SSC-213

A GUIDE FOR ULTRASONIC TESTING AND EVALUATION OF WELD FLAWS

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1970

Dear Sir:

To maintain the high degree of safety and reliability in ship fabrication, the Ship Structure Committee has completed a project that provides an ultrasonic inspection guide that retains the comparable radiographic standard provided earlier.

The results of this project are contained in this report.

Sincerely,

W. F. Rea, III
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

SSC-213

Final Report
on
Project SR-188, "Ultrasonic Test Guide"
to the
Ship Structure Committee

A GUIDE FOR ULTRASONIC TESTING AND EVALUATION OF WELD FLAWS

by

R. A. Youshaw
U.S. Naval Ordnance Laboratory

under

Department of the Navy
Naval Ship Engineering Center
Project No. SF 35422306
Task 02022

U. S. Coast Guard Headquarters
Washington, D.C.
1970

ABSTRACT

This document presents procedures and acceptance limits for contact ultrasonic inspection of steel butt welds in the thickness range of 1/4 to 2 inches. The acceptance limits described in the following sections are compatible with those set forth in SSC-177, "Guide for Interpretation of Nondestructive Tests of Welds in Ship Hull Structures" for radiographic inspection and should therefore result in satisfactory ship welds.

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SCOPE

This document presents procedures and acceptance limits for contact ultrasonic inspection of steel butt welds in the thickness range of 1/4 to 2 inches. The acceptance limits described in the following sections are compatible with those set forth in SSC-177, "Guide for Interpretation of Nondestructive Tests of Welds in Ship Hull Structures" for radiographic inspection and should therefore result in satisfactory ship welds. Occasions may arise where radiographic inspection could provide additional information.

TEST METHOD

General - The procedures given apply to the contact ultrasonic inspection of butt welds. Weld inspection is accomplished by introducing shear waves into a plate at a selected angle and manipulating the transducer so as to scan the entire weld, Fig. A-1.

