Standard Practice for Ultrasonic Examination of Heavy Steel Forgings[1]

This standard is issued under the fixed designation A 388/A 388M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice[2] covers the examination procedures for the contact, pulse-echo ultrasonic examination of heavy steel forgings by the straight and angle-beam techniques. The straight beam techniques include utilization of the DGS (Distance Gain-Size) method. See Appendix X3.

1.2 This practice is to be used whenever the inquiry, contract, order, or specification states that forgings are to be subject to ultrasonic examination in accordance with Practice A 388/A 388M.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 This specification and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation [SI units], the material shall be furnished to inch-pound units.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 469/A 469M Specification for Vacuum-Treated Steel Forgings for Generator Rotors

A 745/A 745M Practice for Ultrasonic Examination of Austenitic Steel Forgings

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E 428 Practice for Fabrication and Control of Metal, Other than Aluminum Reference, Blocks Used in Ultrasonic Examination

E 1065 Guide for Evaluating Characteristics of Ultrasonic Search Units

2.2 *ANSI Standard:*

B 46.1 Surface Texture[4]

2.3 *Other Document:*

Recommended Practice for Nondestructive Personnel Qualification and Certification SNT-TC-1A, (1988 or later)[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *indication levels (clusters)*, *n*—five or more indications in a volume representing a 2-in. [50-mm] or smaller cube in the forging.

3.1.2 *individual indications*, *n*—single indications showing a decrease in amplitude as the search unit is moved in any direction from the position of maximum amplitude and which are too small to be considered traveling or planar.

3.1.3 *planar indications*, *n*—indications shall be considered continuous over a plane if they have a major axis greater than 1 in. [25 mm] or twice the major dimension of the transducer, whichever is greater, and do not travel.

3.1.4 *traveling indications*, *n*—inductions whose leading edge moves a distance equivalent to 1 in. [25 mm] or more of metal depth with movement of the transducer over the surface of the forging.

4. Ordering Information

4.1 When this practice is to be applied to an inquiry, contract, or order, the purchaser shall so state and shall also furnish the following information:

4.1.1 Designation number (including year date),

4.1.2 Method of establishing the sensitivity in accordance with 8.2.2 and 8.3.3 (Vee- or rectangular-notch),

[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-388/SA-388M in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[5] Available from the American Society for Nondestructive Testing, 1711 Arlingate Ln., P.O. Box 28518, Columbus, OH 43228–0518.

***A Summary of Changes section appears at the end of this standard.**

4.1.2.1 The diameter and test metal distance of the flat-bottom hole and the material of the reference block in accordance with 8.2.2.2,

4.1.3 Quality level for the entire forging or portions thereof in accordance with 11.3, and

4.1.4 Any options in accordance with 1.4, 5.4, 5.5, 6.1, 7.1, 7.2, 8.1.11, 9.1, and 9.2.

5. Apparatus

5.1 An ultrasonic, pulsed, reflection type of instrument shall be used for this examination. The system shall have a minimum capability for examining at frequencies from 1 to 5 MHz. On examining austenitic stainless forgings the system shall have the capabilities for examining at frequencies down to 0.4 MHz.

5.1.1 The ultrasonic instrument shall provide linear presentation (within 5 %) for at least 75 % of the screen height (sweep line to top of screen). The 5 % linearity referred to is descriptive of the screen presentation of amplitude. Instrument linearity shall be verified in accordance with the intent of Practice E 317. Any set of blocks processed in accordance with Practice E 317 or E 428 may be used to establish the specified ±5 % instrument linearity.

5.1.2 The electronic apparatus shall contain an attenuator (accurate over its useful range to ±10 % (+1 dB) of the amplitude ratio) which will allow measurement of indications beyond the linear range of the instrument.

