



<b>AEROSPACE MATERIAL SPECIFICATION</b>	<b>AMS2628™</b>	<b>REV. C</b>
	Issued 1996-10 Reaffirmed 2007-02 Revised 2024-05	
Superseding AMS2628B		
Enhanced Ultrasonic Immersion Inspection for Titanium Alloy and other Metal Alloy Billets		

RATIONALE

AMS2628C is the result of a Five-Year Review and update of the specification. The revision updates definitions (see 2.6).

1. SCOPE

1.1 Purpose

This specification covers procedures for ultrasonic immersion inspection of premium-grade wrought titanium and titanium alloy round billet 5 inches (127 mm) and over in nominal diameter (see 2.6.1). Metal alloy billets other than titanium may be tested to this specification with the use of suitable reference standards.

1.2 Application

This inspection procedure has been used typically for locating internal defects such as cracks, voids, inclusions, and other structural discontinuities that may or may not be exposed to the surface in billets, but usage is not limited to such applications. Testing normally will be by longitudinal procedure, but shear wave procedure may be added when agreed upon by the purchaser and processor. This specification includes zoned inspections with single element transducers or with a phased array transducer.

Method 1 - Single element transducers, with single or multiple zones

Method 2 - Phased array transducers

When the method is not specified, selection is at the discretion of the supplier.

Class A - Acceptance based on signal-to-noise and amplitude (see Table 1A)

Class B and C - Acceptance based on amplitude only (see Table 1A)

Other acceptance levels may be called out by the cognizant engineering organization (CEO), which may include near-surface hole depth, calibration FBH size, calibration amplitude, maximum acceptable amplitude, maximum acceptable signal-to-noise ratio, and data recording method.

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- 1.2.1 These procedures may be applied to nickel and other alloys with suitable reference standards. Acceptance criteria for non-premium titanium and alloys other than titanium shall be defined by the referencing specification or the purchaser.

## 2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

### 2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

AS7766 Terms Used in Aerospace Metals Specifications

### 2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, [www.astm.org](http://www.astm.org).

ASTM E317 Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

ASTM E1065 Evaluating Characteristics of Ultrasonic Search Units

ASTM E1316 Standard Terminology for Nondestructive Examinations

### 2.3 AIA Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, [www.aia-aerospace.org](http://www.aia-aerospace.org).

NAS-410 Nondestructive Testing Personnel Qualification and Certification

### 2.4 ASME Publications

Available from ASME, P.O. Box 2900, 22 Law Drive, Fairfield, NJ 07007-2900, Tel: 800-843-2763 (U.S./Canada), 001-800-843-2763 (Mexico), 973-882-1170 (outside North America), [www.asme.org](http://www.asme.org).

ASME B46.1 Surface Texture

### 2.5 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

#### 2.5.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

AMS-STD-2154 Inspection, Ultrasonic, Wrought Metals, Process For

## 2.5.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, [www.astm.org](http://www.astm.org).

ASTM E127 Fabrication and Control of Flat Bottom Hole Ultrasonic Standard Reference Blocks

## 2.6 Definitions

Terms used in AMS are defined in AS7766. Refer to ASTM E1316 for terms related to nondestructive inspection.

### 2.6.1 PREMIUM-GRADE TITANIUM

The term premium-grade titanium as used in this document originates from the JETQC-001 (Jet Engine Titanium Quality Committee) intent to have 100% of the material used primarily for the forging of high-energy rotor components inspected for Type 1 (hard alpha) and high-density inclusions before any of that material is forged.

## 3. TECHNICAL REQUIREMENTS

### 3.1 Qualification

#### 3.1.1 Personnel

Shall be certified to and shall function within the limits of their levels in accordance with NAS-410 or other procedures acceptable to the purchaser.

#### 3.1.2 Facilities

Shall be subject to review and approval by the purchaser. Reference specifications, procedures, and documentation necessary to verify the qualification of equipment and test personnel shall be available to the purchaser upon request.

#### 3.1.3 Written Procedure

Ultrasonic inspections performed in accordance with this specification shall be detailed in written procedures. Procedures shall be prepared by the processor and approved by the purchaser. Procedures shall include not less than the following information:

- a. Billet diameter and alloy
- b. Equipment to be used, including software and software version numbers
- c. Inspection configuration including zones, if applicable
- d. Amplitudes for calibration, evaluation threshold, and reject limits
- e. Rotational speed and index
- f. Pulse repetition rate
- g. Calibration standard serial number, size, and, if applicable, correction factors
- h. Method used for distance amplitude corrections
- i. Method for attenuation correction
- j. Gate length and delay per zone, if applicable

- k. Methods for surface preparation and surface texture control
- l. Transducer manufacturer and model number
- m. Method for application and control of focal laws for phased array applications
- n. Data analysis software and version number

#### 3.1.4 Exceptions

No exception shall be taken to the written procedure or this specification unless approved by the purchaser.

### 3.2 Equipment

Equipment specifications defined in 3.2.1, paragraphs 3.2.1.2.1 through 3.2.1.2.3, are applicable to inspections utilizing single-element transducers. In addition to those requirements, the specifications of paragraphs 3.2.1.2.4 through 3.2.1.2.9 apply for inspections using phased array instruments.

#### 3.2.1 Ultrasonic Instrument

3.2.1.1 Shall be capable of producing, receiving, and displaying high-frequency electrical pulses at the required frequencies and energy levels. Shall be capable of operating with the number of transducers required to test all zones, including monitoring of the back wall echo. The instrument shall be able to operate in the pulse-echo mode at frequencies of 2.25 through 10 MHz and a bandwidth of 1 to 20 MHz. Gates, distance-amplitude correction (DAC) system, and other electronic aids to ultrasonic testing and interpretation shall be used as required. An alarm system, auto-stop, recorder, or combination of these may be used.

#### 3.2.1.2 Instrument Performance

The horizontal limit and linearity, the vertical limit and linearity, and the accuracy of calibrated gain controls shall be evaluated in accordance with ASTM E317 with the following requirements and exceptions:

3.2.1.2.1 The horizontal limit and linearity shall be measured by plotting signal displacement against known thickness in the range of 1 to 8 inches (25 to 203 mm) in 1-inch (25-mm) increments; the allowable differences in thickness between that indicated by the signal displacement and actual measured thickness shall be within  $\pm 3\%$  of the measured thickness of the respective block. Substitute performance checks are permissible when agreed upon by the purchaser and processor.

3.2.1.2.2 Vertical linearity shall be within  $\pm 2\%$  of full scale over the range of 10 to 80% of full scale.

3.2.1.2.3 Accuracy of calibrated gain control shall be within  $\pm 2$  dB over a range of 50 dB.

3.2.1.2.4 The phased array instrument must have a minimum of 64 pulse channels and a minimum of 128 receive channels in accordance with the probe design for the full volume inspection of the billet.

