ARTICLE 23
ULTRASONIC STANDARDS

SPECIFICATION FOR ULTRASONIC
EXAMINATION OF HEAVY
STEEL FORGINGS

SA-388/SA-388M

(Identical with ASTM Specification A 388/A 388M-04)

1. Scope

1.1 This practice 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 inch-pound or SI units are to be regarded as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

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:*

A 469 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 Examination Instruments and Systems Without the Use of Electronic Measurement Instruments

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection

2.2 *ANSI Standard:*

B46.1 Surface Texture

2.3 *Other Document:*

Recommended Practice for Nondestructive Personnel Qualification and Certification SNT-TC-1A, Supplement C — Ultrasonic Testing

3. Ordering Information

3.1 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:

3.1.1 Method of establishing the sensitivity in accordance with 7.2.2 and 7.3.3 (Vee or rectangular notch),

3.1.1.1 The diameter and test metal distance of the flat-bottom hole and the material of the reference block in accordance with 7.2.2.2,

3.1.2 Quality level for the entire forging or portions thereof in accordance with 10.3, and

3.1.3 Any options in accordance with 6.1, 6.2, and 7.1.11.

4. Apparatus

4.1 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.

4.1.1 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.

4.1.2 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.

4.2 *Search Units* having a transducer with a maximum active area of 1 in.^{2} [650 mm^2] with $^3/_4$ in. [20 mm] minimum to $1^1/_8$ in. [30 mm] maximum dimensions shall be used for straight-beam scanning (see 7.2); and search units equipped from $^1/_2$ by 1 in. [13 by 25 mm] to 1 by 1 in. [25 by 25 mm] shall be used for angle-beam scanning (see 7.3).

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

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

4.3 *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.

4.4 *Reference Blocks* containing flat-bottom holes may be used for calibration of equipment in accordance with 4.1.1 and may be used to establish recording levels for straight-beam examination when so specified by the order or contract.

4.5 *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.

5. Personnel Requirements

5.1 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 or another national standard that is acceptable to both the purchaser and the supplier.

6. Preparation of Forging for Ultrasonic Examination

6.1 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.

6.2 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.

6.3 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, etc.

7. Procedure

7.1 *General:*

7.1.1 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.

7.1.2 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.

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

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

7.1.5 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.

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

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

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

7.1.9 In addition, examine hollow forgings by angle-beam technique from the outside diameter surface as required in 7.3.1.

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

7.1.11 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.

7.2 *Straight-Beam Examination:*

7.2.1 For straight-beam examination use a nominal $2\frac{1}{4}$-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.

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

7.2.2.1 *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.

7.2.2.2 *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).

7.2.2.3 *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.

7.2.2.4 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 baseline coincides with the sweep line of the CRT screen. Place the probe on the forging, adjust the gain to make the first backwall echo appear clearly on the 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 backwall echo is on the DGS scale value corresponding to the thickness of the forging. Adjust the gain so the forging backwall 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).

7.2.3 *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.

7.2.4 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.

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

7.3.1 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.

7.3.2 Use a 1 MHz, 45 deg 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.

7.3.3 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 deg 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 $^{1}/_{4}$ 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 IDs 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.

7.3.4 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 deg 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.

8. Recording

8.1 *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.

8.1.1 In the back-reflection technique, individual indications equal to or exceeding 10% of the back reflection from an adjacent area free from indications; in the reference-block or DGS technique, indications equal to or exceeding 100% of the reference amplitude.

8.1.2 An indication that is continuous on the same plane regardless of amplitude, and found over an area larger than twice the diameter of the search unit. The extent of such an indication shall be accurately measured along with variations in amplitudes of reflections.

8.1.2.1 Planar indications shall be considered continuous over a plane if they have a major axis greater than 1 in. [25 mm]. In recording these indications, corrections must be made for beam divergence at the estimated flaw depth.

8.1.3 In the back-reflection technique, discontinuity indications equal to or exceeding 5% of the back reflection. In the reference-block technique, indications equal to or exceeding 50% of the reference amplitude providing that they travel, are continuous, or appear as clusters.

8.1.3.1 Traveling indications are herein defined as indications whose leading edge moves a distance equivalent to 1 in. [25 mm] or more of metal depth with movement of the search unit over the surface of the forging.

