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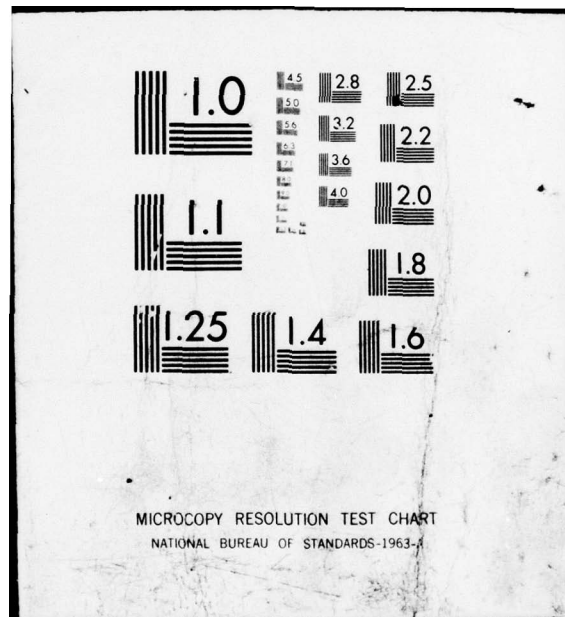
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**An Acoustic Transponder for Calibrating
Ultrasonic Equipment.**

10 HENRY H. CHASKELIS

Mechanics of Materials Branch
Ocean Technology Division

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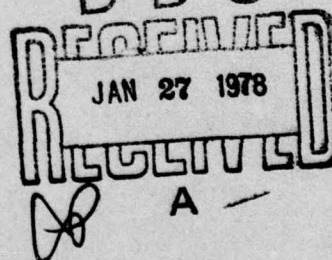
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AN ACOUSTIC TRANSPONDER FOR CALIBRATING ULTRASONIC EQUIPMENT

INTRODUCTION

The initial ultrasonic inspection of materials and structures must be carried out with thoroughness and precision commensurate to the critical damage results which would occur due to various failure modes. For extended life or reusable items, subsequent maintenance inspections must either be equivalent to the initial test or follow the growth pattern of the various anomalies previously found but which are not yet critical. For the nuclear industry the potential damage due to failure is most serious. Therefore it is not only crucial to implement a very thorough nondestructive evaluation (NDE) program, but also it is most prudent to be thoroughly cognizant of the possible tolerance degradation of the inspection system itself. This report addresses such a topic with respect to the use of ultrasonic inspection systems. Furthermore, as a partial solution to the complex problem of tolerance degradation a recently developed acoustic transponder device is discussed. This device is an outgrowth of a previously reported work (Ref. 1). Currently there are six units which are being evaluated in the field.

Tolerance Degradation of an Ultrasonic Inspection System

The term tolerance degradation refers to the situation whereby, during the examination for one unknown parameter (the flaw), the existence of other unknowns (instrument or test peculiarities) prevents the unique or accurate determination of the desired parameter. For example, interpolating the echo strength from a flaw relative to that of several known flaws requires that the amplifier be linear. Failure to verify the linearity of the amplifier may be the cause of inaccurate readings. In practice there are many degradation modes that may act interdependently, which makes an analysis rather difficult. To alleviate this problem it is desirable to group the various tolerance degradation modes and relate them to the actual measurement which is undertaken.

For ultrasonic testing, the basic quantities measured are the pressure amplitude, the frequency variations in pressure amplitude (spectrum), the relative phase, and a time-dependent parameter (velocity). These measurements are made and recorded with respect to some coordinate axes which serve as reference points at the surface of the inspected object. Of these five measurable quantities* the most commonly used today for industrial NDE are pressure amplitude, time, and location (coordinate axes). The degradation modes therefore refer to the possible inaccuracies which may occur, due to either test technique or instrumentation causes, when measuring these quantities. To further aid in systematically dealing with degradation modes it is worthwhile to separate the domains under which these occur. These are the acoustic field, electromechanical interaction, and the electronic components.