#### 3.2.1.2.5 Dynamic Depth Focusing (DDF)

The phased array system shall be capable of dynamically focusing the beam within a part, where focusing on transmission is fixed with depth and focusing on reception varies over a depth range. This option must be integrated into the instrument's software to allow for application to sector scans, electronic scans, and with every array configuration designed for billet inspection. DDF for the system must have the capability to maintain a consistent UT beam width throughout the inspection depth of the material. This is a function of both the DDF capability of the system and the design of the phased array probe.

#### 3.2.1.2.6 Pulse Width

The phased array system shall provide the ability to adjust the pulse width in a range that includes a minimum of 30 to 200 ns.

- 3.2.1.2.7 The phased array instrument must have a minimum of four inspection gates with amplitude and time-of-flight (TOF) capability. In addition, a synchronization gate is required.
- 3.2.1.2.8 The phased array instrument must be capable of applying the minimum number of focal laws required for the test. When beam sweeping is required, the instrument must be capable of applying a minimum of 128 focal laws.
- 3.2.1.2.9 The phased array instrument must have the capability of applying DAC with a minimum dynamic range of 0 to 40 dB with the ability to adjust in  $\pm 0.25$  dB or smaller increments.

### 3.2.2 Ultrasonic Search Units

Search units shall be evaluated in accordance with ASTM E1065 to determine frequency response, peak frequency, and bandwidth. The peak frequency shall be not less than 4 MHz. Search units shall be tested to determine the beam width at -6 dB, or as required by 3.5.2 and 3.5.3, in the billet axial and circumferential directions. The beam width measurements should be performed using flat-bottom hole targets close to the focal plane of the transducer in cylindrical test standards such as those shown in Appendix C, Figures C1 through C9. In the case of a phased array system, the beam widths should be measured upon receipt of the transducer for all diameters of billet that will be inspected with the transducer at a minimum of two depths in the billet calibration standards. The two depths should comprise a near surface calibration hole and a hole at mid-depth.

### 3.2.3 Voltage Regulator

The line voltage shall be regulated within  $\pm 10\%$ .

### 3.2.4 Couplant

Clean water shall be used as the couplant material; rust inhibitors, wetting agents, or both may be added. The water shall be free of visible air bubbles, which may interfere with the ultrasonic test.

### 3.2.5 Data Acquisition System

If a digital data acquisition system is used to record the data, it shall meet the requirements listed in 3.2.5.1 to 3.2.5.6.

#### 3.2.5.1 Components

The system shall consist of encoders for axial and circumferential position, an analog-to-digital (A/D) signal conversion device, computer, graphic display monitor, graphic printer, an archival storage system, and appropriate software.

#### 3.2.5.2 A/D Conversion

For each pulse, the peak ultrasonic amplitude in the gated region of each inspection zone shall be digitized to a minimum resolution of 8 bits over the full range of amplitudes used for data acquisition. For phased array inspection, the time position in the gate of the peak amplitude shall also be recorded. The A/D converter shall be calibrated and adjusted using procedures recommended by the manufacturer.

#### 3.2.5.3 Recording System Linearity

The recording system shall be shown to reproduce recorded amplitude data to an accuracy of  $\pm 2\%$  of full scale.

#### 3.2.5.4 Digital Data Storage

Digital amplitudes and the corresponding encoder positions shall be stored. For each ultrasonic amplitude, the corresponding encoder positions shall be retrievable by the operator for relocation and evaluation of indications. The data storage system shall provide traceability of axial position of indications in the billet.

### 3.2.5.5 Digital Data Archiving

All inspection data files shall be archived and accessible on storage media acceptable to the purchaser.

### 3.2.5.6 Analysis of Digital Data

Software to analyze the digital data shall perform not less than the following functions: display location and amplitude; select region of interest (ROI); calculate mean, minimum, maximum, and standard deviation of amplitude in ROI, and signal-to-noise ratio (see 4.1.1).

### 3.2.6 Reference Standards

Shall be fabricated from alloys acoustically similar to the alloy to be tested.

#### 3.2.6.1 Initial Selection of Material for Reference Standards

The reference standard material shall have ultrasonic attenuation similar to the material to be inspected. This shall be verified by comparison of the first back-surface reflection in the standard material, away from any edge in the test block, to the first back-surface reflection from similar regions, away from any edge, in a number of samples of typical production billet material. Back-surface echoes averaged over a region of 1-inch (25-mm) length by 360 degrees circumferential at three regions over the length of the billet are recommended to be within  $\pm 6$  dB. Reference standard diameter shall be within  $\pm 0.5$  inch ( $\pm 12.7$  mm) of the nominal diameter of the material to be tested.

3.2.6.2 Calibration reflectors shall be flat-bottom holes of the diameter shown in Table 1. The standard shall contain a minimum of one hole at the shallow and deep depths of each inspection zone and shall contain holes at a minimum of four depth locations, with the shallowest being at the depth shown in Table 1 and the deepest being 0.5 inch deeper than the center of the billet. Recommended configurations are shown in Appendix C, Figures C1 through C9 for fixed focus transducers. Recommended configurations for phased array inspections are shown in Appendix D.

3.2.6.3 Reference standards shall include a full round section for attenuation compensation measurement. The full round section shall be of the same material, with the same attenuation properties as the rest of the reference standard, and shall be permanently attached or clearly identified as part of the reference standard.

3.2.6.4 Reference standards shall be subject to calibration, certification, and recall procedures required by the purchaser.

#### 3.2.7 System Operation (Dynamic Response)

The total system shall have dynamic response adequate to provide correct amplitude data for all inspection scan and recording parameters.

### 3.3 Surface Preparation

3.3.1 Surfaces to be inspected shall not produce ultrasonic reflections that interfere with the test. Surface texture shall be determined in accordance with ANSI B46.1. A surface roughness of 125 microinches ( $3.2 \mu\text{m}$ ), or better, is normally sufficient to ensure it can be inspected.

3.3.2 Regions with surface discontinuities, such as local grind-outs, are not considered inspectable and shall be cut out and removed from further processing. Such regions shall be reported on the inspection report. It is recommended that any required grind-out operations be performed after ultrasonic inspection.

### 3.4 Standardization of Apparatus

Before inspecting the product, the equipment shall be adjusted, using appropriate reference blocks, to produce clearly defined echoes of amplitude equal to or exceeding 80% of full scale from all calibration targets in each zone.

- 3.4.1 Standardization amplitudes shall be achieved by use of electronic DAC or by direct comparison in a zoned inspection. In the case of fixed focus zoned inspection without the use of DAC, the zones shall be in accordance with Appendix A, Tables A1 through A9, using transducers described in Appendix B, Tables B1 through B5, or equivalent, and approved by the purchaser.
- 3.4.2 Instruments shall be warmed up for not less than 10 minutes before being used. Sufficient time shall also be allowed for temperature of water, reference blocks, transducers, and product to stabilize before standardization and testing.
- 3.4.3 Standardization Check

To ensure valid results, a standardization check shall be made as a minimum prior to and after the test of each part configuration. Any change in equipment operation that results in a sensitivity reduction of more than 2 dB of the test system shall require retesting of all product or parts tested since the previous standardization. The interval between standardizations may be extended subject to the purchaser's agreement.

