Standard Practice for Detection of Large Inclusions in Bearing Quality Steel by the Ultrasonic Method[1]

This standard is issued under the fixed designation E588; 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 covers a procedure for the rating of rectangular steel sections by immersion ultrasonic techniques. Its purpose is to provide information on the content of large inclusions or clusters of small inclusions for determining the suitability of a steel lot for bearing applications. This practice in no manner defines or establishes limits of acceptability.

1.2 For this document, large inclusions are defined in ultrasonic terms as those having a reflecting area equivalent to or larger than a 1⁄64-in. diameter flat-bottom hole in a steel reference block of similar properties and thickness. In metallographic terms, large inclusions, defined in this way, are of approximately the same size as the smallest detectable sizes revealed by the macroscopic methods of Test Methods E45. In some cases, inclusions smaller than those described previously can be detected either individually or in clusters, depending on their type, chemical composition, orientation to the ultrasonic beam and distance from the sound entry surface of the specimen.

1.3 *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:*[2]

E45 Test Methods for Determining the Inclusion Content of Steel

E214 Practice for Immersed Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves (Withdrawn 2007)[3]

E428 Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

2.2 *ASNT Documents:*

SNT-TC-1A Recommended Practicefor Personnel Qualification and Certification in Nondestructive Testing[4]

ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel[4]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology E1316.

4. Basis of Application

4.1 *Agreements Between Using Parties*— In order for this practice to be effectively used, the following items require agreement between the using parties.

4.1.1 *Evaluation of Nondestructive Testing Agencies* —An agreement is required as to whether the nondestructive testing agency, as defined in Specification E543, must be formally evaluated and qualified to perform the examination. If such an evaluation is specified, a documented procedure such as Specification E543 shall be used as the basis for evaluation.

4.1.2 *Personnel Qualification*—Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ASNT CP-189, SNT-TC-1A, or a similar document. The practice or standard used and its applicable

---

[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 A01.28 on Bearing Steels.

Current edition approved Oct. 1, 2014. Published October 2014. Originally approved in 1976. Last previous edition approved in 2009 as E588 – 03(2009). DOI: 10.1520/E0588-03R14.

[2] 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.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

revision shall be specified in the contractual agreement between the using parties.

4.1.3 *Search Unit Performance Tests*—Annex A1 defines the minimum manufacturer's specifications for search units to be used with this practice. The extent of testing and verification of these parameters to be performed by the manufacturer shall be specified in the contractual agreement between the using parties.

5. Summary of Practice

5.1 The general technique used is immersion ultrasonic testing by the reflection method using pulsed longitudinal waves such as described in Practice E214. Specific additional requirements for sample preparation, equipment operating parameters and calibration, and expression of results are delineated in this procedure. Special focused search units having operating characteristics as defined in Annex A1 are required.

6. Significance and Use

6.1 *Comparison with Other Inclusion Rating Methods*—Because the test is performed on a volumetric rather than a surface-examination basis, the ultrasonic method is inherently better able to detect infrequently occurring large inclusions or clusters of small inclusions than eddy current, magnetic particle, microscopical, or macroscopic examination procedures.

6.2 *Limitation of Inclusion Size and Type*—A limitation of the method is that it will not detect all inclusions. Inclusion chemistry, size, shape, location, and distribution may limit the ability of the method to provide indications distinct from those generated by the surrounding metallurgical structure. The recommended practice is only meaningfully applicable to examination of steel wherein the inclusion size and type are within the detection capabilities of the method. For steel wherein inclusion size, dispersion, and chemistry prevent optimum inclusion detection by ultrasonics, microscopical methods detailed in Test Methods E45 may be applied.

7. Interference

7.1 *Reflections from Multiple Inclusions*—An ultrasonic indication can represent the reflection from a single inclusion; however, it typically represents the vector summation of reflections from clusters of small inclusions contained within a volume of a few cubic millimetres.

7.2 *Response as a Function of Inclusion Type*—The individual inclusion reflections can have different amplitudes because of different inclusion characteristics. In addition, the individual reflections may have different phase characteristics when arriving at the search unit if the travel distances are different.

8. Apparatus

8.1 *Equipment Required*—An equipment system with the following components is needed to conduct this test: ultrasonic test instrument, search unit, a means of recording signals of various amplitudes, a system reference block, instrument calibration block, and an immersion tank with suitable scanning accessories.