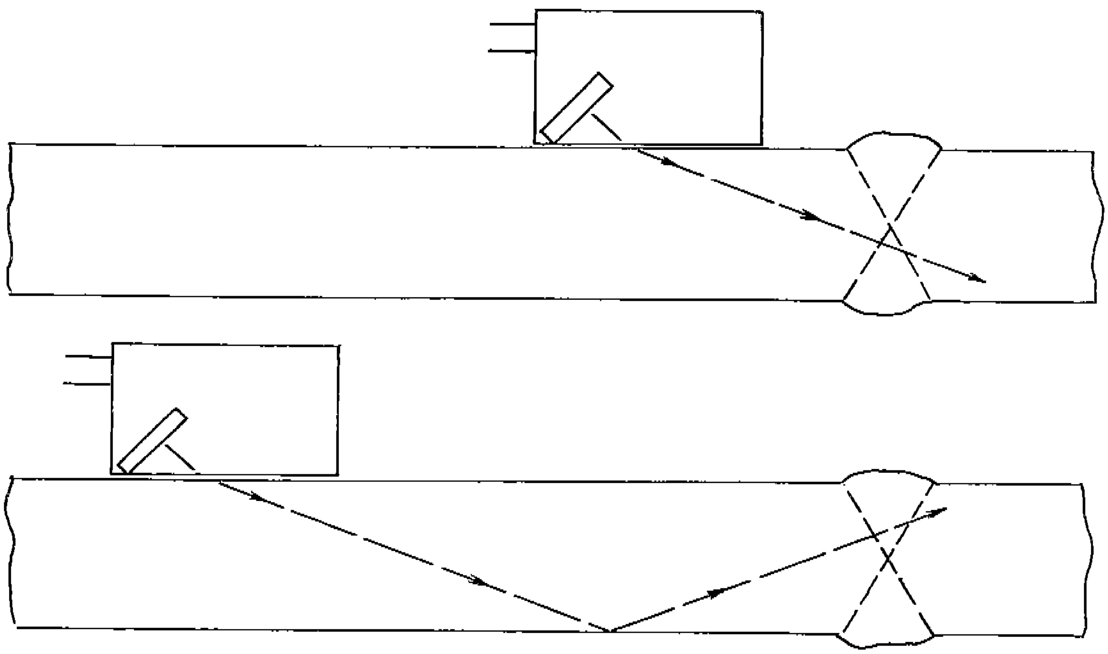


FIG. A-1. TECHNIQUE FOR INSPECTING BUTT WELDS WITH SHEAR WAVES

Equipment - The ultrasonic instrument shall be of the pulse-echo type with an A-scan presentation. It shall be capable of generating, receiving and displaying screen pulses from 1 to 5 MHz on the cathode ray tube. The instrument shall have a circuitry to provide a continuously increasing amplification with respect to time or distance of travel. A calibrated decibel attenuator control is recommended. Battery powered equipment must contain an alarm to signal battery depletion prior to instrument shut-off due to battery exhaustion.

<u>Transducers</u> - The maximum dimension (manufacturers' specifications) of the transducer active element shall not exceed one inch. A ratio of 2:1 width to height of the active element is recommended. A nominal test frequency of 2.25 MHz is recommended.

<u>Selection of Probes</u> - The primary consideration for selecting a probe shall be the thickness of the plate. The following shear wave angles are recommended:

70° for plate thicknesses 1/4" to 1/2"

60° or 70° for plate thicknesses 1/2" to 1-1/2"

45° or 60° for plate thicknesses 1-1/2" to 2-1/2".

The transducer angle should be checked periodically with the International Institute of Welding Test Block, Fig. A-2.

<u>Couplant</u> - A liquid such as glycerin diluted with alcohol or water and to which a wetting agent has been added is recommended for acoustic coupling between the transducer and the plate. Most oils are acceptable. For overhead work and for places of difficult access certain types of grease may

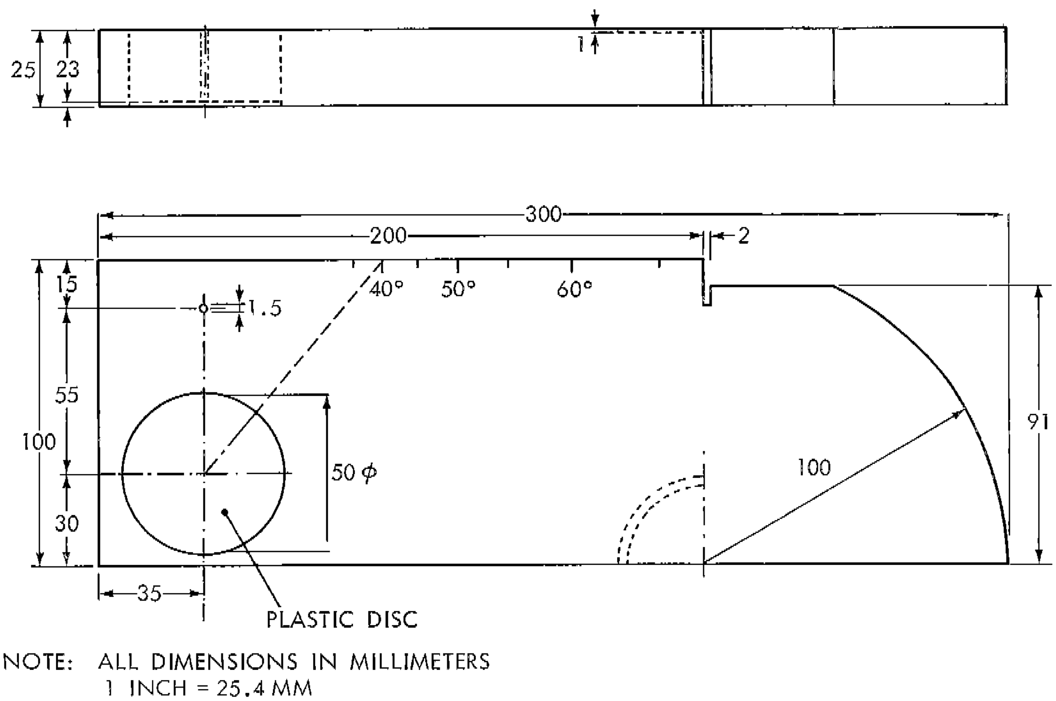


FIG. A-2. INTERNATIONAL INSTITUTE OF WELDING TEST BLOCK FOR ULTRASONIC CALIBRATION prove useful. Any couplant should be removed upon completion of the inspection.