### 3.5 General Scanning Procedure

#### 3.5.1 Attenuation Compensation

Acoustic compatibility shall be applied by comparing the backwall echo (BE) or the reference standard material to the average BE over three regions (360 degrees circumferential by 1-inch [25-mm] length) of the material being tested near the center and each end of the billet. If the compatibility difference is within 4 dB, no gain compensation shall be required for inspection. If the compatibility of the BE of the material differs by more than 4 dB from the reference standard, the inspection gain shall be adjusted to compensate in accordance with the approved test procedure of 3.1.3 (i).

#### 3.5.2 Evaluation Threshold

An evaluation threshold shall be defined in the procedure such that any rejectable indication will be certain to exceed the evaluation threshold during scanning. Any signal exceeding the evaluation threshold during evaluation shall be relocated and further evaluated ultrasonically. The evaluation threshold will generally be 6 dB below the acceptance limit but may be varied by indexing in accordance with 3.5.3.

#### 3.5.3 Indexing

Index distance, pulse repetition rate, and rotational speed shall be controlled to provide adequate data sampling.

- 3.5.3.1 The maximum diagonal distance between sampled data points shall be calculated from the index distance, the pulse repetition rate, and the rotation speed. These parameters shall be controlled such that a rejectable indication will exceed the evaluation limit regardless of its location relative to the sampled points. For example, if the evaluation threshold is -6 dB from the reject level, then the -6 dB sound beam diameter from adjacent and diagonal pulses shall provide complete coverage as illustrated in Figure 1.

- 3.5.4 The instrument control settings and test parameters established during standardization shall not be changed during testing with the exception of changes in gate length, which may be required to perform the dynamic standardization check.

### 3.6 Inspection

- 3.6.1 Sound entry angle shall be perpendicular to the surface. Billet followers shall maintain perpendicularity within  $\pm 1.0$  degree.

- 3.6.1.1 Phased array inspection may incorporate beam sweeping to mitigate potential beam misalignment.

#### 3.6.2 Water Travel

The water travel distance shall be within  $\pm 0.1$  inch ( $\pm 2.5$  mm) of that used for calibration.

### 3.6.3 Surface Area of Product to be Scanned

100% of the circumference shall be scanned over the entire length of the billet.

### 3.6.4 Depth Range of Product to be Gated

The depth range from the near-surface hole shown in Table 1 to 0.5 inch (13 mm) past the center line shall be gated as a minimum.

3.6.5 Use of DAC and/or zoning shall not be changed from standardization to inspection.

3.6.6 For premium-grade titanium materials, the entire heat shall be inspected to the same classification prior to shipment of any product from the heat (see 2.6.1).

## 4. QUALITY ASSURANCE PROVISIONS

### 4.1 Acceptance Criteria

Acceptance levels and classifications shall be as shown in Table 1. Additional high sensitivity sonic or other inspections will be specified as necessary to meet major rotor engine hardware operating requirements.

4.1.1 For purposes of determining signal acceptance based on its signal-to-noise ratio, signal-to-noise ratio is defined as:

$$(\text{Signal} - \text{Mean})/(\text{Peak} - \text{Mean})$$

where:

signal = the highest amplitude obtained from the suspected indication

mean = the mean value of noise in a region surrounding or adjacent to the indication

peak = the highest amplitude value of noise in the surrounding or adjacent region, excluding electrical noise signals

4.1.2 For Classification A, product must meet both amplitude and signal-to-noise acceptance requirements.

### 4.2 Disposition

4.2.1 Product exhibiting ultrasonically evaluated indications not in excess of acceptance limits shown in Table 1 may be accepted without remedial operations.

4.2.2 All indications in excess of acceptance limits shown in Table 1 shall be removed and metallographically evaluated. Disposition of remaining product in a heat shall be in accordance with the purchaser agreement.

### 4.3 Records

The testing source shall prepare and maintain, for the time specified by the purchaser, records of the requirements and techniques for each size and configuration of product and all recorded data from billet inspection. These records shall be accessible for review by the purchaser at any reasonable time.

#### 4.4 Reporting

The testing source shall provide a report with each shipment. This report shall contain not less than the following information:

Description of the product tested, including alloy, heat number, billet identifications, and dimensions  
Report of all indications exceeding acceptance limits with disposition according to the purchaser agreement  
Report of all indications over evaluation threshold as required by the purchaser  
Billet map showing location of indication and any material removed due to indications or surface discontinuities  
Location of any regions not inspectable  
Noise level for each billet

#### 5. PREPARATION FOR DELIVERY

Not applicable.

#### 6. ACKNOWLEDGMENT

A processor shall mention this specification number in all quotations and when acknowledging purchase orders.

#### 7. REJECTIONS

Product not inspected in accordance with this specification, or with modifications authorized by the purchaser, will be subject to rejection.

#### 8. NOTES

##### 8.1 Revision Indicator

A change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

##### 8.2 Test Conditions

It is essential that thorough understanding be developed between the purchaser and processor regarding interpretation of the results of inspection and how they shall be recorded and reported. Ultrasonic testing is so comprehensive that it is necessary that all interested parties fully recognize that indications may appear that do not reflect conditions detrimental to use of the product. Agreement between the purchaser and processor should be established in advance on the following:

8.2.1 Local grinding depressions will cause sonic wave attenuation, loss of back reflection, and inability to meet standards locally.

8.3 Dimensions and properties in inch/pound units and the Fahrenheit temperatures are primary; dimensions and properties in SI units and the Celsius temperatures are shown as the approximate equivalents of the primary units and are presented only for information.

8.4 Section 3.2.6.1 specifies that material for a new standard be within 6 dB of the material to test. Section 3.5.1 does not impose a  $\pm 6$  dB limit on the use of a standard and specifies the use of gain compensation if there is a compatibility difference. The 3.2.6.1 requirement does not restrict the usability of a particular standard in 3.5.1.

