PORTABLE INSTRUMENT FOR DETECTION OF SURFACE FLAWS USING EMATs

C. F. Vasile, R. B. Houston and E. Pongracz-Bartha
Rockwell International Science Center
1049 Camino Dos Rios
Thousand Oaks, California 91360

R. E. Lee
Albuquerque Development Laboratory
Rockwell International Science Center
2340 Alamo, SE
Albuquerque, New Mexico 87106

ABSTRACT

The work reported here is the development of a first prototype portable ultrasonic inspection instrument based on EMAT (electromagnetic acoustic transducer) technology. The goal was to demonstrate EMAT inspection capabilities for small-size flaws in metal parts and to build a self-contained NDE unit that had a high degree of signal processing on-board so that human interpretation was minimized. The unit also served as a test bed, so that a number of new concepts could be evaluated. This instrument is viewed as an important step in the development of future NDE equipment.

DESCRIPTION OF UNIT AND BASIC CAPABILITIES

The EMAT flaw detector instrument (see Fig. 1) is capable of launching and detecting ultrasonic energy in metal parts using transducers that are physically separate from the specimen under investigation.[1,2] This operation eliminates the inconvenient and restrictive coupling medium (fluid) that is required by conventional piezoelectric ultrasonic instruments. The prototype is designed to inspect for surface flaws in both ferrous and nonferrous materials using a 1 MHz surface-acoustic-wave launched from a unidirectional EMAT transducer. This single transducer serves both as a generator and detector of straight crested surface waves. The unit is a radical departure from conventional equipment in that all information can be displayed in a digital format using the front panel digital LC (liquid crystal) display. Front panel ports are available if a display of reflected signal amplitude versus time (A-scan) is desired.

The instrument has two modes of operation:

Search Mode - Ultrasonic signals are introduced into the part and reflections monitored automatically. Reflected signals larger than a threshold that is operator-set sound an audio alarm. The distance between transducer and flaw is automatically displayed on the digital meter. Stray reflections are excluded by a range-gate circuit (set according to the size of part under inspection) so that natural part boundaries will not trigger the unit. A number of closely spaced flaws can be separated (resolved) by a "signal select" circuit that allows monitoring of the first, second (etc.) reflections occurring in a given time interval.

Inspection Mode - The instrument measures the magnitude of the signal reflected from the flaw and compares it to a preset signal level. This preset level is derived from a "standard" used for calibration. The LC meter displays the ratio (in dB) of the signal from the flaw under investigation compared to the standard. Positive readings indicate flaws reflecting more signal than the standard and negative readings less signal than the standard.

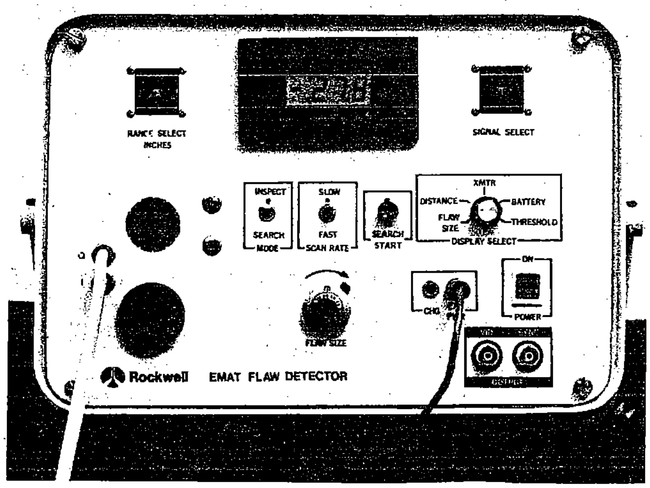

Fig. 1. Photograph of EMAT Flaw Detector Instrument.

The unit is self-testing in that the transmitter signal can be monitored and displayed on the LC meter. Also, the battery (or power supply) condition can be displayed. The threshold level (corresponding to the calibration standard) can be set from a 10-turn potentiometer and is displayable on the digital meter.

The instrument is designed to operate on an internal battery that will allow over 8 hours of continuous operation between recharging cycles. Repetition rates at which ultrasonic pulses are generated can be set at either 100 pulses/sec for fast inspection or

1 pulse/sec for increased battery life. The instrument battery can be fully recharged in about 8 hours through a front panel jack. Alternatively, where dc power is available, an external power port (12 volts at 0.6 amps) can be utilized to supply the required power to the instrument.

An rf output signal is available at the front panel, along with a synchronizing pulse for oscilloscope display of the detected flaw reflection. Signal levels of about 50 to 100 mv are achieved for flaws 0.010 inches deep and 0.25 inches wide on the surface of a ferrous metal (corresponding to a signal-to-noise ratio of better than 20 dB at the 1 MHz frequency of operation).