Surface Preparation - The average plate as received from the mill has a surface that is smooth enough for ultrasonic inspection. Plate with loose scale, flaked paint, excess rust, or pitting will require grinding. After welding, the surface of the base metal where the probe is to be manipulated should be cleaned of weld splatter. If surface irregularities on the weld bead interfere with the ultrasonic test or cause difficulties in interpretation then the weld bead should be ground reasonably smooth.

Base Metal Inspection - Although the presence of laminations in the base metal may not be a basis for rejection, these reflectors may mask a part of the weld from the ultrasonic beam, Fig. A-3, or cause the operator to incorrectly locate a discontinuity, Fig. A-4. Laminations can be detected ultrasonically with a straight beam (longitudinal waves). When laminations are encountered, the inspection should be made from the other side of the weld.

PERSONNEL QUALIFICATION

Supplement C, Ultrasonic Testing Method, TC-1A Recommended Practice, American Society for Nondestructive Testing, shall apply. Ultrasonic testing may be carried out by a Level II operator or by a Level I operator under the direct supervision of a Level II operator.

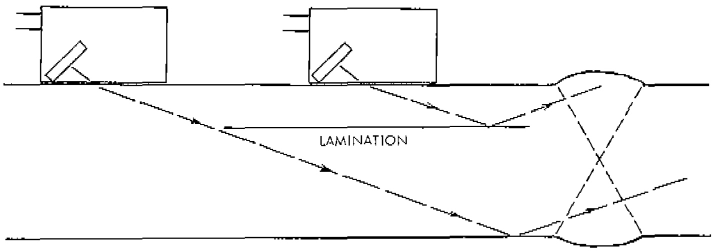


FIG. A-3. MASKING EFFECT OF A BASE METAL LAMINATION

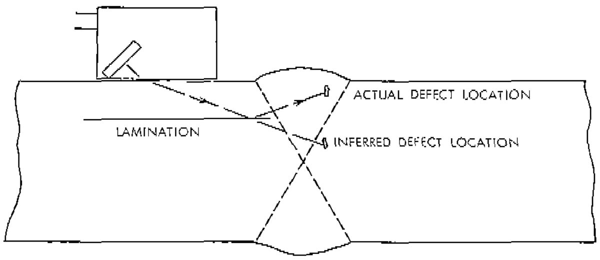


FIG. A-4. POSITION ERRORS INTRODUCED BY BASE METAL LAMINATION

CALIBRATION STANDARDS

A test block shall be prepared from material experimentally determined to be defect free and which is acoustically similar to the work material. This block should be 1-1/4" thick with a series of 1/16" diameter drilled holes spaced to provide path lengths equivalent to the longest and shortest path lengths to be used in the weld inspection. Intermediate distances should also be provided. The scanning surfaces should be approximately 250 RMS, prepared by the grinding method with the direction of grind parallel to the long dimension of the test block. Figure 5 illustrates an acceptable design.

SURFACE FINISH ON THE SCANNING SURFACES TO BE APPROXIMATELY 250 RMS PREPARED BY GRINDING METHOD WITH THE DIRECTION OF GRIND PARALLEL TO THE LONG DIMENSIONS OF THE BLOCK.

