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Optimization and Application of Electrodynamic Acoustic Wave Transducers

Abstract

I'm going to talk about the use of electromagnetic acoustic wave transducers, or EMATS as I call them, as they are being used for bulk wave generation. They have been applied specifically to the problem of measuring the intensity distribution of acoustic waves that are scattered by defects of known geometries. Related studies have been done elsewhere for some time and have formed an integral part of this general program.

Disciplines

Materials Science and Engineering

OPTIMIZATION AND APPLICATION OF ELECTRODYNAMIC ACOUSTIC WAVE TRANSDUCERS

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First, I would like to say that my affiliation as of Monday is with Lawrence Livermore Laboratories, but this work was all done at Cornell University.

I'm going to talk about the use of electromagnetic acoustic wave transducers, or EMATS as I call them, as they are being used for bulk wave generation. They have been applied specifically to the problem of measuring the intensity distribution of acoustic waves that are scattered by defects of known geometries. Related studies have been done elsewhere for some time and have formed an integral part of this general program.

Our measurements involve the use of a fixed transmitting element and a movable receiving element so that the intensity distribution can be mapped over a surface. Prior to our measurements, most work has involved compressional waves, although some work has been done using a combination of incident shear waves and the mode converted compressional waves scattered from the defect.

There is substantial interest in being able to generate incident shear waves and then detect the shear waves scattered by the defect. By setting the orientation of the induced current and the magnetic field, you can determine whether EMATS have sensitivity to either shear or compressional disturbances. If you pick your geometry correctly, you can both generate and detect shear waves. We have extended some of our earlier work, done during the first year of this program, to study the intensity distribution of waves scattered by defects of known geometry.

In the first part of this program, we developed a system which uses a small scanned EMAT to map the displacement field or beam profile of a larger EMAT and showed that one could obtain very good quantitative measurements of the displacement, that is, of the beam profile. With this experience, we designed a system which was the first step in being able to utilize scanned EMATS for quantitative intensity distribution measurements.

After a few preliminary measurements, we settled upon what I will refer to as a single surface access method where you have a fixed transmitter and a movable receiver coil near a single surface. The excitation coil is about 1 cm square and the receiver coil is about 1/2 mm thick and 1 1/2 mm square. This geometry has the advantage that scattering back from a defect is not measured against any background level. If the through transmission geometry were used, then there would be a large background signal produced by the unscattered acoustic energy. For the small defects of interest here, the unscattered energy would greatly exceed the scattered signals. The single surface geometry is also convenient for use within an electromagnet since the overall thickness can be made small, 5 cm is easily realized, so that quite reasonable magnetic fields of the proper orientation can be achieved.

It is probably clear that this geometry presents some problems. First, let us consider the receiver coil as a conducting element which sits in the electromagnetic field produced by the transmitter coil, thereby distorting this field.

To give you an idea of how significant this distortion can be, the skin depth in copper at 5 MHz is about 30 microns, or 1 mil. Any practical receiver coil is going to be made of wire of 1 mil or greater in size (unless you have an elf to wind it for you), and hence will produce some distortion of the drive field. I'll return to this problem of drive field distortion a little later but there are other problems that one should consider first.

One of these is overload of the receiver circuitry. This is easily realized by noting that the electric field outside the transmitter coil is the order of 1 V/mm, whereas the electric field that the receiver coil must sense in order to detect the reflection from a 1 mm void is the order of 1 μV/mm. This means that the current passing through the transmitter coil must drop to very low values before the voltages that they induce in the receiver coil are down to an acceptably low level. This oscillator ring-down was troublesome in the apparatus that we used, but there was no difficulty in circumventing this problem by using longer transit times. We had a dead time of about 6 microseconds which corresponds to 18 mm of total transit distance in aluminum.

A much more serious problem is outlined in Fig. 1 which shows portions of the pulse echo pattern for the scattering of a shear wave (wavelength - 0.6 mm) incident on a 1 mm diameter cylindrical flaw. The shear wave polarization is parallel to the flaw axis. If the receiver coil is placed directly over the flaw, you get the reflection as shown in Fig. 1a. With the receiver coil moved 5 mm normal to the flaw axis, you get the echo pattern in Fig. 1b. The expected decrease in response is clearly observed.

Because we are scanning across a flat surface, the signal from the displaced coil should also be displaced in time; for the conditions in Fig. 1b, it should be about .2 μs later but there is no apparent shift. This is even more evident when the receiver coil position is shifted to 10 mm which should then produce a 0.8 μs shift.

Figure 1c does show a response about .8 μs later, which is, in fact, due to scattering from the cylindrical flaw. However, there is also a response corresponding to the unshifted coil position. This is not due to a real scattered signal received by the coil when it is displaced 10 mm from the axis. Instead, this signal appears at the surface

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directly above the flaw, that is, the pickup coil, and is coupled essentially instantaneously through the vacuum into the coil. This illustrates one of the major difficulties in using EMATs, namely, when trying to detect a small response adjacent to a much larger one, you must take account of possible coupling through the vacuum. Such spurious responses can be minimized by shielding the receiver coil. This works well in the through transmission geometry, but clearly introduces distortion into the drive field for single surface access.