8.2 *Ultrasonic Instrument*—The ultrasonic instrument shall be capable of generating and receiving electrical pulses of 10-MHz frequency at levels compatible with the test requirements. It shall have both an A-scan presentation and an analog or digital output. It shall be the ultrasonic instrument manufacturer's responsibility that instruments supplied for use with this test meet the minimum requirements delineated in this recommended practice.

8.2.1 *Receiver Characteristics*—The center frequency shall be 10 ± 0.5 MHz. The bandpass of the receiver shall be at least 1.3 MHz (3 dB points).

8.2.2 *Dynamic Range*—The dynamic range of the instrument shall permit detection of steel balls with a 16-to-1 diameter ratio at a given sensitivity. Balls shall be placed in water at the focal point of the search unit. Each size ball within this range shall give a significantly different amplitude of indication.

8.2.3 *Stability*—The signal amplitude of a usable full-scale indication shall not vary more than 5 % after 1 h of instrument warm-up, and preferably by less than 2 % (4-h test with air temperature being held to ±1.2°C over a temperature range of 17.5 to 25.5°C).

8.2.4 *Sweep Length and Linearity*—Sweep length of oscilloscope presentation shall be capable of being adjusted to represent 1 mm = 1.27 mm of steel. A minimum of 80 mm of the sweep display shall be linear to within 5 % of full scale. The signal amplitude of an indication from a target shall not vary more than ±4 % over the gated portion of the sweep employed in calibration and testing.

8.2.5 *Repetition Rate*—The repetition rate of the pulser shall not be less than 500 pulses per second.

8.3 *Search Units*—Ultrasonic search units for this test shall be spherically focused immersion-type units. Uniform performance characteristics of search units are critical for obtaining reproducible test measurements. (See Annex A1, which delineates search unit performance characteristics to be met by search unit manufacturers.) Performance characteristics of search units requiring consideration are: the uniformity of focal distance in water, center frequency, frequency spectrum, lens radius, width of field, and beam symmetry.

8.3.1 *Focal Length*—A focused beam of radiated ultrasonic energy is recommended to provide lateral resolution of small defects and to improve testing sensitivity in the region near the focal point. The focal length of a search unit is defined in this discussion as the distance in water, on the search unit axis, between the search unit and the surface of a ½-in. or 12-mm diameter ball target at which the highest reflection amplitude indication is obtained. Different focal length transducers may be used to obtain optimum response at selected distances below the test sample surface. (Variation of search unit-to-specimen surface water path would also affect the focal point within the test sample.)

8.3.2 *Search Unit Characteristics*—Search units generally employed have the following frequency and focal length as purchased:

Frequency	Focal Length in Water
10 ± 0.5 MHz	8.2 ± 0.3 in. (208.3 ± 7.6 mm)

8.3.3 *Beam Symmetry*—Each search unit should be rotated on its ultrasonic beam axis (not necessarily geometric axis) until a particular circumferential orientation is found which gives a maximum severity, or count, from the system reference block. This search unit orientation shall be identified and employed in subsequent tests. Search units that exhibit variations in indication amplitude in excess of 15 % during rotation shall not be considered satisfactory for the test. There are other methods, such as optimum response over a precision and uniform taut wire, that have been found to be usable.

8.3.4 *Performance*—The performance capabilities of all new search units shall be verified by an actual test on the system reference block. The data obtained for new search units should be compared with that obtained for other search units having the same specifications and tested under identical conditions.

8.4 *Immersion Tank and Accessories*— An immersion tank with associated scanning and indexing facilities shall be used.

8.4.1 *Search Unit Angulation*—The tank shall be provided with a manipulator capable of continuously angulating the search unit in two vertical mutually perpendicular planes permitting the required normalization.

8.4.2 *Scanning and Indexing*—The tank bridge and carriage assemblies shall provide *X-Y* motion to the search unit. The scanning shall be parallel or perpendicular (depending on the procedure) to the test specimen axis and the indexing shall be perpendicular to the scanning.

8.4.3 *Test Specimen Mounting*—The tank shall be provided with fixturing permitting the mounting of the entry surface of the test specimen parallel to the bridge travel so that the distance between search unit and specimen remains constant within ±1⁄64 in. (0.4 mm).

8.4.4 *Couplant:*

8.4.4.1 The inspection solution shall consist of tap or distilled water to which a wetting agent has been added to disperse air bubbles. The pH of the water shall be maintained within 7½ to 8½. Rust preventives may also be added. All chemical additives shall be held within concentrations that do not adversely affect test performance. Water temperature must be held between 19.5 and 25.5°C. It is important that excessive thermal gradients do not exist between the search unit and the calibration standards.