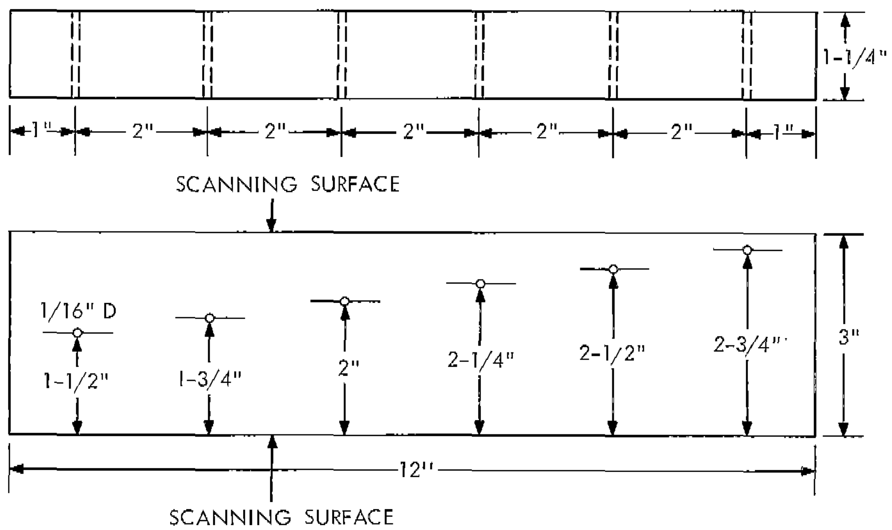


FIG. A-5. TYPICAL REFERENCE CALIBRATION STANDARD

INSTRUMENT CALIBRATION

Two levels of signal amplitude are defined in this Guide - ARL (Amplitude Reject Level) and DRL (Disregard Level). These two levels are established as follows:

The delay controls are used to position the initial pulse at the left of the viewing screen at a location marked zero on a reticule or screen scale. The instrument range controls can then be adjusted to display signals from the reference calibration drilled holes for the distances to be considered.

The distance amplitude correction controls are to be adjusted to compensate for signal loss due to distance of travel, i.e., the height of signals from all the reference drilled holes should be made equal.

When a decibel attenuator is available, the instrument gain control is to be adjusted to set the equalized signals from the reference reflectors at 40% of full screen height, Fig. A-6. The gain is then increased by 6 decibels. At this setting, the ARL is 6 decibels above the 40% line and the DRL (screen height below which indications are to be disregarded) shall be the 40% line, Fig. A-6.

When a decibel attenuator is not available, the instrument gain control is to be adjusted to set the equalized signals from the reference reflectors at 80% of full screen height, Fig. A-7. For this setting the 40% line shall be the DRL and the 80% line shall be the ARL, Fig. A-7.

In both of the above cases the calibration should be checked frequently.

WELD INSPECTION

Longitudinal defects are found by directing the sound beam normal to the length of the weld and moving the transducer back and forth, Fig. A-8, to scan the entire weld. Simultaneously, the transducer is oscillated through a small angle. The back and forth motions should be repeated at intervals which do not exceed 80% of the width of the transducer as the probe is moved along the weld.

Transverse defects are detected as follows:

a. For welds ground smooth the transducer is placed on top of the weld and moved along its length, Fig. A-9.

b. For welds not ground smooth the transducer is placed alongside and not quite parallel to the weld and moved along the length, Fig. A-10.

The entire weld and heat affected zone should be scanned. The weld should be inspected from both sides of one surface.

DISCONTINUITY LENGTH DETERMINATIONS

When discontinuities are detected, the sound beam should be directed so as to maximize the signal amplitude. The transducer is then moved parallel to the discontinuity and away from the position of maximum signal amplitude. The extremity of the discontinuity is defined as the point at which the signal amplitude drops to one-half of the peak value. This point is marked using the center line of the wedge as an index. In a similar manner, the other extremity is found and the distance between marks is defined as the length of the discontinuity. The minimum recordable length of a discontinuity shall be 1/8".

