Custom EMAT Instrumentation: Correlation Receiver and Flaw Detector

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New, custom instrumentation is presented which is designed to complement and exploit the unique properties of EMAT's. A two channel correlation receiver is described which allows simultaneous detection of the in-phase and quadrature components of an ultrasonic signal with the optimum noise figure and improved interference rejection. In addition, a prototype, fully self-contained EMAT flaw detector is presented. This is a surface wave device for handheld use and incorporates such features as battery operations, correlation detection, search and inspect modes, and digital readout of flaw position and reflected signal amplitude.

Figure 1 shows that custom instrumentation is being developed to detect flaws in certain materials. The technology involves the utilization of EMAT's, electromagnetic transducers, and correlation processing electronics. Flaw identification is accomplished by pattern recognition techniques on the processed waveforms.

Figure 2 shows that a basic flaw detection system can be formed using the realtime acoustic echo from both known and unknown reflectors. The echo signals are processed with known references to yield both in-phase and quadrature information. A realtime correlation technique is implemented to process the signals.

In Fig. 3, the relationships between the in-phase, $V_i$, and quadrature, $V_q$, signals are formulated. The conditions that determine the optimum signal to noise ratio, the phase of the detected acoustic signal, and the Fourier transform of the received signal are given.

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- OPTIMUM SIGNAL TO NOISE RATIO
- ENHANCED ELECTRICAL INTERFERENCE REJECTION
- MINIMIZES EFFECTS OF CLUTTER
- PROVIDES SIMPLE MEANS FOR MEASURING RELATIVE PHASE AS WELL AS AMPLITUDE OF RECEIVED ACOUSTIC SIGNALS
- SIMPLIFIES SIGNAL AVERAGING
- REAL TIME FOURIER ANALYSIS
- ANALOG MULTIPLIER OUTPUTS WILL INDICATE PRESENCE OF DISPERSION

Fig. 1 Advantages of correlation receiver to NDE instrumentation.
TONE BURST
DELAYED
COHERENT
REFERENCE SIGNALS

\[ r(t) = \cos(w_0 t + \phi) \]

BASIC RELATIONS

\[ V_i = \int_{t_0}^{t} (a(t) + \delta_0) \cos(w_0 t + \phi - \epsilon(t)) \cos (w_1 t) \, dt \]
\[ V_o = \int_{t_0}^{t} (a(t) + \delta_0) \cos(w_0 t + \phi - \epsilon(t)) \sin (w_1 t) \, dt \]

\( \delta_0 = \text{NOISE IN SIGNAL CHANNEL} \)

Fig. 2 Application of realtime correlation to NDE measurements.

GENERAL RESPONSE

\[ V_i = \int_{t_0}^{t} (a(t) + \delta_0) \cos(w_0 t + \phi - \epsilon(t)) \cos (w_1 t) \, dt \]
\[ V_o = \int_{t_0}^{t} (a(t) + \delta_0) \cos(w_0 t + \phi - \epsilon(t)) \sin (w_1 t) \, dt \]

PHASE MEASUREMENT

FOR NOISE \( \delta_0 = 0 \)

\[ \frac{V_o}{V_i} \tan(\phi) = \frac{\epsilon(t)}{T} \]

SELECT \( \phi = 0 \), \( \delta_0 = 0 \), \( w_1 = w_0 + T = 2 \pi f_{0} \)

Fig. 3 Measurement capabilities.

OPTIMUM RECEIVER

SELECT \( \phi = 0 \), \( \delta_0 = 0 \), \( w_1 = w_0 + T = 2 \pi f_{0} \)

SENSITIVITY

\( <V_i> \) AND \( <V_o> \) ARE TIME AVERAGES ACHIEVED BY USING MULTIPLE TONE BURSTS

AND LOW PASS FILTERING \( a(t) \delta_0 < N \) REPETITION RATE \( N \)

FOURIER ANALYSIS

SELECT \( w_1 = w_0 \), \( \delta_0 = 0 \), \( \phi = 0 \)

\[ V_i (\omega) = \int \cos(w_0 t + \phi) e^{-i\omega t} \, dt \]

\[ = \text{FOURIER TRANSFORM OF RECEIVED SIGNAL EVALUATED AT } \omega = w_0 \]

RECEIVED 0.5 MHz ACOUSTIC SIGNAL

OUTPUT OF ANALOG MULTIPLIER WITH REFERENCE
CONSISTING OF 15 \( \mu s \), 0.5 MHz TONE BURST IN PHASE WITH CENTRAL
15 \( \mu s \), PORTION OF RECEIVED
ACOUSTIC SIGNAL

Fig. 4 Typical waveforms of an EMAT acoustic signal.

FEATURES

- 1 MHz NON-CONTACT SURFACE WAVE EMAT PROBE
- SINGLE UNIDIRECTIONAL TRANSMITTER/RECEIVER EMAT
- PERMANENT MAGNET TRANSUCER
- PORTABLE – LOW POWER – BATTERY OPERATED
- INCORPORATES TWO CHANNEL CORRELATION RECEIVER
- SEARCH MODE
  - MANUAL IN X – ELECTRONIC IN Y
  - DIGITAL OUTPUT – ESTIMATE OF DEFECT SIZE AND DISTANCE FROM PROBE
- INSPECTION MODE
  - SELECTABLE RANGE GATES
  - SIGNAL AVERAGING

Fig. 5 Prototype EMAT flaw detector.
AN ULTRASONIC INSPECTION SYSTEM WITH HIGH NEAR-SURFACE DETECTABILITY

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ABSTRACT

An updated NDE instrument has been designed that is compatible with existing water path pulse echo instruments. The use of modern integrated circuit video amplifiers and broad band signal processing in the receiver permits improvements in signal-to-noise and band width to be simultaneously achieved. Additional circuits provide a variable depth--variable width processing gate, a peak detector for strip chart recording, and means for triggering from the front surface reflection.

These circuit improvements, together with a specially designed transducer permit defects to be sensed that lie within 0.050" of the surface--thus representing about a factor of two improvement compared to commercially available instruments.

Details of the electronics subsystems comprising the transmitter and receiver will be shown, and the structure of the transducer will be described.