*Fundamentally this could be reduced to just three; amplitude, space and time
Manuscript submitted June 29, 1977

THE ACOUSTIC DOMAIN

An acoustic source coupled to some medium will radiate a field in accordance with certain physical laws. In standard ultrasonic practice the reflected (and some scattered) portion of this field is used to detect and evaluate the homogeneity of the medium. This reflected field is dependent on wavelength, materials constants (impedance) and geometric factors. Therefore the accuracy and consistency of the measured intensity, time, and spatial coordinate will be proportionally affected with respect to the a-priori knowledge of, or variation in, these three acoustic domain factors. For example, suppose a fairly accurate thickness measurement is desired by use of the pulse echo technique. Time (T) is the usual quantity measured and, the most general relationship to part thickness is:

$$T = \frac{Nt \sec}{V_2} \left[\sin^{-1} \frac{V_2}{V_1} \sin \alpha \right].$$

Here N refers to the number of traverses through the part thickness t , α is a directional angle and V_2 and V_1 are velocities of the specimen and coupling medium respectively. If one of the geometric factors is not precisely known, say the direction in which the source emits, then the thickness calculation will be in error by a multiplicative amount related to the secant of the angle in error (Fig. 1). Assuming the piezoelement is misaligned in the transducer housing by 1 degree of arc, the accuracy can be no better than the third decimal place if $V_2 = V_1$. The situation is more grave if one attempts to "average out" the time measurement over a multiple bounce path (N) or uses the N and $N + 1$ multiples as a measurement base.

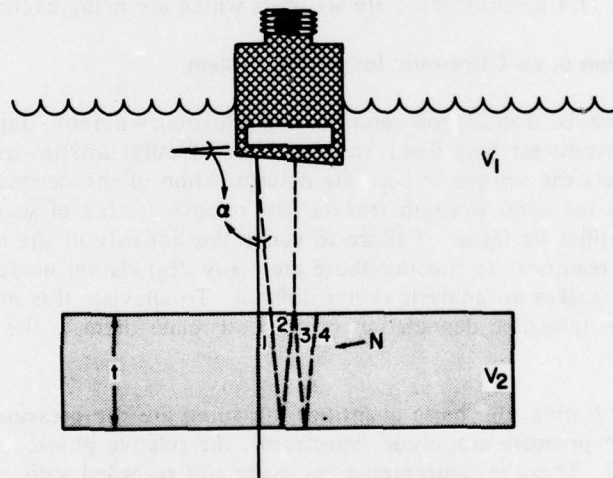


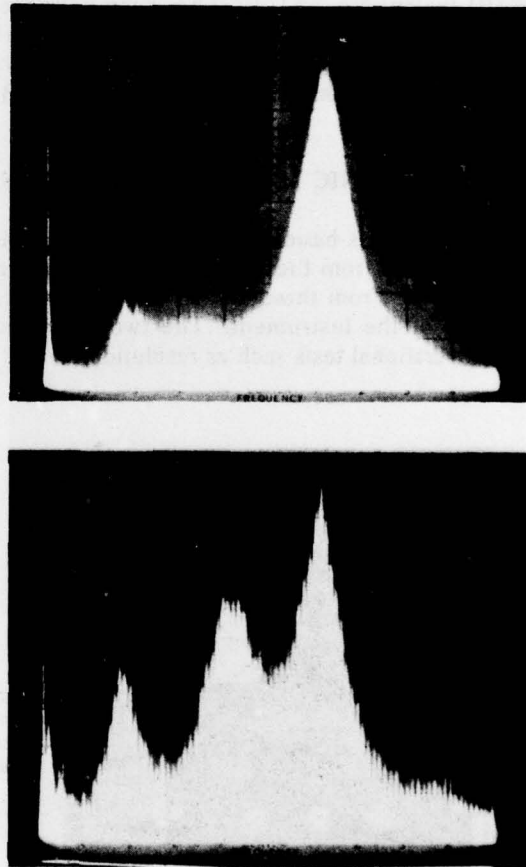
Fig. 1 - Accuracy of measured thickness t depends not only on knowledge of instrumentation precision and material velocity V_2 , but also on acoustic path. A normal ray would follow the solid line but angulation errors α will cause the ray to follow the dashed line. This error will be dependent also on the velocities V_1 , and V_2 and the number of half-bounces N .