8.4.4.2 A means of circulating the immersion inspection solution shall be employed, when necessary, to dissipate thermal gradients.

8.5 *Readout Equipment*—Various types of instrumentation have been employed in conjunction with ultrasonic instruments for many years to determine the number of occurrences of various amplitude indications. These include level counters, pulse counters, integrators, strip chart recorders, B-scan recorders, C-scan recorders, memory oscilloscopes, and computer techniques. With pulse counters, both repetition rate and scanning speed must be held within a 5 % tolerance and, preferably, 2 %.

8.6 *System Reference Block*—A system reference block (defined dimensionally in Section 9.2) is required for initial adjustments and operational testing of the equipment. This sample should be selected to provide reflection signals at all counting levels. Depth distribution of inclusions in the selected reference block should make its response characteristics relatively insensitive to minor focal length variations between different search units. The reference block should give a minimum change in total counts of 10 % for each 10 % increase or decrease in amplitude setting. A maximum of 30 % change in count for each 10 % change in amplitude setting should not be exceeded. It should be suitably protected from corrosion to assure its longevity.

9. Test Specimens

9.1 *General*—Test specimens must be either in the rolled or forged condition. If forged, upset forging is prohibited in order to maintain the rolling direction. Care should be taken not to overheat the forging to avoid spurious ultrasonic indications. Specimen location and frequency shall be as agreed upon between the supplier and the purchaser.

9.2 *Specimen Size and Shape*—Specimens shall have a minimum cross-sectional dimension after preparation of 3½ in. (88.9 mm). The area scanned shall be sufficient to permit testing of a minimum of 25 in.^{3} (410 cm^3) of the specimen. The tested volume equals the scanned area multiplied by the gated depth. If special consideration is given, thinner samples may be tested.

9.3 *Entry Surface Finish*—The test surface through which the sound enters the specimen shall be machined and ground. This finish in any direction over the surface shall be preferably 10 to 80 µin. (0.25 to 2.0 µm). Final material removal may require a dressed grinding wheel to avoid spurious, near-surface indications. All four sides are to be ground.

9.4 *Heat Treatment*—Thermal conditioning of the specimens is required to minimize acoustic anomalies. Typical heat treatment may consist of normalizing or quenching and tempering, depending on steel type, to meet the ultrasonic penetrability requirement of Section 9.5. Certain steels may require special thermal treatment such as a double temper to obtain suitable acoustic properties.

9.5 *Ultrasonic Penetrability*—The ultrasonic penetrability shall be determined to be suitable for the inspection. The penetrability is acceptable if the third back reflection of the specimen is 25 % of full screen height, over the center of the billet specimen, at standard test conditions and test sensitivity.

10. Procedure

10.1 *General:*

10.1.1 *Operating Frequency*—The operating frequency for most bearing steels is 10 MHz. Ten megahertz is recommended as the highest practical frequency available within existing manufacturing capabilities to produce search units with uniform performance characteristics. Higher frequencies give better resolution, while lower frequencies give better penetration.

10.1.2 *Normalizing Search Unit*—Normalizing the search unit beam to the entry surface is a precise adjustment and requires extreme care. Normalizing can be accomplished over billet specimens with parallel ground sides by adjusting for a maximum first far field back reflection in an area where no material discontinuities are present to distort the ultrasonic beam. An alternative method that has been found useful is to maximize the far field reflections from a hardened steel plate with parallel ground sides, such as a 58 to 64 HRC hardness test block, placed on top of the ground billet surface.

10.1.3 *Water Distance*—The water distance between the search unit and entry surface shall not be less than 1 ± 1⁄16 in. (25.4 ± 1.6 mm) for every 4 in. (102 mm) of specimen thickness. In no case should the water distance be less than 1 ± 1⁄16 in.

10.1.4 *Monitoring Gates*—Either single or multiple gates may be employed.

10.1.5 *Scanning of Specimen*—Scanning of the specimen must be perpendicular to the rolling direction with a scan index of 0.050 in. (1.27 mm). Scanning closer than ½ in. (12.7 mm) to the prepared surface edge should be avoided because of false echoes from the edge. Two adjacent sides are to be inspected. Test specimens must be at room temperature before scanning.