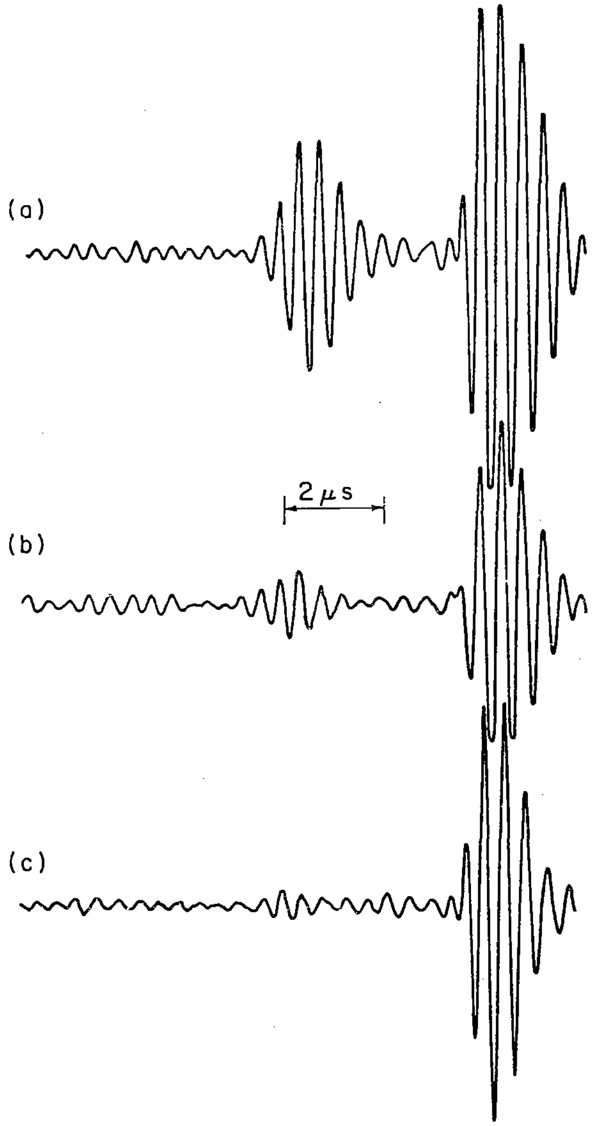

Figure 1. A portion of pulse-echo pattern showing scattering from a 1mm cylindrical flaw and the back surface (largest response) with the receiver coil. (1a) Directly above the flaw (1b) Displaced 5mm normal to the flaw axis (1c) Displaced 10mm

Another way around this coupling problem is to use shorter pulses of larger current which increases sensitivity and allows you to take full advantage of the differences in arrival time. For example, in the sequence shown in Fig. 1, if the pulses were very short, then even the vacuum-coupled signal would not distort much of the scattered signal. Thus, using shorter pulses would be a very significant advantage in this work.

One can also change the geometry to illuminate the void from the side and then scan along the top surface. In this case, the magnetic field would be parallel to one side of the specimen. An angular range of ± 30 degrees or more about 90 degrees could be studied and this would also give very significant information about the defect.

Lastly, I would like to show the type of resolution that can be obtained. Figure 2 shows the profile for vertically polarized shear waves back scattered from a 1.2mm diameter flat bottom hole. You get very good signals. These responses are very reproducible and have good signal-to-noise ratio, but because of the vacuum-field coupling that I referred to earlier, one could not take this as a quantitative measure of the scattering but only as a qualitative measure of the intensity distribution.

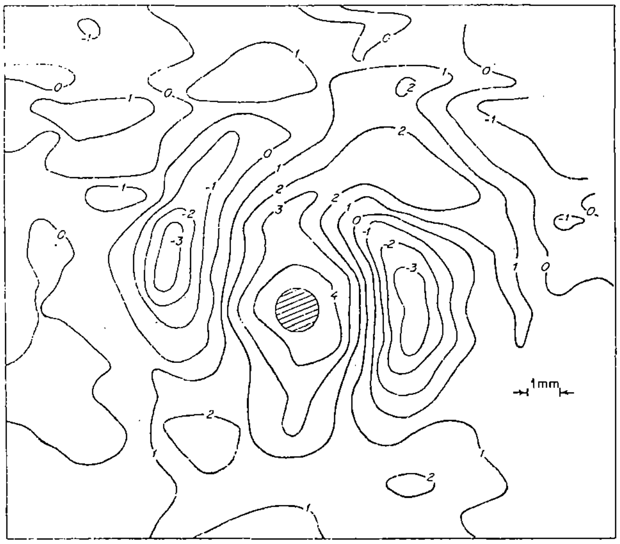

Figure 2. Equal amplitude contours for scattering back from a 1.2mm diameter flat-bottomed hole

This summarizes where we are at the moment in using the electromagnetic acoustic wave transducers for scattering studies. Some changes in the instrumentation and setup should allow quantitative results to be obtained.

I would also like to mention that we have done some work on making compact permanent magnet transducers weighing in the 200 to 250 gram range and having insertion losses of about 95 to 105 db that have turned out to be quite useful. It may be possible to use these in scattering studies. Further information on our permanent magnet EMAT work is available in an NBS Report.

Thank you.

DISCUSSION

DR. SY FRIEDMAN (Naval R and D Center): I have a relatively elementary question. Those shear waves that you are studying are propagating normal to the surface--

DR. MAXFIELD: This is correct.

DR. FRIEDMAN: There is no simple way to get them to come in at an angle of a conventional acoustic shear wave transducer?

DR. MAXFIELD: Oh yes, you can get angle waves. I believe Tom Moran will be describing some of this.

MR. FRIEDMAN: Okay, fine, I'll wait.

DR. JERRY TIEMANN (General Electric Co.): About how many amperes or watts do you use in your oscillator or coils, transmitter coils?

DR. MAXFIELD: We use, in these measurements, 5 or 6 amperes peak rf current. It's relatively easy to increase this, and I think that Fortunko and Thompson are going to describe some work up to maybe 100 amps of peak current in essentially a pulse excitation instead of an rf envelope type of excitation. Pulse currents up to about 2,000 ameres have been used, and this given back surface received signals of the order of 30 millivolts. Large currents produce large signals even with permanent magnets which give you maybe 3 or 4 kilogauss fields.