ELECTROMECHANICAL INTERACTION

The conversion between electrical and mechanical energy occurs at the transducer. By virtue of certain material and orientation properties the transducer both affects and is affected by contact with electrical and mechanical forces. As a source of acoustic energy, its dimensions, homogeneity, and coupling coefficients (materials constants) determine the radiation field generated. However, the impedance difference due to mechanical contact also causes a change in the electrical characteristics. The converse also occurs. Therefore both the electrical and mechanical impedances influence the acoustic field generated. Likewise, when used as a receiver, the charge created by the presence of an acoustic pressure field is affected, by the impedances.

Because of these interactions it is possible to generate errors in the accuracy of two of the measured quantities; amplitude and time. For example, a change in the mechanical impedance (as in immersion versus contact testing) can change the transducer center frequency and bandwidth (Fig. 2). This effectively will change the directivity pattern of the acoustic wave in the medium. In turn the return echo from an otherwise identical situation may be different.

Fig. 2 - Spectral analysis photograph of return echo from flat fused silica specimen. The upper and lower sides respectively show the results of contact versus immersion test. Although the peak frequency remained at 6 MHz (1 MHz per division, linear amplitude presentation) the lower frequencies are significantly damped when the transducer is loaded by direct contact with the specimen.



ELECTRONIC COMPONENTS

At this juncture one enters into the more familiar yet least resolved problem area, the electronics package. Basically the standard ultrasonic electronic package consists of a pulser, receiver stages, display section (space and time base), and the associated power supplies. Both the pulser and first receiver stage (including the pulser front end limiters) are affected by coupling to the transducer. The rest of the package may be affected by inherent design differences, line source problems, temperature fluctuations, etc., all of which may cause errors in the measurement.

As previously mentioned the many tolerance degradation modes which exist may be subdivided into two basic categories:

- 1) Modes related to the test technology which affects the quantities being measured; intensity, time, location.
- 2) Modes related to the accuracy and stability of the measuring instrument; the electronics package.

To avoid or at least minimize the first kind of error mode requires knowledgeable, competent, and experienced ultrasonic practitioners. The second kind requires a means to test the precision of the measurement instrument. To this end a device called the Electronic Test Block (ETB) (patent No. 3,531,977) has been developed at NRL. A previous report (1) discussed the overall capabilities of a device conceived to have a much broader application and the partial success of the preliminary laboratory model. This report presents the current status of a more limited in scope commercial version of the ETB, which is presently being evaluated at various field activities.

THE ELECTRONIC TEST BLOCK: OPERATING PRINCIPLES

The ETB is basically an electronic-controlled acoustic transponder (Fig. 3). It senses the acoustic signal from the instrument under test and returns pulses of known amplitude and time relationship. From these known echoes a proper assessment can be made of the measurement accuracy of the instrument. The two basic qualities assessed are time and amplitude. Also, other operational tests such as resolution and dB attenuator accuracy can be made.

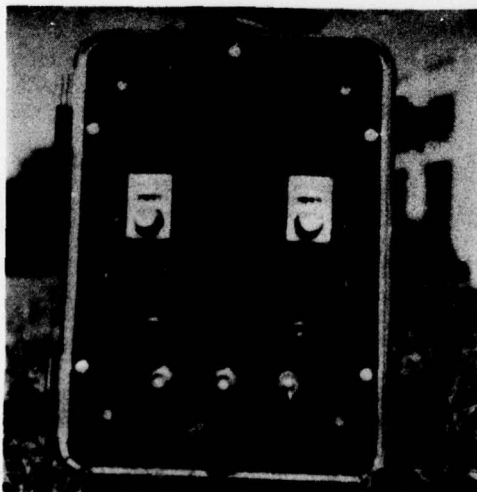


Fig. 3 - Battery or line operated ETB built to Navy specifications. The front panel has been designed for ease of operation. Rugged case and electronic assembly allow its use under shipyard conditions.

As previously discussed there exists a two-way interaction between the transducer and electronics package. For this reason it is important to test the instrument and transducer combination. The ETB does this. By use of the built in transducers (Fig. 4) the calibrated electronic signals are linearly converted to the acoustic domain. At this point the known reference is introduced to the equipment being tested.

In practice the ETB returns two signals in synchronism with each incoming acoustic pulse (Fig. 5). While in the amplitude linearity mode, the amplitude of the second pulse is half that of the first. This ratio is maintained over a 40 dB range. For the resolution test mode, each pulser is independently controlled. While in these test modes, the timing of the two pulses is also controlled by the operator by means of thumb wheel switches on the front panel. Both the delay from the starting signal and the separation of the two pulses is so controlled.