5.2 *Search Units*, having a transducer with a maximum active area of 1 in.^{2} [650 mm^2] with ¾ in. [20 mm] minimum to 1⅛ in. [30 mm] maximum dimensions shall be used for straight-beam scanning (see 8.2); and search units with ½ in. [13 mm] minimum to 1 in. [25 mm] maximum dimensions shall be used for angle-beam scanning (see 8.3).

5.2.1 *Transducers* shall be utilized at their rated frequencies.

5.2.2 Other search units may be used for evaluating and pinpointing indications.

5.3 *Couplants*, having good wetting characteristics such as SAE No. 20 or No. 30 motor oil, glycerin, pine oil, or water shall be used. Couplants may not be comparable to one another and the same couplant shall be used for calibration and examination.

5.4 *Reference Blocks*, containing flat-bottom holes may be used for calibration of equipment in accordance with 5.1.1 and may be used to establish recording levels for straight-beam examination when so specified by the order or contract.

5.5 *DGS Scales*, matched to the ultrasonic test unit and transducer to be utilized, may be used to establish recording levels for straight beam examination, when so specified by the order or contract. The DGS scale range must be selected to include the full thickness cross-section of the forging to be examined. An example of a DGS overlay is found in Appendix X3.

6. Personnel Requirements

6.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A (1988 or later) or another national standard that is acceptable to both the purchaser and the supplier.

7. Preparation of Forging for Ultrasonic Examination

7.1 Unless otherwise specified in the order or contract, the forging shall be machined to provide cylindrical surfaces for radial examination in the case of round forgings; the ends of the forgings shall be machined perpendicular to the axis of the forging for the axial examination. Faces of disk and rectangular forgings shall be machined flat and parallel to one another.

7.2 The surface roughness of exterior finishes shall not exceed 250 µin. [6 µm] unless otherwise shown on the forging drawing or stated in the order or the contract.

7.3 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, and so forth.

8. Procedure

8.1 *General*:

8.1.1 As far as practicable, subject the entire volume of the forging to ultrasonic examination. Because of radii at change of sections and other local configurations, it may be impossible to examine some sections of a forging.

8.1.2 Perform the ultrasonic examination after heat treatment for mechanical properties (exclusive of stress-relief treatments) but prior to drilling holes, cutting keyways, tapers, grooves, or machining sections to contour. If the configuration of the forging required for the treatment for mechanical properties prohibits a subsequent complete examination of the forging, it shall be permissible to examine prior to treatment for mechanical properties. In such cases, reexamine the forging ultrasonically as completely as possible after heat treatment.

8.1.3 To ensure complete coverage of the forging volume, index the search unit with at least 15 % overlap with each pass.

8.1.4 For manual scanning, do not exceed a scanning rate of 6 in./s [150 mm/s].

8.1.5 For automated scanning, adjust scanning speed or instrument repetition rate, or both, to permit detection of the smallest discontinuities referenced in the specification and to allow the recording or signaling device to function. At no time shall the scanning speed exceed the speed at which an acceptable calibration was made.

8.1.6 If possible, scan all sections of forgings in two perpendicular directions.

8.1.7 Scan disk forgings using a straight beam technique from at least one flat face and radially from the circumference, whenever practicable.

8.1.8 Scan cylindrical sections and hollow forgings radially using a straight-beam technique. When practicable, also examine the forging in the axial direction.

8.1.9 In addition, examine hollow forgings by angle-beam technique from the outside diameter surface as required in 8.3.1.

8.1.10 In rechecking or reevaluation by manufacturer or purchaser, use comparable equipment, search units, frequency, and couplant.

8.1.11 Forgings may be examined either stationary or while rotating in a lathe or on rollers. If not specified by the purchaser, either method may be used at the manufacturer's option.

8.2 *Straight-Beam Examination*:

8.2.1 For straight-beam examination use a nominal 2¼-MHz search unit whenever practicable; however, 1 MHz is the preferred frequency for coarse grained austenitic materials and long testing distances. In many instances on examining coarse grained austenitic materials it may be necessary to use a frequency of 0.4 MHz. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws.