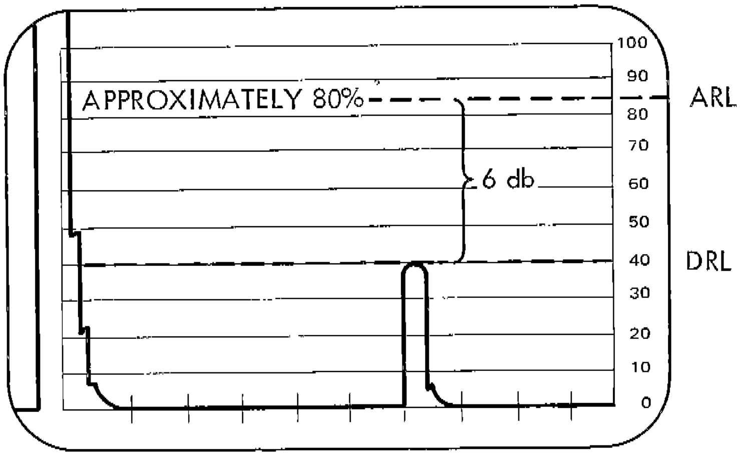


FIG. A-6. TYPICAL VIEWING SCREEN CALIBRATION
FOR INSTRUMENTS WITH DECIBEL ATTENUATION CONTROLS

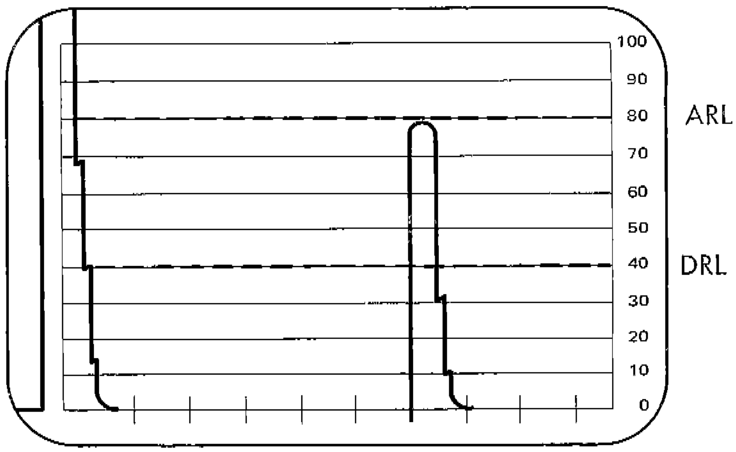


FIG. A-7. TYPICAL VIEWING SCREEN CALIBRATION
FOR INSTRUMENTS WITHOUT DECIBEL ATTENUATION CONTROLS

NOTE: CALIBRATION IS PERFORMED WITH THE REFLECTION OBTAINED FROM THE WALL OF A 1/16" DRILLED HOLE USING DISTANCE-AMPLITUDE CORRECTIONS.