Fig. 4 - A pair of transducers is provided per ETB. These units can adapt to immersion, through transmission and shear wave testing. The holding fixture for the tested unit allows the operator free use of both hands.

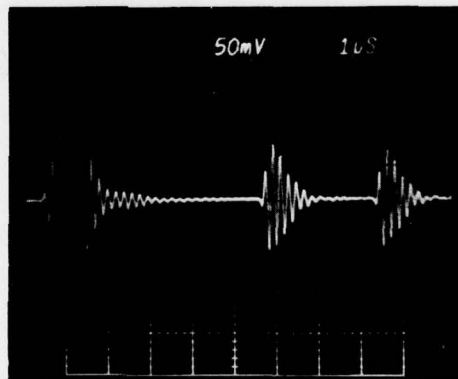
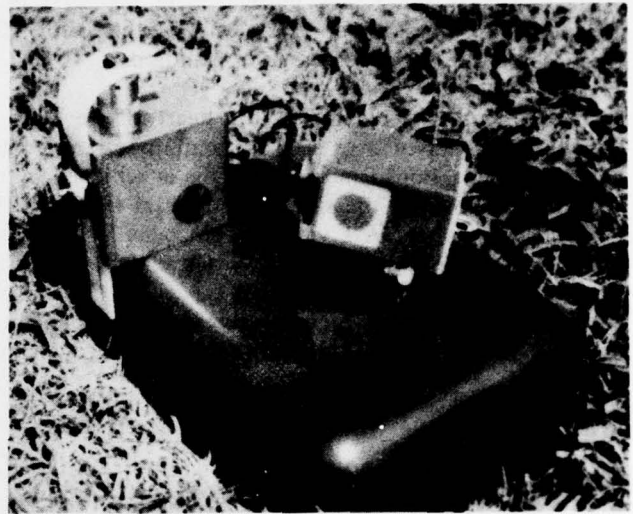


Fig. 5 - Oscilloscope trace of incoming signal to ETB and two return echoes provided by ETB (from left to right).

The principal reason for controlling the time and amplitude of the ETB is to be able to verify the ultrasonic instrument measurement precision under actual test conditions. Most instruments do not maintain the same accuracy throughout the entire dynamic range capability. For this reason the ETB was developed to make on-site assessments.

THE ELECTRONICS

There are four principal functional areas in the electronics package. These are the timing circuit, pulser network, operational logic board, and power supply.

The timing circuit comprises a hard start* 10 MHz pulsed oscillator and two sets of count-down counter chains. Upon receipt of an input pulse the oscillator is turned on. The counter chains in turn count down in $0.1 \mu\text{s}$ increments (1 cycle) from a preset number entered via the time control front panel switches. By this means an accurate time control is established in order to trigger the ETB's pulsers. The precision of the time measurement is principally dependent on the accuracy of the 10 MHz oscillator. This may be referenced, via established practices, to the National Bureau of Standards.

A unique pulser circuit is the heart of the ETB. The principal requirement is that the transducer be pulsed over a 40 dB amplitude range with no other changes occurring (i.e. frequency content, impedance, etc.). This is achieved by use of silicon-controlled rectifier (SCR) switches as shown in the simplified diagram (Fig. 6). The main amplitude is controlled by the low-voltage amplifier A-1 via the front panel "pulse amplitude" potentiometer. The output of A-1 is independently amplified by each channel consisting of A-2 or A-3 and two transistors. By this means the pulse discharge capacitors C-1 and C-2 are charged to the desired voltage. When the SCR string is fired via trigger signals applied to Q-1 and Q-2, the transducer is pulsed by the discharge of the capacitors to ground through the SCR's. The SCR string is then tem-