10.1.6 *Scanning Speed*—Permissible scanning speed is a function of counter response and instrument repetition rate. A generally accepted speed is 4 in. (101.6 mm)/s. It shall be limited to that which gives a recorded evaluation of a sample within 5 % of that obtained when the sample is scanned at less than 1 in. (25.4 mm)/s, or one third of normal operating speed, whichever is the slower.

10.1.7 *Sensitivity*—The test sensitivity shall not produce background material indications exceeding an amplitude of one half of the lowest counting level.

10.1.8 *Operational Performance*—Periodically check overall equipment performance by conducting a test on the system reference block specimen. The deviation permitted shall not exceed the variation in counts obtained by altering the electronic gain by ±10 %. For practical purposes, the ±10 % electronic gain shall be defined as equivalent to the difference in response from ball targets varying by 10 % in diameters.

10.2 *Description of Method*—This method is applicable to the determination of the relative cleanliness of bearing-quality steel. Equipment, calibration, and method of analyzing test results have been made as simple as possible within the limits of having a workable test. An immersed ultrasonic test is conducted with a 10-MHz focused search unit, three-level type counter to indicate test results, steel balls to establish counter levels, an instrument calibration block, and a system reference block specimen. The specimen is scanned in a direction perpendicular to the rolling direction, and counts are recorded only when the search unit passes transversely over either a single inclusion or a cluster of inclusions which give rise to a discrete ultrasonic indication exceeding a counting level.

10.2.1 *Special Equipment and Accessories:*

10.2.1.1 A three-level pulse counter having separate adjustable thresholds for each level shall be used to determine the number of occurrences of various amplitude indications. The input circuits to the counters shall employ sufficient filtering to eliminate counter operation from extraneous high-frequency signals. The equipment shall have sufficient hysteresis to prevent counting spurious variations (jitter).

10.2.2 *Calibration Standards:*

10.2.2.1 Counter calibration requires a set of three ball targets with size ratio of 12:7:4. Highly polished stainless steel ball sets with a surface roughness of 2 µin. (.05 mm) Ra maximum and with diameters of ¾ in., 7⁄16 in., and ¼ in., or 12 mm, 7 mm, and 4 mm, may be employed. (A ½ in. ball is an acceptable substitute for the 7⁄16 in. ball.)

10.2.2.2 Test instrument calibration is performed with a 10-mm hemispherically shaped hole instrument calibration block described in Annex A2. This reference target shall be 1.7 in. (43.2 mm) below the entry surface of the standard.

10.2.2.3 A system reference block specified in 8.6 shall be employed to verify instrument calibration and to cross reference equipment performance between a number of instruments.

10.2.3 *Equipment Calibration Procedures:*

10.2.3.1 Equipment calibration is a two-step procedure that requires counter level calibration followed by ultrasonic test instrument sensitivity calibration.

10.2.3.2 Adjust the three-level counter using a set of highly polished stainless steel balls with a surface roughness of 2 µin. (.05 µm) Ra maximum and having a diameter ratio of 12:7:4. Position the search unit above the largest ball at a distance for maximum signal amplitude corresponding to the focal distance specified in 8.3.2. Adjust the test instrument sensitivity to produce a signal at 80 % of full screen height. At this setting, record the signal amplitude and adjust the level-three counter to count. This procedure determines the Level 3 (high) amplitude counting threshold. Without changing the test instrument sensitivity setting, position the search unit at its focal distance over the medium- and small-size balls. Adjust counter thresholds similar to the procedure for Level 3 and record the signal amplitudes for the Level 2 (medium) and Level 1 (low) amplitude counting thresholds.

10.2.3.3 The instrument test sensitivity is established by using a 10 mm sensitivity block as defined in Annex A2. Center the transducer over the hemispherically shaped hole of the sensitivity block using a water path distance between 1.1 to 1.7 in. Adjust for maximum signal strength in the XY axes. In the Z axis, adjust the water path distance between 1.1 and 1.7 in. to maximize signal strength. Adjust instrument sensitivity to the sensitivity of the Level 3 threshold (as established in 10.2.3.2). Increase the instrument sensitivity by 24dB for billet inspection.

10.2.4 *Cross Referencing Between Equipment Users*—If cross referencing of system reference blocks has been performed with other users of the method (as delineated in Annex A3), a fine adjustment of sensitivity (not to exceed ±1.5 dB) may be performed to discount variations in search unit response, counter hysteresis, and other instrumentation variables

10.2.5 *General Instructions and Procedures:*

10.2.5.1 Adjust the water path distance so that the search unit face is located 1 ± 1⁄16 in. (25.4 ± 1.6 mm) from the test specimen entry surface. This adjustment may be performed with a rule, reference spacer, or by use of calibrated water path measurements on the test instrument display.