8.2.2 Establish the instrument sensitivity by either the reflection, reference-block technique, or DGS method (see Appendix X3 for an explanation of the DGS method).

8.2.2.1 *Back-Reflection Technique (Back-Reflection Calibration Applicable to Forgings with Parallel Entry and Back Surfaces)*—With the attenuator set at an appropriate level, for example 5 to 1 or 14 dB, adjust the instrument controls to obtain a back reflection approximately 75 % of the full-screen height from the opposite side of the forging. Scan the forging at the maximum amplification setting of the attenuator (attenuator set at 1 to 1). Carry out the evaluation of discontinuities with the gain control set at the reference level. Recalibration is required for significant changes in section thickness or diameter.

NOTE 1—High sensitivity levels are not usually employed when inspecting austenitic steel forgings due to attendant high level of "noise" or "hash" caused by coarse grain structure.

8.2.2.2 *Reference-Block Calibration*—The test surface roughness on the calibration standard shall be comparable to, but no better than, the item to be examined. Adjust the instrument controls to obtain the required signal amplitude from the flat-bottom hole in the specified reference block. Utilize the attenuator in order to set up on amplitudes larger than the vertical linearity of the instrument. In those cases, remove the attenuation prior to scanning the forging.

NOTE 2—When flat-surfaced reference block calibration is specified, adjust the amplitude of indication from the reference block or blocks to compensate for examination surface curvature (an example is given in Appendix X1).

8.2.2.3 *DGS Calibration*—Prior to use, verify that the DGS overlay matches the transducer size and frequency. Accuracy of the overlay can be verified by reference blocks and procedures outlined in Practice E 317. Overlays are to be serialized to match the ultrasonic transducer and pulse echo testing system that they are to be utilized with.

8.2.2.4 Choose the appropriate DGS scale for the cross-sectional thickness of the forging to be examined. Insert the overlay over the CRT screen, ensuring the DGS scale base line coincides with the sweep line of the CRT screen. Place the probe on the forging, adjust the gain to make the first back-wall echo appear clearly on CRT screen. Using the Delay and Sweep control, shift the screen pattern so that the leading edge of the initial pulse is on zero of the DGS scale and the back-wall echo is on the DGS scale value corresponding to the thickness of the forging. Adjust the gain so the forging back-wall echo matches the height of the DGS reference slope within ±1 Db. Once adjusted, increase the gain by the Db shown on the DGS scale for the reference slope. Instrument is now calibrated and flaw sizes that can be reliably detected can be directly read from the CRT screen. These flaw sizes are the equivalent flat bottom reflector that can be used as a reference point.

NOTE 3—The above can be utilized on all solid forgings. Cylindrical hollow forgings, and drilled or bored forgings must be corrected to compensate for attenuation due to the central hole (see Appendix X4).

8.2.3 *Recalibration*—Any change in the search unit, couplant, instrument setting, or scanning speed from that used for calibration shall require recalibration. Perform a calibration check at least once every 8 h shift. When a loss of 15 % or greater in the gain level is indicated, reestablish the required calibration and reexamine all of the material examined in the preceding calibration period. When an increase of 15 % or greater in the gain level is indicated, reevaluate all recorded indications.

8.2.4 During the examination of the forging, monitor the back reflection for any significant reduction in amplitude. Reduction in back-reflection amplitude may indicate not only the presence of a discontinuity but also poor coupling of the search unit with the surface of the forging, nonparallel back-reflection surface, or local variations of attenuation in the forging. Recheck any areas causing loss of back reflection.

8.3 *Angle-Beam Examination—Rings and Hollow Forgings*:

8.3.1 Perform the examination from the circumference of rings and hollow forgings that have an axial length greater than 2 in. [50 mm] and an outside to inside diameter ratio of less than 2.0 to 1.

