Accurate Simulations of EMAT Signal Amplitude and Shape based on FEM using a coupled ECT-UT formulation

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Abstract

The paper reports the progress to obtain accurate simulations of amplitude of EMAT signal from defects in metallic plates by means of FEM simulations. The simulations results are applied to a FEM model based on a two-dimensional coupled eddy-current (ECT) and ultrasound (UT) formulation, by using various numerical integration methods as Crank-Nicolson, Backward Euler and Newmark-beta method. The paper presents the methodology to acquire convergence of the large variation in the EMAT signal from a defect to the same final EMAT signal, not only in the defect amplitude but also in the shape of the time transient EMAT signal when using different methods. Accurate EMAT signals can be obtained by means of the combination of high order finite elements (FEM) and advanced numerical time integration, to reach the converged EMAT signal in the shortest time, opening the way to simulate accurate signals form faraway defects.

1 Introduction

In the electro-magnetic acoustic transducer (EMAT) there is a combination of eddy current testing (ECT) and ultrasound testing (UT) that can be used to detect defects in metallic plates located usually close (10~40 cm) from the sensor location [1]. Numerical simulations of EMAT signals are based on finite element (FEM) models that are integrating the signal to obtain the time-transient solution, as shown in Fig. 1. In the past the authors developed a coupled formulation in a two-dimensional FEM formulation that combine both the eddy currents and ultrasound propagation of shear wave in a mixed physics-coupled equation [2]. In the literature, numerical simulations of EMAT signal [3-4], usually refer only to the maximum amplitude A(t) near the peak signal, and not taking into account its shape. Until now, numerical FEM simulations of EMAT signal amplitude varies largely, depending on various parameters as: FEM mesh, time step in integration procedure, distance of defect to sensor and others, that make it difficult to reliable analyze by simulations new EMAT sensors with high precision as in ECT technology. Therefore, accurate and fast simulations of not only of the amplitude but also of the shape of EMAT signal using FEM will be crucial in future EMAT signal analysis and design.

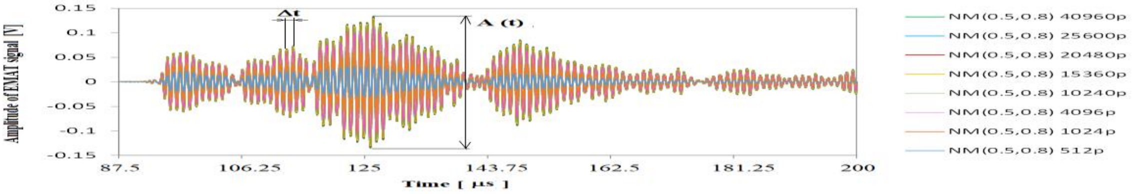

Fig. 1 Simulations of EMAT signal with a varying amplitude A(t) around the peak zone using Newmark

The present paper investigates and presents the combined effect of various sources (integration methods, FEM mesh interpolation, others) that modify the amplitude and shape of EMAT signal, when FEM simulations in two-dimensional approximation are employed. The paper, presents the methodology to obtain the right and correct simulated EMAT signal from the beginning not only in amplitude but also in shape, and also in the shortest time, opening the way to reliable analyze and interpret and design future new EMAT sensors.

2 Theoretical aspects of simulations and analysis and conclusions

In the analysis, the simulated EMAT signal is investigated in the FEM approximation using various integration methods. In numerical simulations not only the amplitude of EMAT signal, but also its transient time shape varies greatly as the various parameters change in the FEM simulations (see Fig 1). If the simulated signal from EMAT does not converge to the same EMAT signal amplitude and shape, it is difficult to know with high accuracy the correct simulated EMAT signal, questioning the reliability of future EMAT sensor design.

Because the simulations of EMAT signal requires the time step integrations, from numerical point of view the influence of time step interval and FEM mesh interpolation plays a very important role in obtaining the right simulated signal (see Fig 2). Simulations showed that as the defect is located further from EMAT sensor location, the precision of time integration is reduced, requiring a much smaller time step interval and consequently a larger time steps, increasing the simulation time to unpractical values (months) for faraway defect signal simulations.

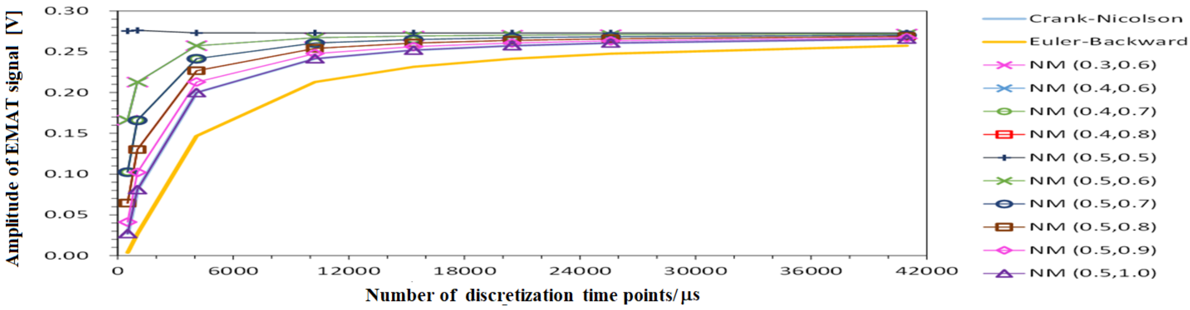

Fig 2. Convergence of EMAT signal with a higher time steps/μs

In order to obtain the converged final EMAT signal, as shown in Fig 2, various methods were implemented and employed to study their combine effect and to obtain the best approach in simulating EMAT signal in the shortest time: a) Integration methods: Crank–Nicolson, Backward Euler and Newmark-beta (NM); b) FEM element approximations: triangular or rectangular; c) FEM element interpolation order: 1^{st}, 2^{nd} ,3^{rd}, 4^{th} and 5^{th}; d) others.

By applying the new procedure to simulate EMAT signal using FEM, it is possible to acquire reliable simulations of defects located far from EMAT sensors, opening the road to future EMAT sensor optimization for faraway defect detection in metallic structures.

References

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