10.2.5.2 Adjust the position of alarm/threshold gate(s) to evaluate indications that occur in the zone 0.7 to 0.9 in. (17.8 to 22.9 mm) from the entry surface to 0.3 to 0.5 in. (7.6 to 12.7 mm) from the bottom of the specimen.

10.2.5.3 Scan the specimen in a direction perpendicular to the rolling direction with a scan index of 0.050 in. (1.27 mm). The scanned area shall be bound by a perimeter that is not within 0.5 in. (12.7 mm) of the prepared surface edge. If the sides of the specimen are rough, a greater distance from the edge may be required to avoid spurious signals.

10.2.6 *System Reference Block Equipment Performance Test*—Verify the overall performance of equipment by conducting a test on the system reference block.

10.2.7 *Test Result Computation:*

10.2.7.1 For each side inspected, test result computation shall consist of counting the number of high-, medium-, and low-level indications and dividing by the volume tested. This provides a rating of the cleanliness, defined as counts per cubic inch.

$$S = \frac{N_l + N_m + N_h}{V}$$

where:

S = severity rating,
N_l = number of low-level indications counted,
N_m = number of medium-level indications counted,
N_h = number of high-level indications counted, and
V = volume of material tested (gated depth × scanned area).

10.2.8 *Report*—The reported results should contain all the information about the test that is necessary in order to duplicate results at the same or some other location. As a minimum, this report should include sample identification, test results on system reference sample, manufacturer's name and type designation of instruments and search units, and date of test. It also may be desirable to keep certain additional information on record, such as: number of counts at each level, severity, volume tested, gate length, total index, scan length, water temperature, sensitivity setting, name of operator, etc. Other information may be reported as agreed upon between the supplier and the purchaser.

10.2.9 *Reduction Ratio*—The reduction ratio from the original as-cast section to the sample size inspected must be reported.

11. Keywords

11.1 bearing steel; cleanliness; nondestructive examination; steel; ultrasonic testing

ANNEXES

(Mandatory Information)

A1. MINIMUM REQUIREMENTS FOR THE MANUFACTURE OF SEARCH UNITS

A1.1 General Characteristics

A1.1.1 The general characteristics of the search units presently used and their tolerances are as follows:

Frequency, MHz	Focal Length in Water, in. (mm)
10 ± 0.5	8.2 ± 0.3 (208.3 ± 7.6)

A1.1.2 The focal length shall be measured while using an instrument of the type employed for testing billet sections. A ½-in. or 12-mm diameter highly polished stainless steel ball target with a surface roughness of 2 µin. (.05 µm) Ra maximum shall be used for this measurement.

A1.2 Spectrum Analysis

A1.2.1 A spectrum analysis of the radiated signal of the transducer shall be performed to determine operating frequency characteristics. The requirements of the spectrum analysis test are as follows:

A1.2.1.1 Pulse-generating equipment shall be used that produces unidirectional voltage pulses having a duration no greater than one-half period of the nominal test frequency, a maximum rise time of 10 ns, and a trace-to-peak amplitude adjustable to 150 ± 5 V when loaded by the search unit and cable.

A1.2.1.2 A ½-in. or 12-mm diameter ball target in water shall be used. The ball target shall be placed in the search unit's far radiated field at 1.2 times the focal distance.

A1.2.1.3 The analyzed radiated signal shall be the front surface reflection from the ball target.

A1.2.1.4 A gate that does not modify signals should be used to avoid interference with the spectrum analysis by signal components from the gate.

A1.2.1.5 A linear oscilloscope presentation (or equivalent) should be used.

A1.2.1.6 The main peak radiation frequency as revealed by this analysis must be within ±0.5 MHz of the specified frequency. No secondary peaks should be within 5 dB of the peak radiation frequency.

A1.2.1.7 The maximum band width as revealed by this analysis must be 4 ± 0.5 MHz measured between points one half the amplitude of the peak radiation.

