FLAW IDENTIFICATION BY ANGLE BEAM ELECTROMAGNETIC ACOUSTIC TRANSDUCERS

Shumpei Hanada, Toshihiko Sugiura
Department of Mechanical Engineering, Faculty of Science and Technology, Keio University,
Yokohama, 223-8522, Japan

Summary This research deals with quantitative nondestructive evaluation by angle beam electromagnetic acoustic transducers (EMATs) through inverse analysis based on elastodynamics and electromagnetics. FEM-BEM simulations, agreeing well with experimental results, show us some relation between the receiver signal's peaks and the size of a flaw. With initial guess based on this relation obtained numerically, flaw size was successfully identified from measured receiver signals through parameter optimization.

INTRODUCTION

Electromagnetic acoustic transducers (EMATs) can transmit and detect ultrasonic waves in a conductive specimen without any contact. This process can be given theoretical modeling and formulation based on elastodynamics and electromagnetics [1]. It suggests some possibility of quantitative nondestructive evaluation using EMATs. This research deals with angle beam EMATs which can transmit ultrasonic waves in oblique directions as plane waves. FEM-BEM simulations of this inspection system show us some relation between the receiver signal's peaks and propagation of ultrasonic waves, and also explain effects of a flaw. Numerical results of receiver signals were compared with experimental ones for verifying our mathematical modeling of the inspection process. Flaw identification is formulated as a problem of parameter optimization. The initial guesses of the parameter were evaluated from the computed relationship between the flaw parameter and the peak's area of the receiver signal. Identification of flaw size was tried from receiver signals obtained in experiments.

MEASURED AND COMPUTED SIGNALS OF RECEIVER EMAT

Figure 1 shows the system in this research: both the transmitter and receiver EMATs are arranged above the same surface of an aluminum specimen. The EMATs and the specimen are supposed to be long enough in the z direction for electromagnetics and elastodynamics to be considered as two-dimensional. Coil pitch P of the EMATs is 2.47mm and the oblique angle θ = 40 deg. A cylindrical cavity of diameter d is located as an artificial flaw inside the specimen. Experiments were carried out for several specimens, each of which has a flaw of different diameter *d*, by supplying 3-pulse 4 App sinusoidal current of frequency 1MHz to the transmitter coil. Experimental results of receiver coil voltage are shown in Fig.2.

Two-dimensional numerical analysis has also been carried out. For the region of the specimen, Maxwell's equations and equations of motion of an elastic body are converted into discrete form by the Galerkin finite element method. The boundary element method is used for the electromagnetic field in the air region. The Newmark β method is adopted for time history analysis. Computed receiver signals, also shown in Fig.2 agree well with the above experimental ones, which validates our numerical analysis.

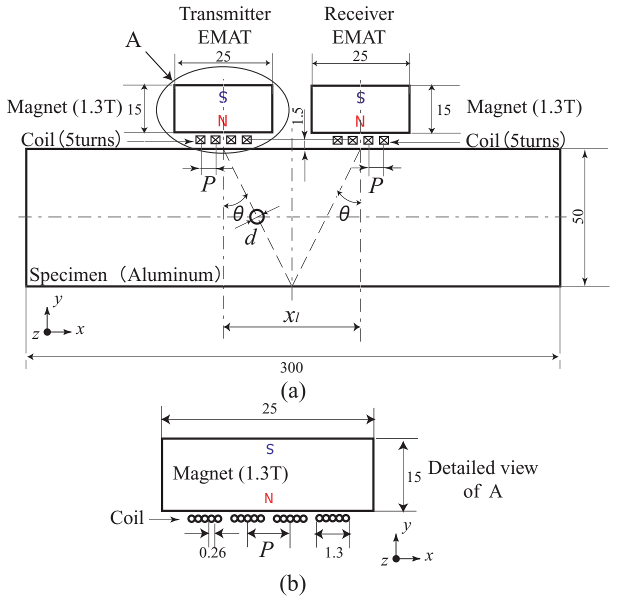
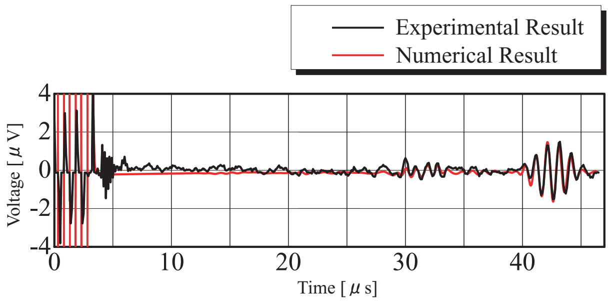
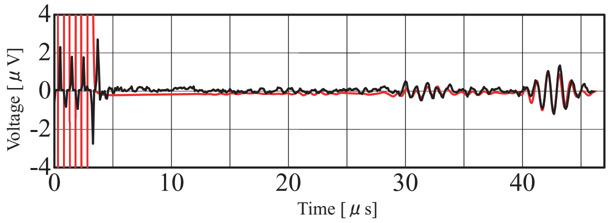


Figure 1. System of angle beam EMATs



(a) d=4.0408mm



(b) d=6.0222mm

Figure 2. Time histories of receiver coil voltage

EFFECTS OF A FLAW ON RECEIVER SIGNALS

The size of a flaw gives distinct change to the value of the peak appearing in the receiver signals at $t = 40\mu s$, as shown in Fig.2. This signal peak, hereafter denoted by [SS], corresponds with the arrival of the S wave reflected at the opposite surface without mode conversion. Effects of the flaw on the propagation of this wave can be understood in more detail from the numerical results. Figure 3 shows the gray scales of the divergence and rotation of computed displacement of the specimen, which thus visualize the propagation of the P and S waves, respectively. As shown in Fig.3, the ultrasonic waves propagating in the oblique direction are in part reflected at the surface of the flaw and cannot reach the receiver. Therefore the peaks[SS] are lower for a bigger flaw.