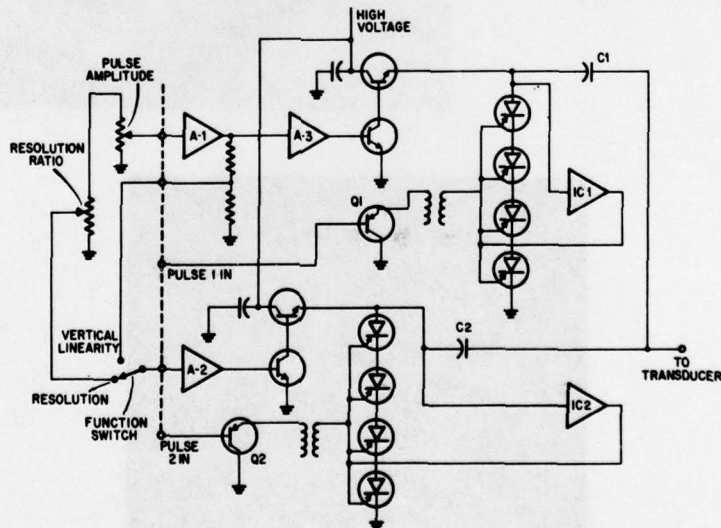


Fig. 6 - Simplified pulse schematic. To the left of the dashed lines are the front panel controls.

*A proper current is kept flowing through the coil so that the turn on characteristics are controlled as to phase and amplitude. By this means the oscillator starting and running amplitudes are the same so no cycle count is missed.

porarily turned off by means of a timed negative bias from IC-1 and IC-2 in order to prevent a refire or burn out. The second pulser's amplitude is independently adjustable by means of the front panel "resolution ratio" potentiometer when the "function" switch is set at the "resolution" position.

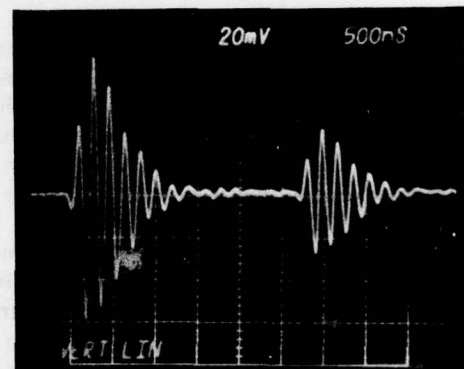
The operational logic board consists of the input signal amplifiers and various flip-flop logic circuits. The received signal is amplified and, if above a preset level, an integrated circuit (IC) is triggered. This input port IC will start the 10 MHz oscillator and enable the first pre set timing counter chain (main delay). When the count reaches "0" the first pulser is activated and at the same time the second countdown chain is started. Upon reaching "0" count the second pulser is fired and, after a 10 μ s delay, the two countdown chains are reloaded, the input port is enabled, and the clock is turned off.

Power is supplied from internal lead acid batteries or an external ac supply. A special charger circuit provides the necessary current to maintain the battery. Either a 9 volt dc charge up to 1/4 ampere or a 10 volt dc charge limited to 1 ampere is supplied to the battery as conditions warrant. A special battery cutoff circuit is incorporated so as to prevent errors due to low voltage and to prevent damaging the batteries by complete discharge.

FIELD OPERATION

To assess the accuracy of the measurement to be made, the ultrasonic instrument is first adjusted by use of the proper reference standard for the test at hand. Next the instrument's transducer is coupled to the ETB's transducer. With the present model it is possible to test in the contact, immersion, and through-transmission modes of operation. The timing and the amplitude controls are then set on the ETB so that the two echoes appear on the screen. If no pulses appear, then the ultrasonic instrument's transducer or pulser must not be strong enough to trigger the ETB. This is an arbitrary lower limit, but it does ferret out "weak" transducers and/or pulsers. If echoes appear, the test can now begin.

Fig. 7 - Oscilloscope trace of the 2:1 ratio signal amplitude pulses returned by the ETB. This signal is taken from the ETB side of the transducer. A plot of dc voltage vs pulse output (no ETB transducer at pulses) or rf pulse output (ETB transducer at pulses) shows the relationship to be linear.



For amplitude linearity one merely observes the accuracy of the 2:1 ratio presented by the pulsers (Fig. 7) much in or the same manner as suggested in ASTM E-317 or MIL STD 271-E. However by using the ETB a significant improvement is offered. Instead of varying the ultrasonic instrument's gain setting (which in reality does not measure linearity*), the ETB's amplitude is varied while maintaining the constant 2:1 ratio. By this simple means, a

*Amplifier linearity is a measure of the relationship between input and output at a constant gain. A change the gain setting while observing the input to output relationship of two fixed input levels does not prove the linearity of the system (Fig. 8).

