CALCULATION OF THE RESPONSE OF ANGLE BEAM EMATs TO FLAWS IN THE FAR FIELD

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ABSTRACT

In the design of a system for NDE, it is necessary to quantify the relationship of flaw size and orientation to transducer signal levels. This is particularly true for automated systems, in which the transducer coordinates cannot be adjusted by an operator to maximize the signal. This paper presents the result of a model calculation for the case of angle beam inspection using EMATs, which appear likely to find extensive use in such systems. Included in the model are calculations of the elastic wave radiation pattern in three dimensions for plates, calculations of the elastic wave scattering from cracks using existent approximate models, and calculation of the electrical response to the scattered wave. Transducer apodization is used to reduce spurious side lobe signals and "blind areas" where flaws are weakly detected. Emphasis is placed on the case of SH wave generation.

One of the most important assets of EMATs for NDE is the possibility of producing an ultrasonic beam of relatively well controlled polarization, intensity, and angular distribution. The mathematical ingredients of a systematic approach to the design of EMATs for an optimized automated NDE system are shown in the flow chart of Fig. 1. The inputs are of three distinct sorts, EMAT parameters, material properties, and the types of flaws which are sought. The design algorithm contains separate modules which calculate the surface tractions resulting from the EMAT parameters, and a medium transfer function depending only on the material properties. These are combined to produce the displacements and stresses in the far field region of the transducer. A third major program module calculates the signal produced by a reflection of these fields from the flaw. This permits such important system characteristics as the variation of signal with flaw orientation to be evaluated and transducer parameters to be optimized to minimize this variation.

The calculation of the surface tractions for a particular EMAT, that of Fig. 5, is described in Fig. 2. These are straightforward, albeit lengthy, expressions from ordinary electromagnetic theory. They result in expressions which are in closed form as a function of x and y (Cartesian coordinates in the plane of the surface), and are numerically Fourier transformed using an FFT algorithm after apodizing with a Kaiser-Bessel window. Because the EMAT studied here (Fig. 5) directly produces tractions only parallel to the surface, the normal (z) component of the displacement was neglected in the medium response (Fig. 3). Though not rigorously correct, this approximation is plausible for moderate distances. The form of the resulting far field expression is shown in Fig. 3. Figure 4 describes the model used for scattering. A result due to Auld exhibits the change in signal as an integral over the crack of certain stress, strain, and velocity products. These were calculated in the Born approximation, with the two dimensional numerical integrals evaluated by a Gaussian algorithm. The coordinate system is shown in Fig. 5, as well as the particular EMAT configuration studied here. Typical results are shown in Fig. 6 for several crack orientations. These results suggest that inspection performance of the system would be acceptable only with orthogonal scans.

The modular computer program appears to be a potentially powerful tool for the NDE system designer. The immediate need is to strengthen the medium module by eliminating the approximate treatment of the plate geometry. It may then be necessary to modify the scattering theory module to utilize a theory more powerful than the Born approximation. One expects that large computers may eventually play a role in QNDE comparable to that they have come to enjoy in optics.

ACKNOWLEDGEMENT

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EACH MAGNET PAIR (POSTER 6) PRODUCES A STATIC FIELD $B_z$.

$$B_z = \mu_0 \mu B_0 \left( \frac{1}{2} \left( V_U - V_L - V_L + V_U \right) \right) \delta \left( x - x_0 \right)$$

MAGNET SURFACE

EACH CURRENT LOOP (POSTER 8) PRODUCES A FIELD $B_x$ AND A CORRESPONDING EDDY CURRENT $K_x$.

$$K_x = \frac{B_x}{\mu_0} = \left( \frac{4\pi}{\delta^2} \right) \left( \frac{1}{2} \right) \left( V_U - V_L \right)$$

LOOPS

ALL INTEGRALS CAN BE CALCULATED ANALYTICALLY. SURFACE TRACTION $T_1$ IS

$$T_1 (x, y) = K_x B_x$$

FOURIER TRANSFORM $T_1 (x, y)$ CALCULATED NUMERICALLY.

Fig. 2 The (SH) source (or detector).

SOURCE COMPONENTS IN HORIZONTAL PLANE, TAKE $u_x = 0$

$$u(x, y, z) = \cos (nx) \phi (y) \delta (z) \left[ \delta (x - L) + \delta (x + L) \right]$$

TRANSDUCER

$$\gamma = \sqrt{\mu_0 / c^2}$$

ONE (NUMERICAL) FOURIER TRANSFORM X ONE (FINITE NORMAL MODE SUM

Fig. 3 The medium (SH approximation).

USING AULD’S RECIPROCITY RESULT,

SIGNAL[2] (WITH CRACK) - SIGNAL[1] (WITHOUT CRACK)

$$u(x, y, z) = \cos (nx) \phi (y) \delta (z) \left[ \delta (x - L) + \delta (x + L) \right]$$

CRACK

AND APPLYING BORN APPROXIMATION, NEED INTEGRAL OF SIGNAL OVER VOLUME OF PENNY SHAPED CRACK, BECAUSE CRACK IS THIN, $K_x B_x$

$$\approx \int \int \int \phi (y) \delta (z) \left[ \delta (x - L) + \delta (x + L) \right]$$

CRACK

GAUSSIAN INTEGRATION PRODUCT FORMULA CALCULATES REMAINING DOUBLE INTEGRAL ACCURATELY WITH MINIMUM COMPUTATION.

Fig. 4 The defect scattering.

Fig. 5 Configuration of EMAT.

### Table 1: Sample Results

<table>
<thead>
<tr>
<th>Angle</th>
<th>OP</th>
<th>DP</th>
<th>NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.99</td>
<td>0.69</td>
<td>2.39</td>
</tr>
</tbody>
</table>

Fig. 6 Sample results.