoms. An adjoint method-based optimization algorithms is proposed, which avoids the repetitive finite difference calculations for every imaging variables. Thus, superior computational efficiency can be achieved by combining these two methods together for the damage imaging. A coupled Piezoelectric (PZT) damage imaging model is proposed to include the interaction between PZT and host structure. Following the formulation of the framework, experimental validation is performed on isotropic and anisotropic material with defects such as cracks, delamination, and voids. The results show that the proposed method can detect and reconstruct multiple damage simultaneously and efficiently, which is promising to be applied to complex large-scale engineering structures.

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