FLAW IDENTIFICATION BY INVERSE ANALYSIS

Flaw identification is formulated as a problem of parameter optimization. Here the diameter d of a cylindrical cavity as a flaw is an unknown parameter to be identified from a measured receiver signal v_m. We define a cost function $R(d)$ as

$$R(d) = \int_{T_1}^{T_2} (v_m(t) - v_c(d;t))^2 dt,$$

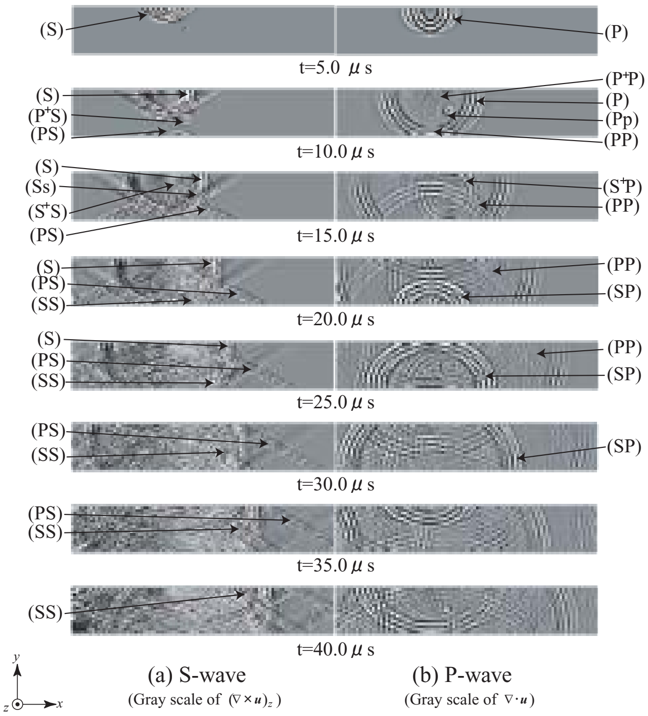
where $v_c(d;t)$ denotes a computed receiver signal for a flaw of diameter d. The optimized parameter d, minimizing this cost function R, can be found by iterative computation with Brent's method. To avoid being trapped in a local optimum, the initial guess d_i was successfully evaluated, as shown in Fig.4, by using the numerically obtained relationship between the area of peak [SS] and the diameter d mentioned in the above section. Figure 5 shows examples of good optimization, verifying the method of flaw identification presented here.

CONCLUSIONS

Numerically predicted receiver signals of angle beam EMATs agree well with the experimental ones, which validates our analysis. The peak [SS] of receiver signals is well influenced by the size of the flaw. By using this relation, initial guesses were successfully evaluated. Flaw size was identified well through optimization from measured receiver signals, which verified the method of flaw identification presented here.

References

[1] R.Ludwig, Z.You and R.Palanisamy: Numerical Simulations of an Electromagnetic Acoustic Transducer-Receiver System for NDT Applications. *IEEE Trans. Magn.* **29-3**:2081–2089, 1993.



(a) S-wave (Gray scale of $(\nabla\times\boldsymbol{u})_z$)

(b) P-wave (Gray scale of $\nabla\cdot\boldsymbol{u}$)

Figure 3. Propagation of *P* and *S* Waves

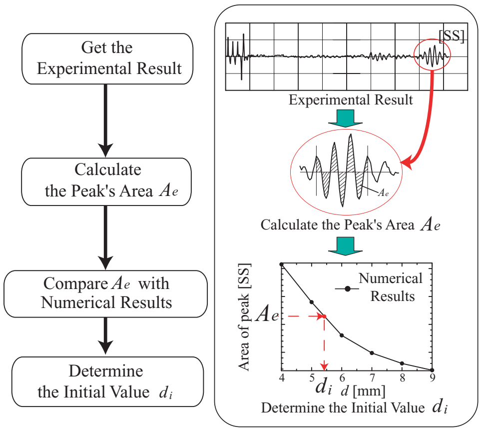
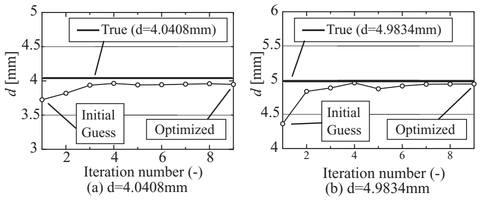


Figure 4. Method of initial guess for flaw size



(a) d=4.0408mm

(b) d=4.9834mm

Figure 5. Flaw identification by optimization