8.3.2 Use a 1 MHz, 45° angle-beam search unit unless thickness, OD/ID ratio, or other geometric configuration results in failure to achieve calibration. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws. For angle-beam inspection of hollow forgings up to 2.0 to 1 ratio, provide the transducer with a wedge or shoe that will result in the beam mode and angle required by the size and shape of the cross section under examination.

8.3.3 Calibrate the instrument for the angle-beam examination to obtain an indication amplitude of approximately 75 % full-screen height from a rectangular or a 60° V-notch on inside diameter (ID) in the axial direction and parallel to the axis of the forging. A separate calibration standard may be used; however, it shall have the same nominal composition, heat treatment, and thickness as the forging it represents. The test surface finish on the calibration standard shall be comparable but no better than the item to be examined. Where a group of identical forgings is made, one of these forgings may be used as the separate calibration standard. Cut the ID notch depth to 3 % maximum of the thickness or ¼ in. [6 mm], whichever is smaller, and its length approximately 1 in. [25 mm]. Thickness is defined as the thickness of the forging to be examined at the time of examination. At the same instrument setting, obtain a reflection from a similar OD notch. Draw a line through the peaks of the first reflections obtained from the ID and OD notches. This shall be the amplitude reference line. It is preferable to have the notches in excess metal or test metal when possible. When the OD notch cannot be detected when examining the OD surface, perform the examination when practicable (some ID's may be too small to permit examination), as indicated above from both the OD and ID surfaces.

Utilize the ID notch when inspecting from the OD, and the OD notch when inspecting from the ID. Curve wedges or shoes may be used when necessary and practicable.

8.3.4 Perform the examination by scanning over the entire surface area circumferentially in both the clockwise and counter-clockwise directions from the OD surface. Examine forgings, which cannot be examined axially using a straight beam, in both axial directions with an angle-beam search unit. For axial scanning, use rectangular or 60° V-notches on the ID and OD for the calibration. These notches shall be perpendicular to the axis of the forging and the same dimensions as the axial notch.

9. Recording

9.1 *Straight-Beam Examination*—Record the following indications as information for the purchaser. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order or contract.

9.1.1 For individual indications, report:

9.1.1.1 In the back-reflection technique, individual indications equal to or exceeding 10 % of a nominal back reflection from an adjacent area free from indications, and

9.1.1.2 In the reference-block or DGS technique, indications equal to or exceeding 100 % of the reference amplitude.

9.1.2 For indications that are planar, traveling, or clustered, determine the location of the edges and the major and minor axes using the half-amplitude (6dB drop) technique and report:

9.1.2.1 The variation in depth or planar area, or both, of traveling indications,

9.1.2.2 The length of major and minor axes of planar indications, and

9.1.2.3 The volume occupied by indication levels and the amplitude range.

9.2 *Angle-Beam Examination*—Record discontinuity indications equal to or exceeding 50 % of the indication from the reference line. When an amplitude reference line cannot be generated, record discontinuity indications equal to or exceeding 50 % of the reference notch. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order.

9.3 Report reduction in back reflection exceeding 50% of the original measured in increments of 10%.

9.4 When recording, corrections must be made for beam divergence at the estimated flaw depth (See Guide E 1065).

9.5 Report indication amplitudes in increments of 10%.

10. Report

10.1 Report the following information:

10.1.1 All recordable indications (see Section 9);

10.1.2 For the purpose of reporting the locations of recordable indications, a sketch shall be prepared showing the physical outline of the forging including dimensions of all areas not inspected due to geometric configuration, the purchaser's drawing number, the purchaser's order number, and the manufacturer's serial number, and the axial, radial, and circumferential distribution of recordable ultrasonic indications;

10.1.3 The designation (including year date) to which the examination was performed as well as the frequency used, method of setting sensitivity, type of instrument, surface finish, couplant, and search unit employed; and

10.1.4 The inspector's name or identity and date the examination was performed.

11. Quality Levels

11.1 This practice is intended for application to forgings, with a wide variety of sizes, shapes, compositions, melting processes, and applications. It is, therefore, impracticable to specify an ultrasonic quality level which would be universally applicable to such a diversity of products. Ultrasonic acceptance or rejection criteria for individual forgings should be based on a realistic appraisal of service requirements and the quality that can normally be obtained in the production of the particular type forging.