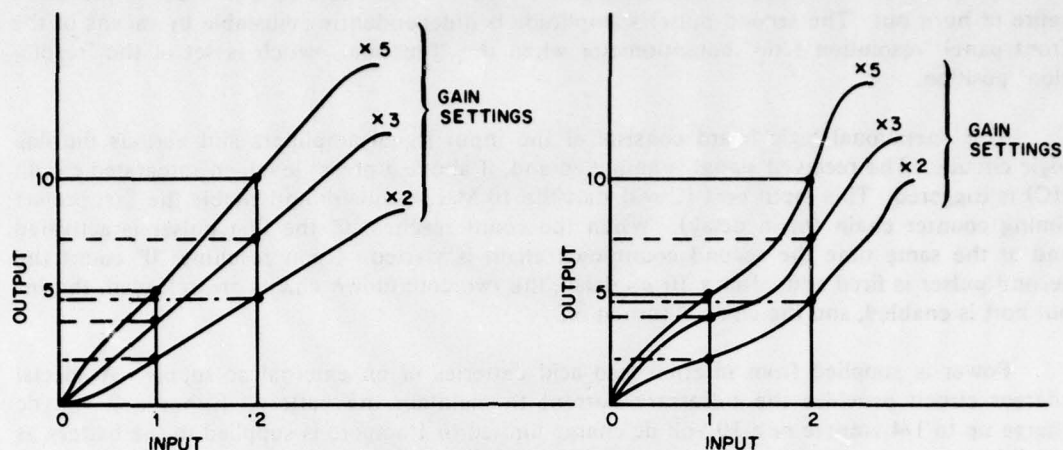


Fig. 8 - A linear and nonlinear amplifier response is shown on the left and right drawings respectively. As shown the two fixed pairs of input signals appear linear on the outputs for the various gain settings demonstrated. To properly verify the linearity of these amplifiers it is required that the two fixed input signals (2:1 ratio) be varied (slide along the abscissa) over the desired testing range.

true linearity test is made. The time base linearity may also be examined by manually advancing the time domain controls. From experience it has been noted that most instruments do not maintain linearity for all combinations of transducers plus damping, gain, and attenuator settings. Conversely it is usually possible to find a combination of settings that will meet the test requirements. This is a very important point which unfortunately has not received enough attention. Such effects reinforce the futility of "testing" for linearity under the current practices. One can usually find a linear place, but will those be the same conditions for the actual test? In principle, if one needs to be assured of amplitude linearity then it must be measured on site under the actual test conditions.

The resolution is evaluated by observing the effects of moving the time domain having previously set the amplitudes of the pulses in a similar relationship as expected for that inspection (Fig. 9). The reason for this procedure has been demonstrated in a previous report (1). Simply stated, temporal resolution is a function of both time and amplitude. Current practice is to use a flat bottom hole (FBH) of known diameter and distance from the front surface of the specimen. Resolution is then described as the ability to display the echoes from the front surface and FBH to some specified criteria. The noise shorted a distance from the FBH to the specimen surface and or the smaller diameter FBH used is then a measure of "better" resolution. Unfortunately, a change in the relative amplitudes of the two signals may cause a change in the apparent resolution capability. A further point, less known but more vital, is the fact that the demonstration of a certain minimum resolution does not assure similar capacity for less stringent requirements (Fig. 10). Problems with both temporal and lateral resolution are really quite complex and have also not yet received the just attention deserved.

CONCLUDING REMARKS

It has been shown that the accuracy of ultrasonic measurement may change due to two categorical variables: those related to the test technology and those related to the measuring instrument electronics. An Electronic Test Block has been developed as an aid in evaluating the