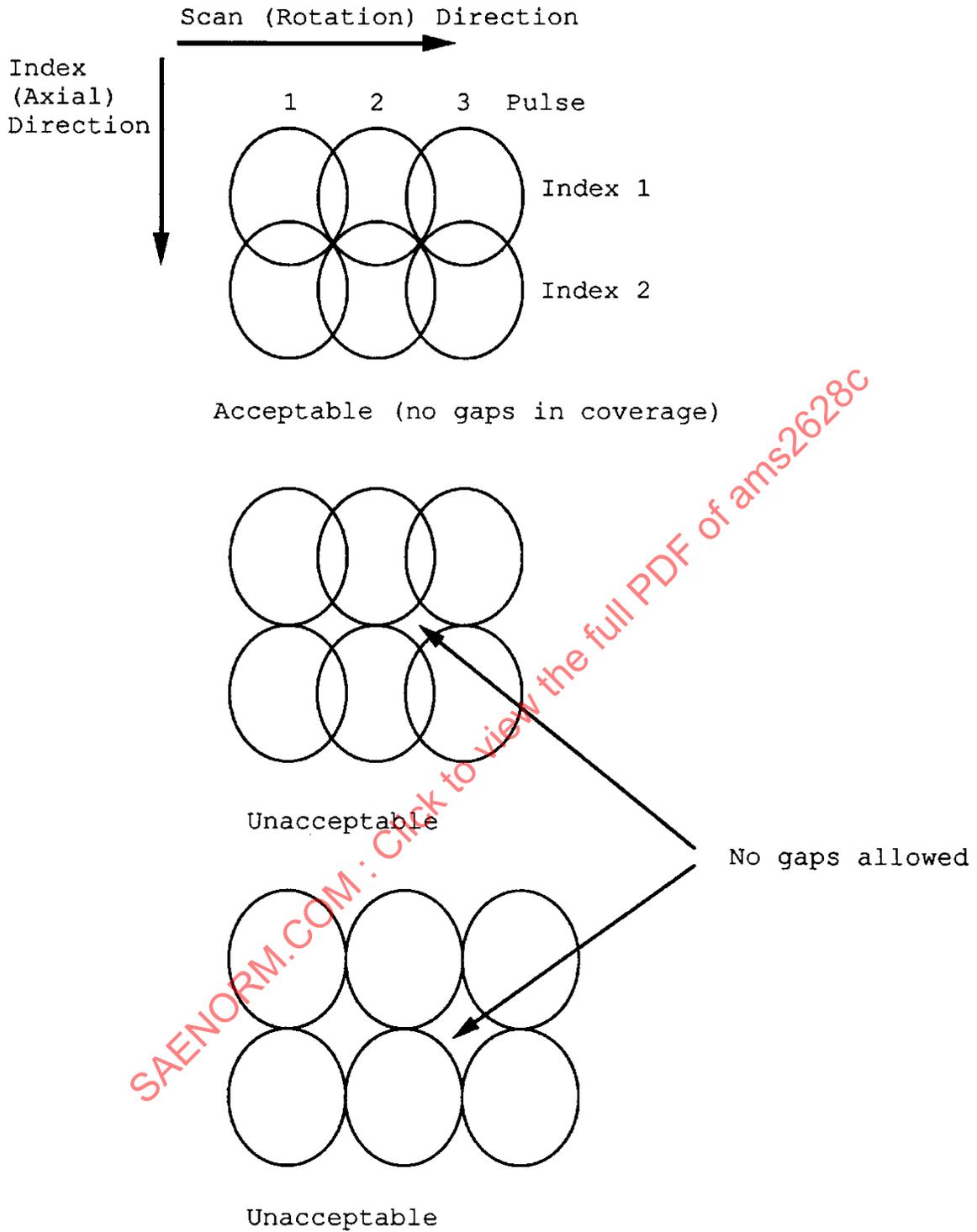


Figure 1 - Acceptable beam overlap conditions in accordance with 3.5.3.1

**Table 1A - Acceptance levels and classification (see 3.2.6.2)**

Ultrasonic Classification	Near-Surface Hole Depth Inch	Billet Diameter Inches	Calibration FBH Diameter Inch	Calibration Amplitude	Max Acceptable Amplitude	Max Acceptable Signal-to-Noise Ratio	Data Recording
A	0.20	≤10	2/64	80%	70%	2.5	Digital
		>10	3/64	80%	40% <sup>(1)</sup>	2.5	
					60% <sup>(2)</sup>	2.5	
B	0.375	≤10	2/64	80%	80%	N/A	Strip Chart or Digital
		>0	3/64	80%	80%	N/A	Strip Chart or Digital
C	0.375	>5	3/64	80%	80%	N/A	Optional

<sup>(1)</sup> Depth less than 4 inches.<sup>(2)</sup> Depth 4 inches and over.**Table 1B - Acceptance levels and classification (see 3.2.6.2)**

Ultrasonic Classification	Near-Surface Hole Depth Millimeters	Billet Diameter Millimeters	Calibration FBH Diameter Millimeters	Calibration Amplitude	Max Acceptable Amplitude	Max Acceptable Signal-to-Noise Ratio	Data Recording
A	5.1	≤254	0.8	80%	70%	2.5	Digital
		>254	1.2	80%	40% <sup>(1)</sup>	2.5	Digital
					60% <sup>(2)</sup>	2.5	Digital
B	9.52	≤254	0.8	80%	80%	N/A	Strip Chart or Digital
		>254	1.2	80%	80%	N/A	Strip Chart or Digital
C	9.52	>127	1.2	80%	80%	N/A	Optional

<sup>(1)</sup> Depth less than 102 mm.<sup>(2)</sup> Depth 102 mm and over.

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## APPENDIX A

## A.1 RECOMMENDED INSPECTION ZONES

## A.1.1 Billet Diameter 5 Inches (127 mm)

Use transducers for 5 to 6 inches (127 to 152 mm) diameter with 3.5 inches (89 mm) waterpath.

**Table A1**

Zone	Zone Start Inches (mm)	Zone End Inches (mm)	Gate Start Inches (mm)	Gate End Inches (mm)	Pulses per Rev.
1	0.2 (5)	0.75 (19)	0.2 (5)	1.15 (29.2)	1024
2	0.75 (19)	1.5 (38)	0.35 (8.9)	1.9 (48)	512
3	1.5 (38)	2.25 (57.2)	1.1 (28)	2.65 (67.3)	512
4	2.25 (57.2)	3 (76)	1.85 (47)	3.4 (86)	256

## A.1.2 Billet Diameter 6 Inches (152 mm)

Use transducers for 5 to 6 inches (127 to 152 mm) diameter with 3.0 inches (76 mm) waterpath.

**Table A2**

Zone	Zone Start Inches (mm)	Zone End Inches (mm)	Gate Start Inches (mm)	Gate End Inches (mm)	Pulses per Rev.
1	0.2 (5)	0.8 (20)	0.2 (5)	1.25 (31.8)	1024
2	0.8 (20)	1.7 (43)	0.4 (10)	2.15 (54.6)	1024
3	1.7 (43)	2.6 (66)	1.25 (31.8)	3.05 (77.5)	512
4	2.6 (66)	3.5 (89)	2.15 (54.6)	3.95 (100.3)	512

## A.1.3 Billet Diameter 7 Inches (178 mm)

Use transducers for 7 to 8 inches (178 to 203 mm) diameter with 3.5 inches (89 mm) waterpath.