TRANSDUCER ELEMENT

EMAT transducers rely upon the forces produced in a metal part when eddy currents induced by an excitation coil interact with an applied static magnetic field from a permanent magnet or electromagnet to generate acoustic waves. The resultant surface traction forces, similar to the forces present in an electric motor, are the cross-products of the induced surface current density times magnet field strength. Due to the wide variety of coil and magnet configurations possible, EMATs are capable of producing numerous types of acoustic waves (surface, horizontal and vertical shear and longitudinal waves).

The particular EMAT transducer used here is composed of 2 printed circuit coils with periodicity of ~3.0 mm that are interlaced (using a two-sided PC board and plated-through holes for connection) so that when each coil is driven at 1 MHz and 90 degrees out of phase with respect to each other they produce a unidirectional sound beam about 1 inch wide. As a result, this EMAT is unidirectional with a front-to-back rejection ratio better than 30 dB.

The magnetic field is derived from a pair of adjacent samarium cobalt magnets 1" long by 1/2" wide that are oriented "N-S and S-N" and cover the entire back surface of the EMAT. A soft-iron keeper is used to close the flux path at the rear of the transducer so that the field produced is essentially uniform and normal magnetic fields in the coil region (Br ~4000 Gauss). There is a "scratch protection" layer (of a tough polymer material 5 mils thick) that covers the front of the coils. The entire transducer assembly occupies a volume of about 1-1/2" x 1-1/2" x 1-1/2" and can be easily maneuvered by hand.

As stated above, essentially straight crested surface waves are produced by this probe design. This can be used as an aid for determining the orientation of flaws. "Crack-like" flaws produce maximum reflection when the wave fronts of the incident surface acoustic wave are aligned parallel to the length of the flaw. Thus, by pointing the transducer at the flaw and scanning it about the flaw, a maximum return corresponds to parallel alignment with the flaw. If equal scattering is observed over a broad angular distribution, then a pit-like flaw is indicated. By knowledge of the scattering properties of different flaws, one can use this instrument to perform flaw characterization.

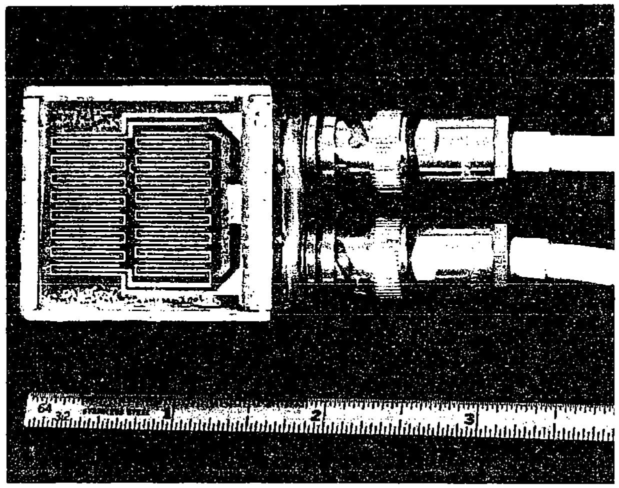

Fig. 2. Photograph of EMAT Transducer Coils for Unidirectional Ultrasonic Generation of Surface Waves.

ELECTRONICS SIGNAL PROCESSING CAPABILITIES

The electronics of the EMAT flaw detector can be subdivided into four functional blocks: (1) a high power transmitter, (2) a low noise receiver, (3) analog signal processing and (4) signal digitization, sampling, and display.

The transmitter is composed of a pulser and a dual 1 MHz bipolar transistor power amplifier circuit, used to drive a high current tone burst of 14-cycles duration, 60 amps peak-to-peak through the coils. The low impedance of the EMAT coil is matched to the transmitter using ferrite core step-up transformers and discrete reactive components.

The dual-channel receiver circuit employs low-noise FET transistors to achieve two purposes. First it amplifies the return signal and establishes the electronic noise figure of the unit. Second, it compensates the phase imbalance of the two signal channels. Since the same EMAT sensor is used to both generate and detect the ultrasonic signal, dual back-to-back diodes and reactive shunting elements are used to protect the receiver from the direct transmitted signal and filter out noise. Matching circuits at the receiver input raise the impedance level to optimize the signal-to-noise performance of the amplifier section. Four stages of amplification produce a gain of ~80 dB and a recovery time of about 20 μsec (from the conclusion of the transmitted signal). This allows flaws of .01" depth and 0.1" width to be easily detected at any range between 1.5" to 18" in front of the EMAT probe.