A1.3 Beam Symmetry Characteristics

A1.3.1 The symmetry of the beam of a search unit affects test sensitivity. Ideally, a search unit will radiate a beam whose cross section is essentially circular. If a search unit radiation beam has an elliptical or other asymmetrical shape, the unit's sensitivity, particularly on elongated targets, can vary considerably with search unit orientation. The symmetry of the radiated beam of search units used in this test shall be evaluated by both of the following methods:

A1.3.1.1 *Method I—Near-Field Beam Symmetry:*

(a) Pulse generation shall be the same as in A1.2.1.1

(b) An amplitude versus position recording shall be taken at the $y - 1$ point (first null on principal axis closest to focal point in near-field) in water along four planes 45° apart. A ½-in. or 12-mm diameter ball target shall be used.

(c) A photographic image of the oscilloscope presentation or chart recording of the signals shall be used to produce a recording of the beam profile.

(d) A symmetry factor shall be calculated by measuring the relative difference of the recorded lobes. A symmetry factor of no greater than 18 is suggested as calculated by adding the amplitude difference units between lobes for each of the four profiles.

A1.3.1.2 *Method II—Far-Field Beam Symmetry:*

(a) The instrument employed shall be of the same type as used for testing billet sections. The far-field beam symmetry shall be measured by observing the radiated field dimensions from the search unit while directed toward a target in water.

(b) A ½-in. or 12-mm diameter ball target shall be placed at 1.2 times the focal length.

(c) The width to the one-half amplitude point of the radiated field shall be measured in four planes 45° apart.

(d) The ratio of the shortest width of field to the longest width of field suggested limit shall be equal to or greater than 0.85.

A1.4 Distance Amplitude Characteristics

A1.4.1 The distance amplitude curve of the search unit shall be determined by observing the amplitudes of reflections, measured with an instrument of the type employed for testing billet sections, from a ½-in. or 12-mm diameter ball target in water.

A1.4.2 The tolerances of the distance amplitude measurements shall be specified at search unit-to-target distances of the following:

A1.4.2.1 The focal length of the search unit.

A1.4.2.2 1.3 times the focal length.

A1.4.2.3 0.8 times the focal length.

A1.4.3 *Amplitude Range*—Amplitude of all indications shall be within linear range of the instrument.

A1.4.3.1 *Ten-megahertz Search Units:*

(a) At 1.3 times the focal length, the amplitude range of the indication shall be 57 % to 83 % of the amplitude at focal distance.

(b) At 0.8 times the focal length, the amplitude range of the indication shall be 67 % to 93 % of the amplitude at focal distance.

A1.5 Minimum Sensitivity of Response

A1.5.1 The search units shall have a minimum sensitivity of response as determined by the following method:

A1.5.1.1 The excitation pulses shall be in accordance with A1.2.1.1 such that their maximum duration at the half-amplitude points is 50 ns for 10-MHz search units.

A1.5.1.2 Measure the received reflected signal amplitude after 40 dB of r-f amplification. The amplitude shall be at least 3.5 V.

A1.6 Search Unit Element

A1.6.1 A ¾-in. (19.1-mm) lithium sulfate (or equivalent) search unit active element is recommended because it provides sufficient area and sensitivity for conducting this test. A disadvantage of lithium sulfate elements is that as a monohydrate piezoelectric crystal, any minute quantity of water entering the element will destroy it. Extreme precautions in manufacture to provide perfect sealing and careful drying after use in testing must be exercised to prevent its destruction from absorption of water.

A1.7 Damping Characteristics

A1.7.1 Acoustic damping shall be incorporated in the transducer to improve its ability to discern closely spaced discontinuities of nearly the same depth.

A1.7.2 Laboratory measurements of damping shall be made by observation of the rate of decay of the pulse envelope of a search unit observed on an oscilloscope. An interpretation called Damping Factor (D) shall be made by counting the number of cycles in the pulse envelope greater than one half the initial pulse amplitude. The damping factor (D) should be less than five units.

A1.7.3 This search unit characteristic affects the sensitivity of a search unit. The condition of the bond between the active element and the damping element may be estimated from an increase in the damping factor. Bond imperfections cause the radiation beam to be asymmetrical and increase the damping factor and search unit operating frequency.

A2. FABRICATION OF 10-mm HEMISPHERICALLY SHAPED HOLE SENSITIVITY BLOCK

A2.1 Ten-millimetre hemispherically shaped hole test blocks shall be fabricated as shown in Fig. A2.1 in accordance with the following description:

A2.1.1 Employ CEVM (or equivilalent) 8620, 4330, or 4340 steel.

A2.1.2 Normalize steel 90°C above the Ac_3 point, holding the steel at temperature for a minimum of 4 h, and furnace cool.