11.2 Heavy austenitic stainless steel forgings are more difficult to penetrate ultrasonically than similar carbon or low-alloy steel forgings. The degree of attenuation normally increases with section size; and the noise level, generally or in isolated areas, may become too great to permit detection of discrete indications. In most instances, this attenuation results from inherent coarse grained microstructure of these austenitic alloys. For these reasons, the methods and standards employed for ultrasonically examining carbon and low-alloy steel forgings may not be applicable to heavy austenitic steel forgings. In general, only straight beam inspecting using a back-reflection reference standard is used. However, utilization of Practice A 745/A 745M for austenitic steel forgings can be considered if flat bottom hole reference standards or angle beam examination of these grades are required.

11.3 Acceptance quality levels shall be established between purchaser and manufacturer on the basis of one or more of the following criteria.

11.3.1 *Straight-Beam Examination*:

11.3.1.1 No indications larger than some percentage of the reference back reflection.

11.3.1.2 No indications equal to or larger than the indication received form the flat-bottom hole in a specific reference block or blocks.

11.3.1.3 No areas showing loss of back reflection larger than some percentage of the reference back reflection.

11.3.1.4 No indications per 11.3.1.1 or 11.3.1.2 coupled with some loss of resultant back reflection per 11.3.1.3.

11.3.1.5 No indications exceeding the reference level specified in the DGS method

11.3.2 *Angle-Beam Examination*—No indications exceeding a stated percentage of the reflection from a reference notch or of the amplitude reference line.

11.4 Intelligent application of ultrasonic quality levels involves an understanding of the effects of many parameters on examination results.

12. Keywords

12.1 angle beam examination; back-reflection; DGS; reference-block; straight beam examination; ultrasonic

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details shall be agreed upon by the manufacturer and the purchaser.

S1. Reporting Criteria

S1.1 Reference block calibration shall be performed using at least three holes, spaced to approximate minimum, mean, and maximum thickness as tested, and shall be used to generate a distance amplitude correction (DAC) curve. The following hole sizes apply:

1. 1⁄16 in. [1.5 mm] flat bottom holes (FBH) for thicknesses less than 1.5 in. [40 mm]
2. 1⁄8 in. [3 mm] FBH for thicknesses of 1.5-6 in. [40-150 mm] inclusive
3. 1⁄4 in. [6 mm] FBH for thicknesses over 6 in. [150 mm]

S1.2 Reporting criteria include:

1. All indications exceeding the DAC curve
2. Two or more indications separated by 1⁄2 in. [12 mm] or less

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL TUNING LEVEL COMPENSATION FOR THE EFFECTS OF FORGING CURVATURE

X1.1 The curve (Fig. X1.1) was determined for the following test conditions:

Material	nickel-molybdenum-vanadium alloy steel (Specification A 469/A 469M, Class 4)
Instrument	Type UR Reflectoscope
Search unit	1⅛-in. [30-mm] diameter quartz
Frequency	2¼ MHz
Reference block	ASTM No. 3-0600 (aluminum)
Reflection area of reference curve	0.010 in.^{2} [6.5 mm^2] in nickel-molybdenum-vanadium alloy steel
Surface finish	250 µin. [6 µm], max, roughness

X1.2 To utilize curve, adjust reflectoscope sensitivity to obtain indicated ultrasonic response on ASTM No. 3-0600 reference block for each diameter as shown. A response of 1 in. [25 mm] sweep-to-peak is used for flat surfaces. Use attenuator to obtain desired amplitude, but do testing at 1 to 1 setting.