**Table A3**

Zone	Zone Start Inches (mm)	Zone End Inches (mm)	Gate Start Inches (mm)	Gate End Inches (mm)	Pulses per Rev.
1	0.2 (5)	0.8 (20)	0.2 (5)	1.2 (30)	1024
2	0.8 (20)	1.6 (41)	0.4 (10)	2.0 (51)	1024
3	1.6 (41)	2.4 (61)	1.2 (30)	2.8 (71)	512
4	2.4 (61)	3.2 (81)	2.0 (51)	3.6 (91)	512
5	3.2 (81)	4.0 (102)	2.8 (71)	4.4 (112)	256

## A.1.4 Billet Diameter 8 Inches (203 mm)

Use transducers for 7 to 8 inches (178 to 203 mm) diameter with 3.0 inches (76 mm) waterpath.

**Table A4**

Zone	Zone Start Inches (mm)	Zone End Inches (mm)	Gate Start Inches (mm)	Gate End Inches (mm)	Pulses per Rev.
1	0.2 (5)	0.9 (23)	0.2 (5)	1.35 (34.3)	1024
2	0.9 (23)	1.8 (46)	0.45 (11.4)	2.25 (57.2)	1024
3	1.8 (46)	2.7 (69)	1.35 (34.3)	3.15 (80)	512
4	2.7 (69)	3.6 (91)	2.25 (57.2)	4.05 (102.9)	512
5	3.6 (91)	4.5 (114)	3.15 (80)	4.95 (125.7)	256

## A.1.5 Billet Diameter 9 Inches (229 mm)

Use transducers for 9 to 10 inches (229 to 254 mm) diameter with 3.5 inches (89 mm) waterpath.

**Table A5**

Zone	Zone Start Inches (mm)	Zone End Inches (mm)	Gate Start Inches (mm)	Gate End Inches (mm)	Pulses per Rev.
1	0.2 (5)	0.8 (20)	0.2 (5)	1.2 (30)	1024
2	0.8 (20)	1.6 (41)	0.4 (10)	2.0 (51)	1024
3	1.6 (41)	2.4 (61)	1.2 (30)	2.8 (71)	1024
4	2.4 (61)	3.2 (81)	2.0 (51)	3.6 (94)	512
5	3.2 (81)	4.1 (104)	2.8 (71)	4.5 (114)	512
6	4.1 (104)	5 (127)	3.7 (94)	5.4 (137)	256

## A.1.6 Billet Diameter 10 Inches (254 mm)

Use transducers for 9 to 10 inches (229 to 254 mm) diameter with 3 inches (76 mm) waterpath.

**Table A6**

Zone	Zone Start Inches (mm)	Zone End Inches (mm)	Gate Start Inches (mm)	Gate End Inches (mm)	Pulses per Rev.
1	0.2 (5)	0.9 (23)	0.2 (5)	1.35 (34.3)	1024
2	0.9 (23)	1.8 (46)	0.45 (11.4)	2.25 (57.2)	1024
3	1.8 (46)	2.7 (69)	1.35 (34.3)	3.15 (80)	1024
4	2.7 (69)	3.6 (91)	2.25 (57.2)	4.05 (102.9)	512
5	3.6 (91)	4.5 (114)	3.15 (80)	4.95 (125.7)	512
6	4.5 (114)	5.5 (140)	4.05 (102.9)	5.95 (151.1)	256

## A.1.7 Billet Diameter 12 Inches (305 mm)

Use transducers for 12 to 13 inches (305 to 330 mm) diameter with 4 inches (102 mm) waterpath.

**Table A7**

Zone	Zone Start Inches (mm)	Zone End Inches (mm)	Gate Start Inches (mm)	Gate End Inches (mm)	Pulses per Rev.
1	0.2 (5)	0.9 (23)	0.2 (5)	1.35 (34.3)	1024
2	0.9 (23)	1.8 (46)	0.45 (11.4)	2.25 (57.2)	1024
3	1.8 (46)	2.7 (69)	1.35 (34.3)	3.15 (80)	1024
4	2.7 (69)	3.6 (91)	2.25 (57.2)	4.05 (102.9)	1024
5	3.6 (91)	4.5 (114)	3.15 (80)	4.95 (125.7)	512
6	4.5 (114)	5.5 (140)	4.05 (102.9)	5.95 (151.1)	512
7	5.5 (140)	6.5 (165)	5.05 (128.3)	6.95 (176.5)	256

## A.1.8 Billet Diameter 13 Inches (330 mm)

Use transducers for 12 to 13 inches (305 to 330 mm) diameter with 3.5 inches (89 mm) waterpath.

**Table A8**

Zone	Zone Start Inches (mm)	Zone End Inches (mm)	Gate Start Inches (mm)	Gate End Inches (mm)	Pulses Per Rev.
1	0.2 (5)	1.0 (25)	0.2 (5)	1.5 (38)	1024
2	1.0 (25)	2.0 (51)	0.5 (13)	2.5 (64)	1024
3	2.0 (51)	3.0 (76)	1.5 (38)	3.5 (89)	1024
4	3.0 (76)	4.0 (102)	2.5 (64)	4.5 (114)	1024
5	4.0 (102)	5.0 (127)	3.5 (89)	5.5 (140)	512
6	5.0 (127)	6.0 (152)	4.5 (114)	6.5 (165)	512
7	6.0 (152)	7.0 (178)	5.5 (140)	7.5 (190)	256

## A.1.9 Billet Diameter 14 Inches (356 mm)

Use transducers for 14 inches (356 mm) diameter with 4.0 inches (102 mm) waterpath.

**Table A9**

Zone	Zone Start Inches (mm)	Zone End Inches (mm)	Gate Start Inches (mm)	Gate End Inches (mm)	Pulses Per Rev.
1	0.2 (5)	1.0 (25)	0.2 (5)	1.5 (38)	1024
2	1.0 (25)	2.0 (51)	0.5 (13)	2.55 (64.8)	1024
3	2.0 (51)	3.1 (79)	1.5 (38)	3.65 (92.7)	1024
4	3.1 (79)	4.2 (107)	2.55 (64.8)	4.75 (120.6)	1024
5	4.2 (107)	5.3 (135)	3.65 (92.7)	5.85 (148.6)	512
6	5.3 (135)	6.4 (163)	4.75 (120.6)	6.95 (176.5)	512
7	6.4 (163)	7.5 (190)	5.85 (148.6)	8.05 (204.5)	256

## APPENDIX B

## B.1 RECOMMENDED TRANSDUCERS FOR ZONED INSPECTION

## B.1.1 Recommended Transducers for 5 to 6 Inches (127 to 152 mm) Diameter

**Table B1**

Zone	Diameter Inches (mm)	Focal Length Axial Inches (mm)	Focal Length Circum. Inches (mm)	Focal Depth Inches (mm)
1	0.75 (19)	4.5 (114)	4.5 (114)	0.4 (10)
2	1.0 (25)	8.0 (203)	5.2 (132)	1.2 (30)
3	1.375 (34.92)	11.8 (300)	5.7 (145)	2.1 (53)
4	1.75 (44.4)	15.5 (394)	6.0 (152)	3.0 (76)