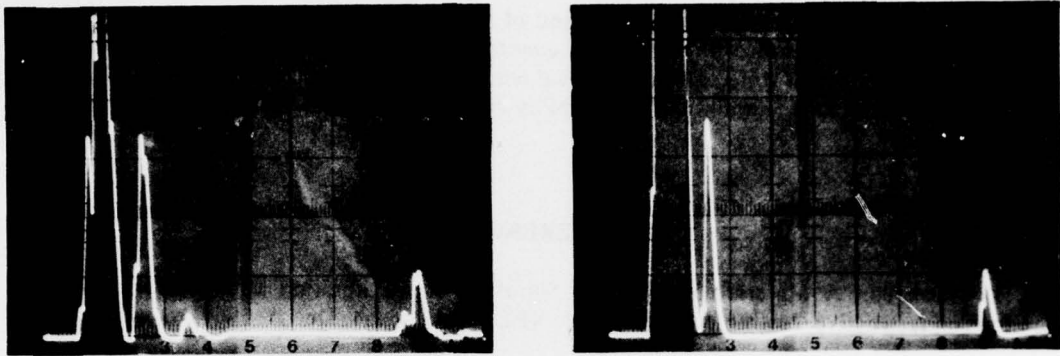


Fig. 9 - At left, standard ultrasonic instrumentation resolving a 5 flat bottom hole near front surface during immersion test. At right the same result but emulated by ETB.

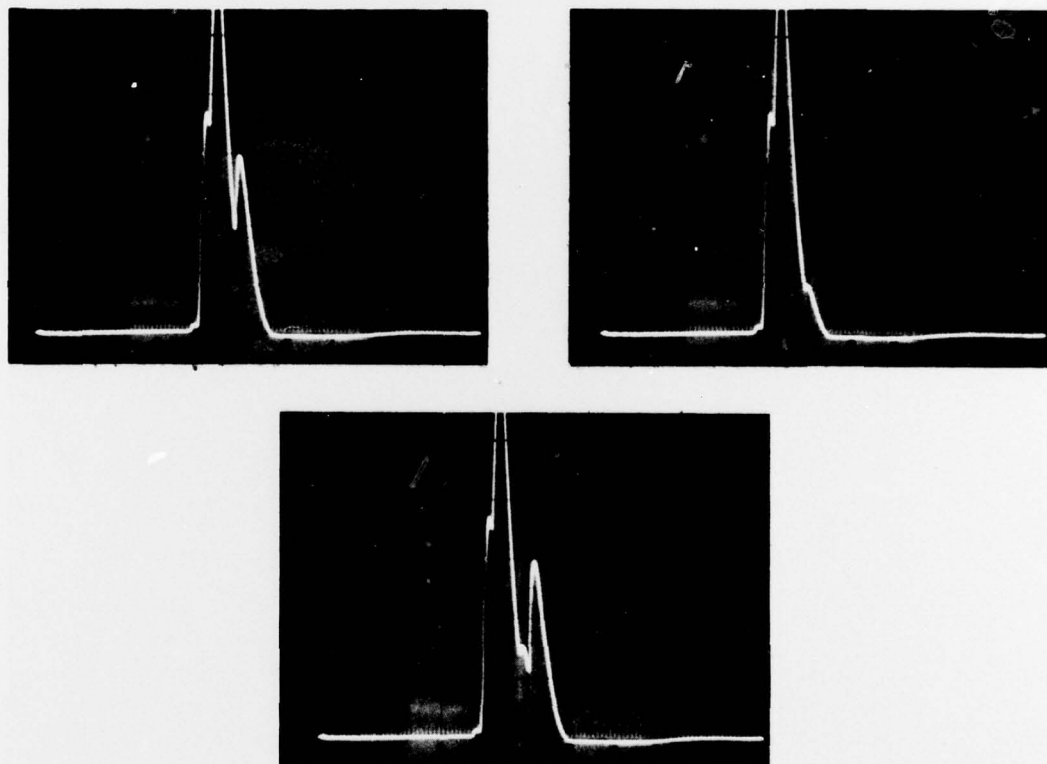


Fig. 10 - ETB depicts resolution problems. Sequence from left to right shows the pulses separated by .6, .7 and .8 μ sec. It should be noted that the relative amplitude of the signals will also determine the resolution capability.

tolerance degradation caused by the second kind of variable. With this device it is now possible to examine the precision of the measured quantities, time and amplitude. This may be accomplished in a very brief time and under actual test conditions. Such an evaluation will prove to be most beneficial for maintaining the reliability of ultrasonic inspection measurements.

REFERENCE

1. H.H. Chaskelis, "A Materials and Defect Simulator for Calibrating Ultrasonic Equipment used in Nondestructive Testing or Inspection," NRL Report 6984, Dec. 5, 1969.