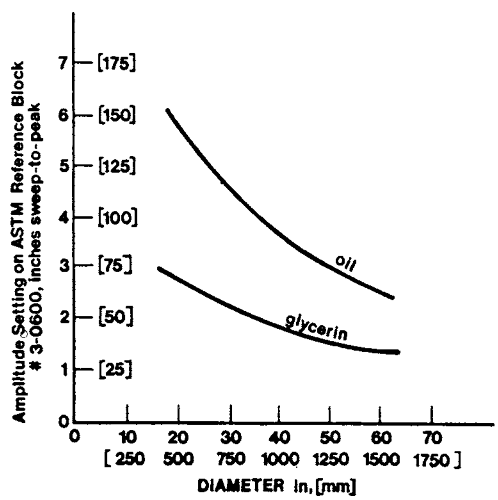


FIG. X1.1 Typical Compensation Curve for Effects of Forging Curvature

X2. INDICATION AMPLITUDE COMPENSATION FOR TEST DISTANCE VARIATIONS

X2.1 The curve (Fig. X2.1) has been determined for the following test conditions:

Material	nickel-molybdenum-vanadium alloy steel (Specification A 469/A 469M, Class 4)
Instrument	Type UR Reflectoscope
Search unit	1⅛-in. [30-mm] diameter quartz
Frequency	2¼ MHz
Couplant	No. 20 oil
Reference block	ASTM No. 3-0600 (aluminum)
Reflection area of reference curve	0.010 in.^{2} [65 mm^2] in nickel-molybdenum-vanadium alloy steel
Surface finish	250 µin. max, roughness

X2.2 To utilize curve, establish amplitude from ASTM reference block to coincide with values from Appendix X1.