## B.1.2 Recommended Transducers for 7 to 8 Inches (178 to 203 mm) Diameter

**Table B2**

Zone	Diameter Inches (mm)	Focal Length Axial Inches (mm)	Focal Length Circum. Inches (mm)	Focal Depth Inches (mm)
1	0.75 (19)	4.5 (114)	4.5 (114)	0.4 (10)
2	1.0 (25)	8.4 (213)	5.7 (145)	1.3 (33)
3	1.375 (34.92)	12.2 (310)	6.3 (160)	2.2 (56)
4	1.75 (44.4)	15.9 (404)	6.7 (170)	3.1 (79)
5	2.35 (59.7)	19.7 (500)	7.0 (178)	4.0 (102)

## B.1.3 Recommended Transducers for 9 to 10 Inches (229 to 254 mm) Diameter

**Table B3**

Zone	Diameter Inches (mm)	Focal Length Axial Inches (mm)	Focal Length Circum. Inches (mm)	Focal Depth Inches (mm)
1	0.75 (19)	4.5 (114)	4.5 (114)	0.4 (10)
2	1.25 (31.8)	8.6 (218)	6.0 (152)	1.3 (33)
3	1.50 (38)	12.3 (312)	6.9 (175)	2.2 (56)
4	1.75 (44.4)	16.1 (409)	7.4 (188)	3.1 (79)
5	2.0 (51)	19.8 (503)	7.7 (196)	4.0 (102)
6	2.35 (59.7)	23.5 (597)	8.0 (203)	5.0 (127)

## B.1.4 Recommended Transducers for 12 to 13 Inches (305 to 330 mm) Diameter

**Table B4**

Zone	Diameter Inches (mm)	Focal Length Axial Inches (mm)	Focal Length Circum. Inches (mm)	Focal Depth Inches (mm)
1	0.75 (19)	5.4 (137)	5.4 (137)	0.4 (10)
2	1.0 (25)	9.8 (249)	7.0 (178)	1.5 (38)
3	1.375 (34.92)	13.9 (353)	8.1 (206)	2.5 (64)
4	1.75 (44.4)	18.1 (460)	8.9 (226)	3.5 (89)
5	2.35 (59.7)	22.3 (566)	9.3 (236)	4.5 (114)
6	2.35 (59.7)	26.4 (671)	9.7 (246)	5.5 (140)
7	2.35 (59.7)	30.6 (777)	10.0 (254)	6.5 (165)

## B.1.5 Recommended Transducers for 14 Inches (356 mm) Diameter

**Table B5**

Zone	Diameter Inches (mm)	Focal Length Axial Inches (mm)	Focal Length Circum. Inches (mm)	Focal Depth Inches (mm)
1	0.75 (19)	6.0 (152)	6.0 (152)	0.5 (13)
2	1.0 (25)	10.3 (262)	7.6 (193)	1.5 (38)
3	1.375 (34.92)	14.4 (366)	8.7 (221)	2.5 (64)
4	1.75 (44.4)	19.0 (483)	9.5 (241)	3.6 (91)
5	2.35 (59.7)	23.6 (599)	10.0 (254)	4.7 (119)
6	2.35 (59.7)	28.2 (716)	10.3 (262)	5.8 (147)
7	2.35 (59.7)	32.8 (833)	10.6 (269)	6.9 (175)