8.1.3.2 A cluster of indications is defined as five or more indications located in a volume representing a 2 in. [50 mm] or smaller cube in the forging.

8.1.4 Reduction in back reflection exceeding 20% of the original measured in increments of 10%.

8.1.5 Amplitudes of recordable indications in increments of 10%.

8.2 *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.

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9. Report

9.1 Report the following information:

9.1.1 All recordable indications (see Section 8).

9.1.2 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.

9.1.3 The specification 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.

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

10. Quality Levels

10.1 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.

10.2 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.

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

10.3.1 *Straight-Beam Examination:*

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

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

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

10.3.1.4 No indications per 10.3.1.1 or 10.3.1.2 coupled with some loss of resultant back reflection per 10.3.1.3.

10.3.1.5 No indications exceeding the reference level specified in the DGS method.

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

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

11. Keywords

11.1 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:

(a) $\frac{1}{16}$ in. [1.5 mm] flat bottom holes (FBH) for thicknesses less than 1.5 in. [40 mm]

(b) $\frac{1}{8}$ in. [3 mm] FBH for thicknesses of 1.5–6 in. [40–150 mm] inclusive

(c) $\frac{1}{4}$ in. [6 mm] FBH for thicknesses over 6 in. [150 mm]

S1.2 Reporting criteria include:

(a) all indications exceeding the DAC curve

(b) two or more indications separated by $\frac{1}{2}$ 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, Class 4)
Instrument	Type UR Reflectoscope
Search unit	$1^1/_8$ in. [30 mm] diameter quartz
Frequency	$2^1/_4$ 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.

X2. INDICATION AMPLITUDE COMPENSATION FOR TEST DISTANCE VARIATIONS

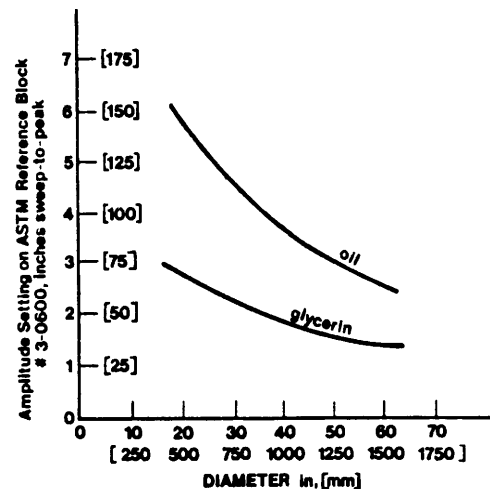**X2.1** The curve (Fig. X2.1) has been determined for the following test conditions:

Material	Nickel-molybdenum-vanadium alloy steel (Specification A 469, Class 4)
Instrument	Type UR Reflectoscope
Search unit	$1^1/_8$ in. [30 mm] diameter quartz
Frequency	$2^1/_4$ MHz
Couplant	No. 20 oil
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. max. roughness

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

X3. BACKGROUND INFORMATION ON THE DGS METHODS

X3.1 The DGS method was developed to determine flaw sizes by comparison to a backwall echo produced on

FIG. X1.1   TYPICAL COMPENSATION CURVE FOR EFFECTS OF FORGING CURVATURE

the part to be ultrasonic tested. The derivation of DGS curves is extensively covered and can be found in standard texts on ultrasonic testing, and will not be covered here. The distance or thickness of the forging (*A*) to be tested, as noted on the overlay, must be accurately defined on the CRT screen. The back reflection (*B*) of the part must be established and suitable gain added. Flaw echo indications that appear can be sized via the flaw size curves (*C*) on the overlay. Item (*D*) depicts the transducers that the overlay works in conjunction with and (*E*) depicts the series of curves that the overlay scales are matched to.

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).

X4.1.2 Proceed as described in 7.2.2.3.

X4.1.3 With the GAIN-dB control, reduce the flaw detector gain by the correction value determined as per the Nomogram (Fig. X4.2). Thus, the flaw detector gain is accurately adjusted.