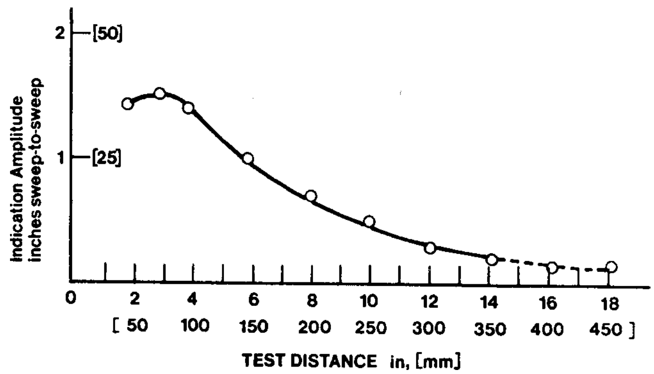


FIG. X2.1 Typical Distance-Amplitude Correction Curve

X3. BACKGROUND INFORMATION ON THE DGS METHODS

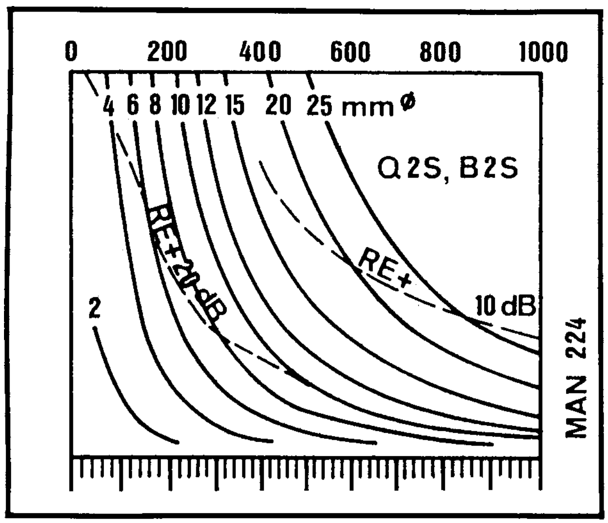


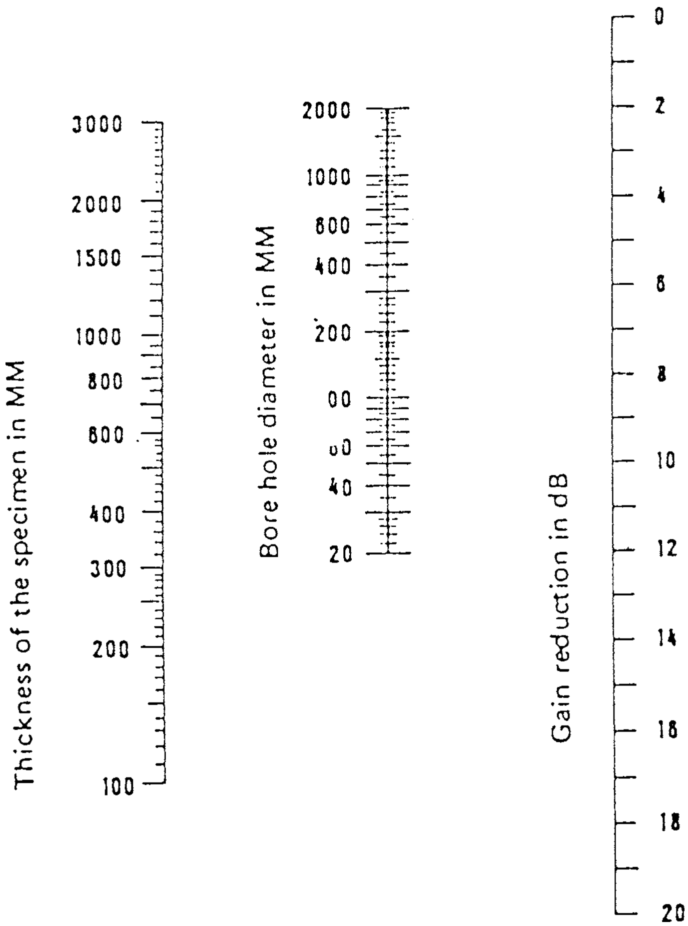
FIG. X3.1 Example of DGS Overlay

X3.1 The overlay in Fig. X3.1 was designed for a 2.0 MHz, 1 in. [25 mm] diameter probe and a maximum test distance of 39.4 in. [1000 mm]. In order to use this overlay, the sweep time base must be accurately calibrated and aligned with the overlay being used. The back reflection is then adjusted to either the RE + 10 dB line or the RE + 20 dB line, based on the thickness being tested; additional gain (10 or 20 dB) is added as designated by the line being used. The RE + 20 line covers a range to approximately 15.7 in. [400 mm] and the RE + 10 line from 15.7 to 39.4 in. [400 to 1000 mm]. At this calibration level, the flaw size is read directly from the screen. Flaw sizes from 0.078 to 1 in. [2 to 25 mm] can be read directly from the overlay.

X4. COMPENSATION FOR CENTER HOLE ATTENUATION ON CYLINDRICAL BORED OR HOLLOW FORGINGS UTILIZING THE DGS METHOD

X4.1 The hole in a cylindrical bored forging causes sound scatter. In these cases, a correction is required which depends on the wall thickness and bore diameter.

X4.1.1 Determine the correction value in dB from the Nomogram (Fig. X4.1). With the gain-dB control, proceed as described in 8.2.2.4 reducing the flaw detector gain by the correction value determined.



NOTE—Metric units are presented in this figure to be consistent with DGS scales presently available. Conversion to English units would also be acceptable.

FIG. X4.1 The Influence of a Central Bore on the Backwall Echo Amplitude of Cylindrical or Plane Parallel Forgings

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A 388/A 388M – 05) that may impact the use of this standard. (Approved March 1, 2007.)

(*1*) Updated transducer sizes shown in 5.2.

(*2*) Revised X3.1.