3D Hybrid modeling for the ultrasonic phased array inspection of porosity in heavy plates: Simulation and experimental validation

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Quantitative modeling and simulation tools are important in design and fabrication of ultrasonic phased array sensors with optimum characteristics and reduce the number of experimental efforts and development time. In order to achieve high accuracy (Amplitude deviation < 1 dB) with a low computational time in the simulation, the modeling tools require not only the high-frequency approximation of the ultrasonic wave propagation but also the high-precision electro-acoustic coupling model. This paper describes a computationally efficient 3D time-dependent hybrid model for the simulation of ultrasonic phased array inspection of porosity in heavy plates. The method applied combines the results of both 3D finite element analysis (PZFLex-FEA) and the semi-analytical ultrasonic simulation ”Ray-Tracing”. As a first step, we present the FEA modeling of an ultrasonic phased array sensor, which includes the full 1-3 piezo-composite design with the arrangement of array elements, conducting electrodes, multi-phase damping material, acoustical matching layer and the electrical circuit of a 50 Ohm coaxial cable. In addition, the current FEA simulation considers the acoustical and electrical cross-talk between the adjacent elements of the ultrasonic phased array sensor. In a second step, the FEA simulated ultrasonic pulse-echo signal and its frequency spectrum of an array element in the farfield-region are further used as the reference input signal in the CIVA-UT Software to simulate the imaging of porosity in heavy plates, quantitatively. Furthermore, the 3D wedge-geometry of the array sensor is modeled and optimized to suppress the unwanted wedge-boundary reflected echoes and to improve the signal-to-noise ratio in the detected signals. In contrast to commonly used simulation tools, the real excitation pulse of an ultrasonic testing equipment is included in the current hybrid modelling to achieve the high accuracy in the simulated result. Finally, the 3D hybrid model simulated angle beam A-scan signals and linear-scan images of the porosity like defects in heavy plates are compared with the real experiments and a good quantitative correlation is achieved.