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APPENDIX C

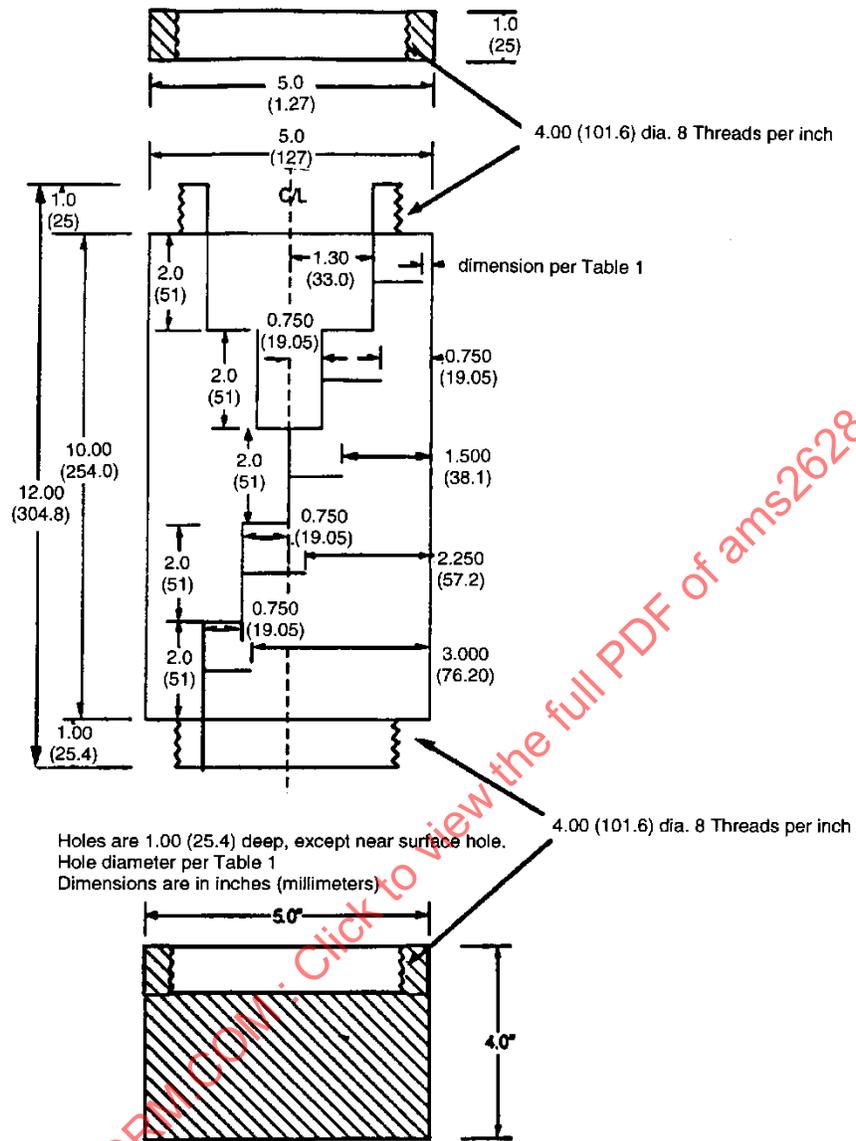


Figure C1 - Titanium calibration standard, 5 inches (127 mm) diameter

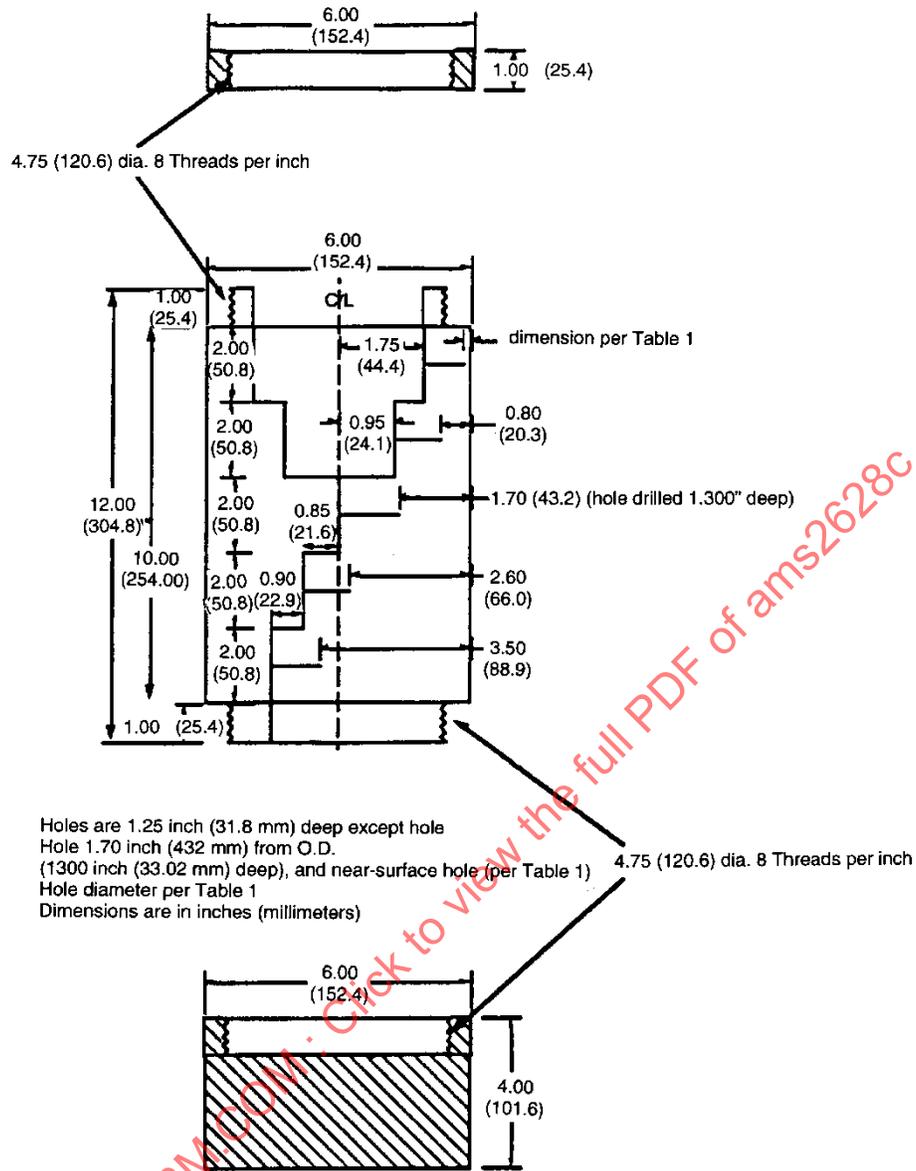


Figure C2 - Titanium calibration standard, 6 inches (152 mm) diameter

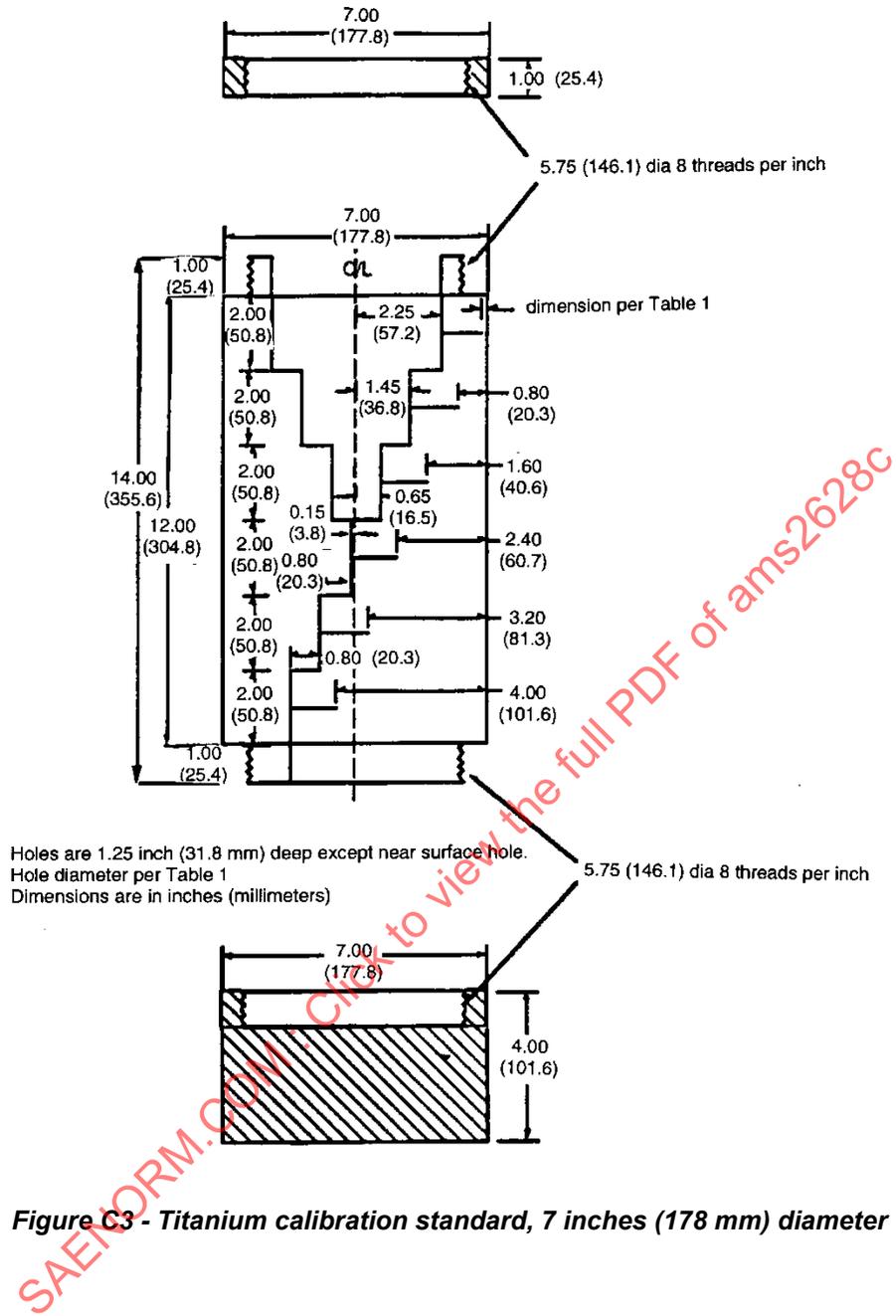