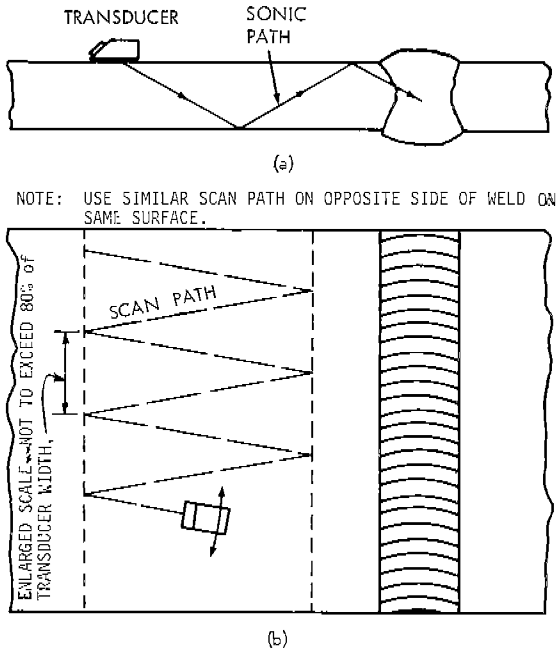


FIG. A-8. TECHNIQUE FOR INSPECTING BUTT WELDS WITH SHEAR WAVES

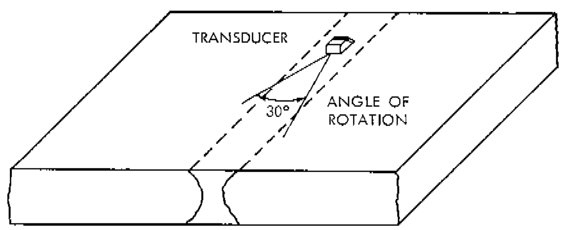


FIG. A-9. SUPPLEMENTARY TECHNIQUE FOR INSPECTING BUTT WELDS WHEN THE WELD BEAD IS GROUND FLUSH

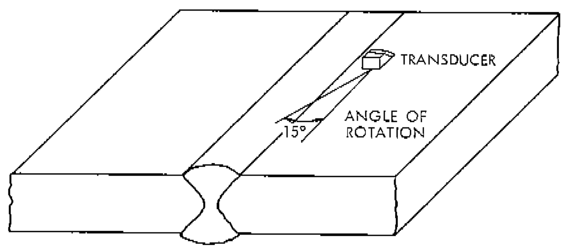


FIG. A-10. SUPPLEMENTARY TECHNIQUE FOR INSPECTING BUTT WELDS WHEN THE WELD BEAD IS NOT GROUND FLUSH

DISCONTINUITY EVALUATION

Discontinuities which do not produce signal amplitudes equal to or greater than the DRL, Fig. A-11, shall be disregarded.

Discontinuities which cause signal amplitudes equal to or greater than the DRL but less than the ARL, Fig. A-12, require a length determination and are evaluated as follows:

a. Defects with length greater than ½ T where T is the thickness of the plate are unacceptable.

b. For multiple indications, where L is the length of the larger discontinuity, if the separation distance is less than 6L then the sum of the adjacent lengths shall not exceed ½ T. If the separation distance is more than 6L then the cumulative length in any 6" length of weld shall not exceed the plate thickness.

Any discontinuity which produces signal amplitudes in excess of the ARL, Fig. A-13, is unacceptable.

When base metals of different thicknesses are welded together the thickness of the thinner member shall be used in determinations of acceptable limits of discontinuities.

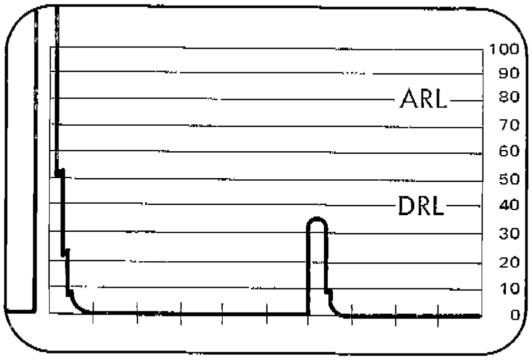
With the ultrasonic instrument calibrated in accordance with the procedures set forth in this Guide, usual signal amplitudes for specific type weld defects in relation to the ARL and DRL are illustrated in Fig. A-14.

When rejectable conditions are encountered, radiography may be useful in determining the nature and extent of the discontinuity.

RECORD OF INSPECTION

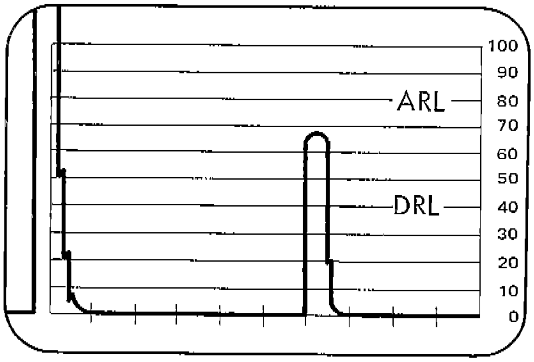
The record of each weld inspection should include:

1. Operator's identity
2. Date
3. Instrument identity
4. Transducer type, size, frequency and angle
5. Identification of test object
6. Location of the weld
7. Type of material
8. Thickness of base plate
9. Type of joint and configuration
10. Condition of the weld bead
11. Couplant
12. Flaw data
13. Inspection coverage, including reference points.