A2.1.3 Rough out blocks to permit compliance with finish dimensions shown in Fig. A2.1. Surface *X* shall be ground.

A2.1.4 Mill a flat-bottom plug recess (approximately ⅞ in. (22 mm) in diameter and 0.150 in. (3.81 mm) deep).

A2.1.5 Mill a 0.4-in. (10.2-mm) diameter hemispherical hole 0.1 in. (3 mm) deep in center of recess.

A2.1.6 Test the bottom of the hole for Brinell hardness using a standard Brinell machine (10-mm ball and 3000-kg load).

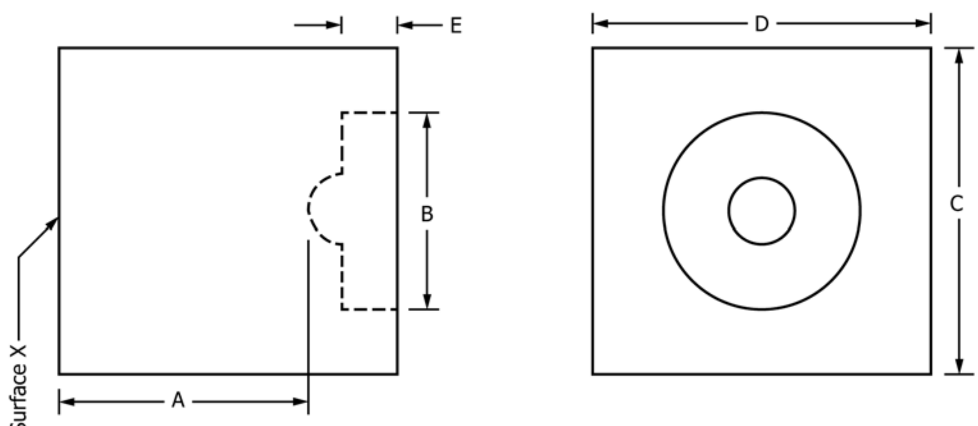
A2.1.7 Braze the 10-mm ball on a rod and insert the rod in a drill press or milling machine.

A2.1.8 Lap the bottom of the hole until no visible imperfections are discernible with a 3× magnifier. The axis of the hemispherical hole and of the rotating rod shall always be kept inclined since the bottom of the ball along the rod's axis will have a zero velocity.

A2.1.9 Grind the block so the *A* dimension is 1.70 ± 0.005 in. (43.2 ± 0.13 mm). The surface finish of surface *X* shall be 15 to 25 rms (0.34 to 0.57 μm aa).

A2.1.10 Plate the block with nickel or chrome (approximately 0.001 in. (0.03 mm) thick).

A2.1.11 Cement the flat plug in the flat-bottom recess.



Dimensions
A = 1.70± 0.005 in. (43.2 ± 0.13 mm)
B = 0.875± 0.125 in. (22.22 ± 3.18 mm)
C = 1.5 in. (38 mm) minimum
D = 1.5 in. (38 mm) minimum
E = 0.15± 0.050 in. (3.8 ± 1.27 mm)

FIG. A2.1 Fabrication of a 10-mm Hemispherically Shaped Hole Sensitivity Block

A3. METHOD OF CROSS REFERENCING SYSTEM REFERENCE BLOCKS

A3.1 Assurance of Proper Equipment Performance

A3.1.1 Assurance of proper equipment performance can only be obtained by periodically conducting tests of a system reference block. Unfortunately, response sensitivity (percent change in counts) for different test specimens or blocks is not a constant for all instrumentation variables.

A3.2 Factors Affecting Counts from a Specimen

A3.2.1 The distribution, type, shape, and location of inclusions in a test billet specimen can cause the response in counts to be either sensitive or insensitive to minor differences in instrumentation, search units, or setup. Consequently, a simple specification for limits on a system reference block, such as permitting a set percentage deviation in counts from an established median, is not practical. The response sensitivity of the particular reference test block as a function of instrumentation gain, etc., must be accounted for.

A3.3 Method of Cross Referencing Different Reference Blocks

A3.3.1 Cross referencing of test blocks may be accomplished by first making a test run on two or more system reference blocks at standard sensitivity. The reference blocks are then rerun using selected higher and lower gain settings. In order to prevent instrumentation inaccuracies, such as linearity differences, from influencing the test, the slightly higher and lower gain settings can be delineated to be the difference of energy reflections between different size balls. This is feasible since amplitude of indications from balls varies directly with ball diameter.