Figure C3 - Titanium calibration standard, 7 inches (178 mm) diameter

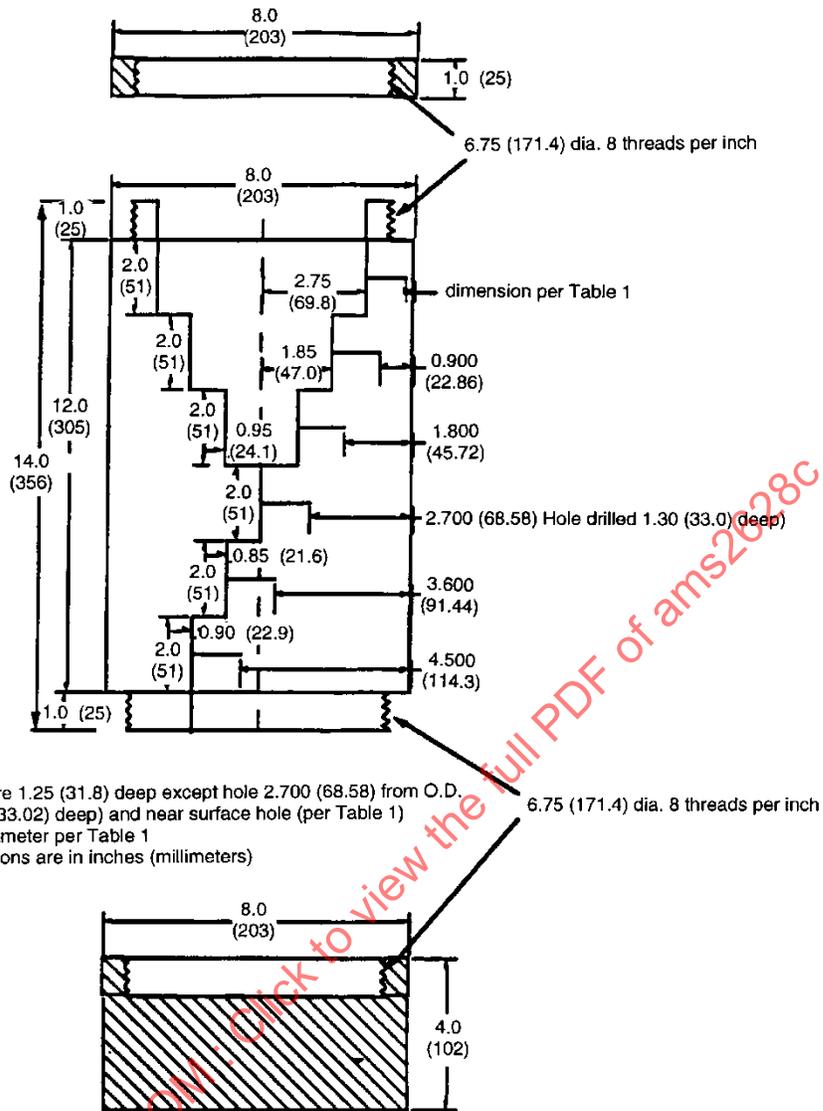


Figure C4 - Titanium calibration standard, 8 inches (203 mm) diameter

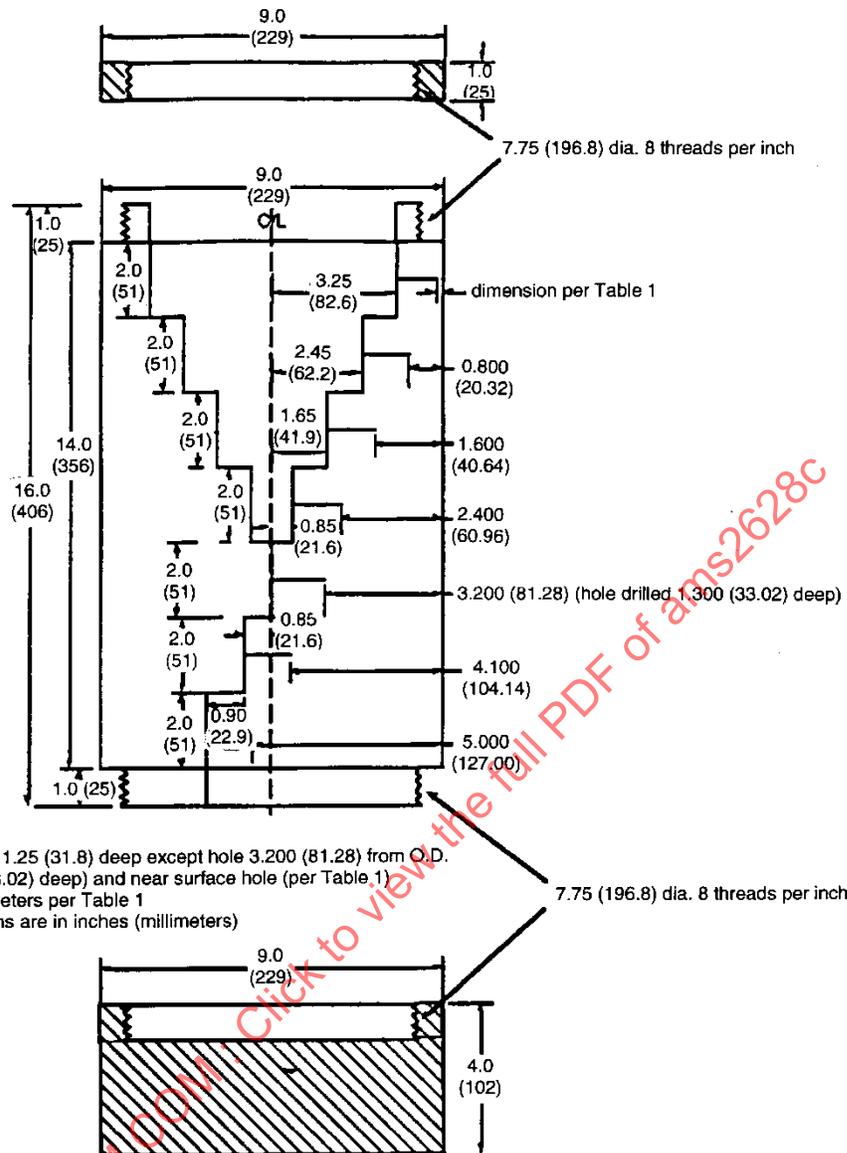


Figure C5 - Titanium calibration standard, 9 inches (229 mm) diameter