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FIG. X2.1   TYPICAL DISTANCE–AMPLITUDE
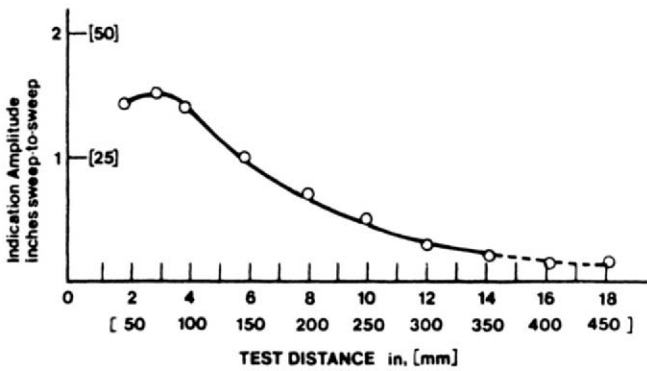CORRECTION CURVE

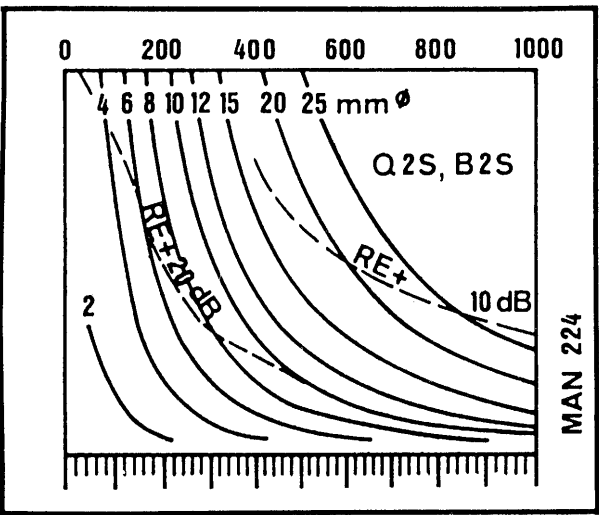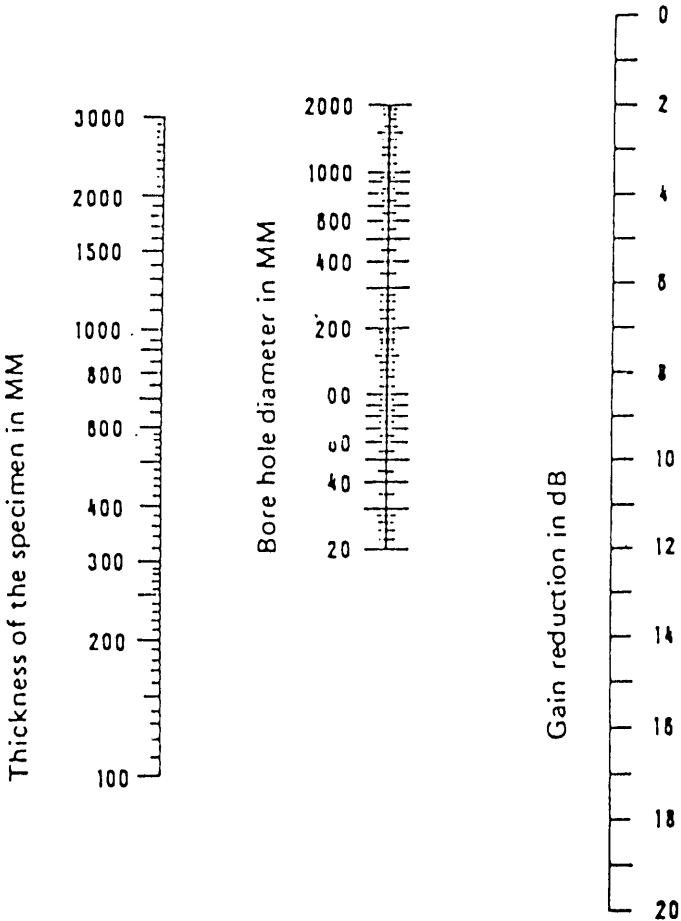FIG. X4.1   EXAMPLE OF DGS OVERLAY

FIG. X4.2   THE INFLUENCE OF A CENTRAL BORE ON THE BACKWALL ECHO AMPLITUDE OF CYLINDRICAL OR
PLANE PARALLEL FORGINGS

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

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