A3.3.2 Test runs of reference blocks at high, low, and standard sensitivity provide correlated data enabling the permissible deviation in counts of each system reference block to be specified.

A3.3.3 Fig. A3.1 illustrates counts obtained on two reference blocks for three different search units. Cross referencing of test blocks in this manner enables one to make minor adjustments in sensitivity to discount variations in search units and instrumentation so as to obtain the desired counts on each system reference block relative to other users of the method.

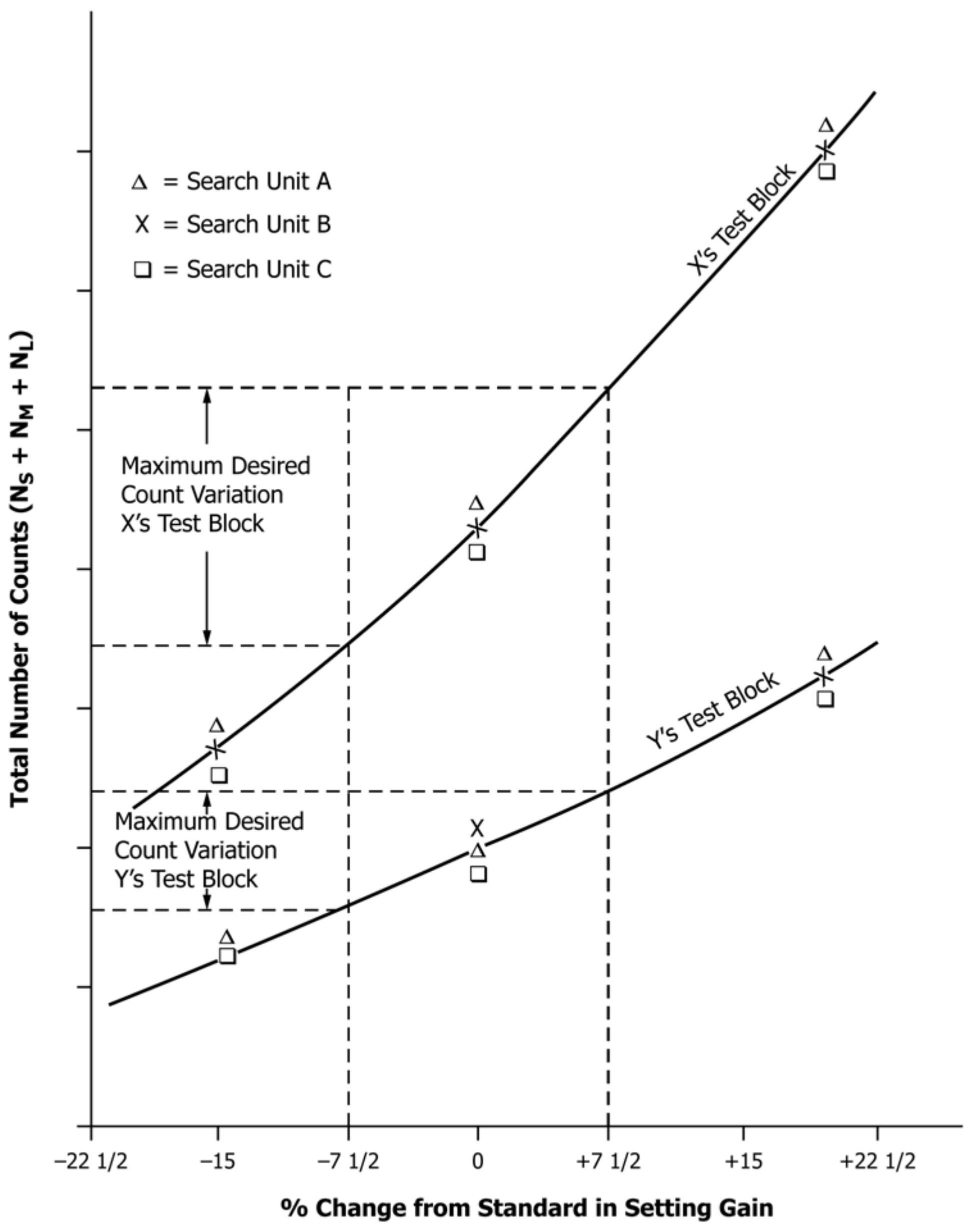


FIG. A3.1 Method of Reference Block Comparison