The analog signal processing performed in this unit is through use of a "correlation receiver", which acts as a nearly matched filter to the triangular-shaped rf waveforms characteristic of flaw reflections in EMAT systems. Figure 3 illustrates the block diagram. To perform the matched filter function and maximize the S/N ratio, the correlation receiver uses two channels: I (in-phase) and Q (quadraturephase). Each channel is driven by a separate EMAT coil and 80 dB preamplifier. The two-channel multiplier circuit multiplies the received flaw signals with a suitably delayed square wave burst supplied by the burst generator (at the time delay corresponding to the ultrasonic range element being inspected for flaws). The square wave burst B_I is phase-shifted 90° from B_Q so that no matter what phase the return flaw signal has, there will be a multiplied output in one channel or the other. This approach essentially removes the phase sensitivity of the measurement technique. The product signals are integrated separately to produce a voltage level corresponding to the signal energy in each channel. The output of the integrator circuit is

$$\int_0^T B(t)\, S(t)\, dt,$$

which (except for a time inversion) is the convolution of the flaw signal with the reference which we desire to achieve. The output of the integrators is then sampled individually and stored as analog voltage levels. An additional operation is performed involving the square root of the sum of the square of the two integrator outputs. This operation is required to preserve the linearity of the detection process independent of phase. The output undergoes further signal processing to achieve the ratio which is displayed as an output on the LC display.

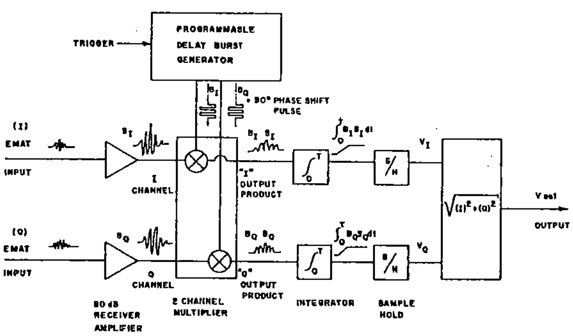

Fig. 3. Block Diagram of Correlation Receiver Portion of EMAT Flaw Detector.

The main advantage of the correlation receiver is the improvement in signal-to-noise performance offered (to within 0.7 dB of exact matched filtering). It offers substantial advantages over narrow band tuned filters for noise reduction, which spread the pulse width (reducing time resolution) and distort the phase linearity. The two-channel approach exhibits a 3 dB noise figure degradation compared to a single-channel approach; however, the two-channel system is phase-insensitive (as required by the detection process).

A full description of the digital circuits which allow display of the various signals and time delays is omitted since it is too detailed to be presented in this paper.

SUMMARY

A prototype portable EMAT instrument has been built which is capable of inspecting metal parts for minute surface flaws. Significant features of the EMAT unit are:

1. Flaw detection demonstrated by detecting EDM notches 0.01" deep by 0.25" wide over a transducer to flaw distance of 1-1/2" to 18" range on a polished steel plate. (15-20 dB S/N ratio).

2. Unidirectional ultrasonic transduction (30 dB front to back isolation).

3. Sonic alert signal when flaws above a certain threshold are found.

4. Automatic readout of distance between the probe and the flaw.

5. Digital output reading that is related to flaw scattering strength.

6. Ability to determine orientation of crack-like surface flaws.

7. Battery operation for field use.

Although the present EMAT transducer head is designed to inspect flat samples, curved or shaped heads will allow inspection of other geometries (pipes or bars). Also, volume (interior) flaws are easily detected using a modified EMAT transducer that emits shear or longitudinal waves into the part under inspection.

Non-contact ultrasonic transduction of this EMAT instrument offers the possibility of very rapid inspection of large area metal parts. This type of equipment is expected to advance the state-of-the-art in NDT inspection over the next few years.

REFERENCES

1. R. B. Thompson "Electromagnetic, Non-contact Transducer", 1973 Ultrasonics Symposium Proceedings , p395 (New York IEEE, 1973).

2. R. B. Thompson "Electromagnetic Generation of Rayleigh and Lamb Waves in Ferromagnetic Materials", 1975 Ultrasonics Symposium Proceedings, p633 (New York IEEE, 1975).

3. R. B. Thompson "Non-contact Transducers", 1977 Ultrasonic Symposium Proceedings, p74 (New York IEEE, 1977).

CODED APERTURE IMAGING IN NDE*

T. M. Cannon and E. E. Fenimore
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

It is sometimes the case in nondestructive evaluation that the position and intensity of a faint radioactive source must be determined. A simple pinhole camera may suffice in many instances, however its small collection efficiency may result in unreasonable exposure times. To correct for the low collection efficiency, a multiple-pinhole (coded) aperture can be substituted for the single pinhole. The result is that many more photons are collected by the camera, however the resulting picture is scrambled beyond recognition and must be somehow decoded. Various coded apertures have been used in the past, including Fresnel zone plates and random arrays.

Recent work at Los Alamos has produced a state-of-the-art advance in coded aperture imaging. The sensitivity of the coded aperture system can be greatly increased by the use of a newly developed uniformly redundant array (URA) as the camera aperture. When coupled with recent advances in computer decoding methods, the URA coded aperture camera can produce images that are totally free of the artifacts that hinder other approaches.

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