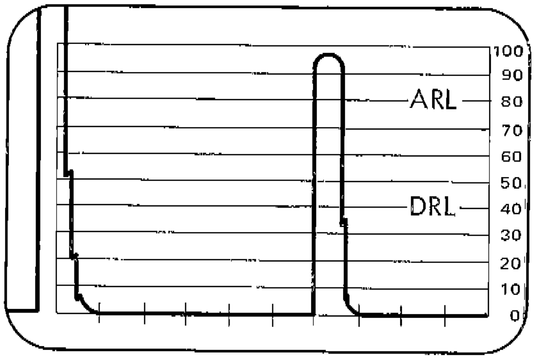
INDICATIONS BELOW THE DRL LEVEL ARE TO BE DISREGARDED

FIG. A-11. TYPICAL EXAMPLE OF ULTRASONIC INDICATIONS BELOW THE DRL.



INDICATIONS EQUAL TO OR GREATER THAN THE DRL LEVEL BUT LESS THAN THE ARL LEVEL REQUIRE A DETERMINATION OF DEFECT LENGTH AND SEPARATION DISTANCE

FIG. A-12. TYPICAL EXAMPLE OF ULTRASONIC INDICATIONS BELOW THE DRL BUT LESS THAN THE ARL



WELDS WHICH PRODUCE INDICATIONS EQUAL TO OR GREATER THAN THE ARL LEVEL ARE REJECTABLE

FIG. A-13. TYPICAL EXAMPLE OF ULTRASONIC INDICATIONS ABOVE THE ARL

WITH THE ULTRASONIC INSTRUMENT CALIBRATED IN ACCORDANCE WITH THE PROCEDURES SET FORTH IN THIS GUIDE, WELD DEFECTS OF THE TYPES LISTED WILL USUALLY PRODUCE SIGNAL AMPLITUDES IN RELATION TO THE ARL AND DRL LEVELS AS SHOWN:

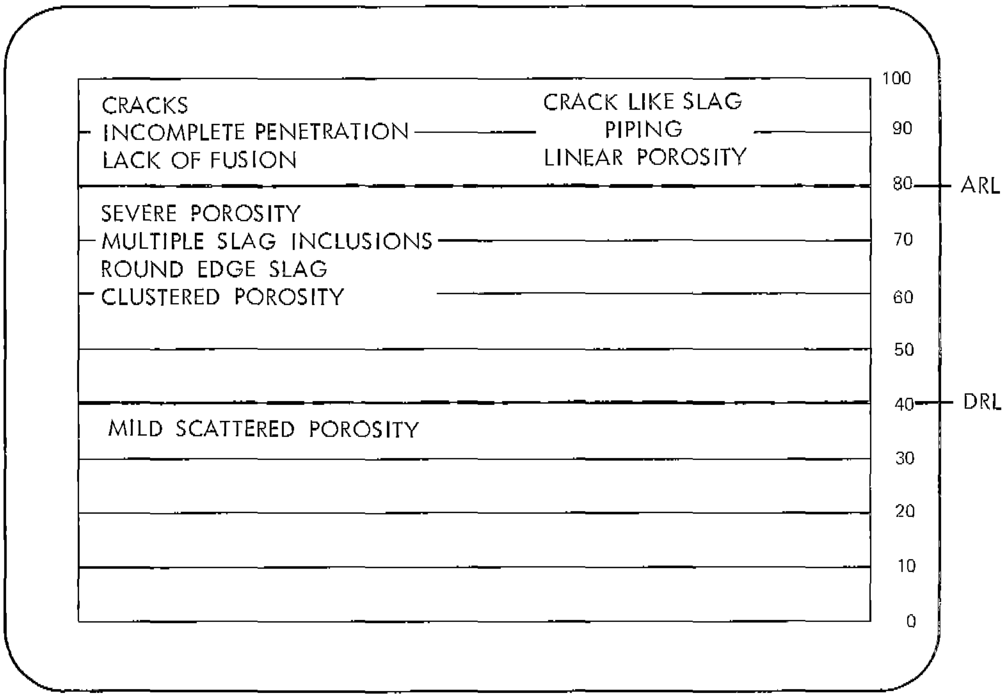


FIG. A-14. TYPICAL ULTRASONIC SIGNAL AMPLITUDES PRODUCED BY VARIOUS DEFECTS

GLOSSARY OF TERMS

A-Scan - A method of data presentation on a cathode ray tube utilizing a horizontal base line which indicates elapsed time when reading from left to right. A vertical deflection from the base line indicates reflected signal amplitudes.

Acoustically Similar - The same type of material as that to be inspected, or another material which has been experimentally proven to have acoustic velocity within ±3% and an attenuation for shear waves at the frequency to be used within ±0.25 dB/inch of the material to be inspected.

Active Element - The piezo-electrical material in the ultrasonic probe.

ARL (Amplitude Reject Level - The horizontal level on the cathode ray tube established by calibration. After calibration the ARL is 80% full screen height or 6 dB above the 40% line if a decibel attenuator is available.

Decibel - A logarithmic function of the ratio of two values. In ultrasonics the two values are the signal amplitude and a reference amplitude.

Decibel Attenuator - A gain control calibrated in decibels.

Delay Controls - An electronic means of horizontally shifting the pattern obtained on the cathode ray tube.

DRL (Disregard Level) - The horizontal level on the cathode ray tube established by calibration. After calibration the DRL is 40% of full screen height.

Frequency - The number of cycles in a unit of time. In ultrasonics the frequency is usually expressed in Megahertz or MHz (million cycles per second).

Longitudinal Waves - A wave form in which the particle motion is essentially in the same direction as the wave propagation.

Megahertz (MHz) - A million cycles per second.

Pulse Echo - The sending of sound into a material in the form of spaced pulses and recording the length of time necessary for each pulse to travel through the medium and return to the source of energy.

RMS (Root Mean Square) - A type of average used in describing surface roughness.

Resulting Angle - The angle formed between the ultrasonic beam as it enters a medium of different characteristics than the one from which it came and a line drawn perpendicular to the interface between the two media.

Scanning Surface - The surface of the base metal where the ultrasonic probe is manipulated.

Shear Wave - A wave form in which the particle motion is perpendicular to the direction of wave travel.

Straight Beam - An ultrasonic technique which does not involve an angle. The wave form is longitudinal.

Transducer - A device for converting energy of one type into another. An ultrasonic transducer converts energy from electrical to mechanical and vice versa.

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13. ABSTRACT

This document presents procedures and acceptance limits for contact ultrasonic inspection of steel butt welds in the thickness range of 1/4 to 2 inches. The acceptance limits described in the following sections are compatible with those set forth in SSC-177, "Guide for Interpretation of Nondestructive Tests of Welds in Ship Hull Structures" for radiographic inspection and should therefore result in statisfactory ship welds.

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SSC-199, *Study of the Factors Which Affect the Adequacy of High-Strength Low-Alloy Steel Weldments for Cargo Ship Hulls* by A. L. Lowenberg. E. B. Norris, A. G. Pickett and R. D. Wylie, August 1969. AD 692262.

SSC-200, *Index of Ship Structure Committee Reports* January 1969. AD 683360

SSC-201, *Midship Wave Bending Moment in a Model of the Cargo Ship "Wolverine State" Running at Oblique Headings in Regular Waves* by M. J. Chiocco and E. Numata. September 1969. AD 695123.

SSC-202, *Midship Wave Bending Moments in a Model of the Cargo Ship "California Bear" Running at Oblique Headings in Regular Waves* by E. Numata and W. F. Yonkers. November 1969. AD 698847.

SSC-203, *Annual Report of the Ship Structure Committee.* November. 1969. AD 699240.

SSC-204, *Simulated Performance Testing for Ship Structure Components* by R. Sherman. 1970. AD 705398.

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