GB/T 5193—2020

(Replaces GB/T 5193—2007)

Method of ultrasonic inspection for wrought titanium and titanium alloy products

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Foreword

This document is drafted in accordance with the rules given in GB/T 1.1-2009.

This document replaces GB/T 5193-2007 Method of ultrasonic inspection for wrought titanium and titanium alloy products. In addition to editorial changes, the main technical changes compared with GB/T 5193-2007 are as follows:

--- The scope of application has been expanded from "cross-sectional thickness 6 mm to 230 mm" to "cross-sectional thickness 6 mm to 500 mm" (see Clause 1; Clause 1 of the 2007 edition);

--- The element "Principle" has been added (see Clause 3);

--- The element "Test conditions" has been added (see Clause 4);

--- The requirement for inspection personnel has been supplemented with "technical qualification training and qualification certification in accordance with the relevant requirements of GB/T 9445 or corresponding standards" (see 4.2; 3.3 of the 2007 edition);

--- The requirement that "pulse-reflection ultrasonic flaw detectors shall be capable of producing, receiving and displaying high-frequency electrical pulses satisfying the required frequency and sensitivity, and shall operate over bandwidths of 2.25 MHz to 10 MHz and 1 MHz to 20 MHz" has been added (see 5.1; 4.1 of the 2007 edition);

--- The working frequency of search units and the recommended products to be inspected have been modified (see 5.2; 4.2 of the 2007 edition);

--- The preferred diameter of water-immersed focusing straight-beam search units has been changed from "φ6 mm ~ φ45 mm" to "φ6 mm ~ φ80 mm" (see 5.2; 3.2 of the 2007 edition);

--- The requirement for the inspection system has been added (see 5.4);

--- The requirements for reference blocks and the flat-bottom hole reflection sensitivity have been modified (see Clause 7 and Table 2; Clause 5 and Table 1 of the 2007 edition);

--- A note has been added: for products larger than 120 mm, when zone water-immersion testing is performed, the longitudinal-wave calibration reflectors may be determined by zone number (see Table 2 and Appendix B);

--- The artificial reflector types for shear-wave test blocks have been added (see 7.6);

--- When the metal path is greater than or equal to three times the near-field distance, the large flat-bottom hole calculation method may be used to adjust the testing sensitivity, and the adjustment method has been specified (see 8.2);

--- The requirements for the artificial signal amplitude and the variation range of the water-immersion beam incidence angle have been modified (see 8.2 and 8.4b); 6.1 and 6.2 of the 2007 edition);

--- The requirements for inspection spacing and the effective beam diameter measurement method have been modified (see 8.3 and 8.4e; 6.9.1 of the 2007 edition);

--- The background noise requirement has been modified (see 8.7; 6.4 of the 2007 edition);

--- The recommended inspection zones, search units and water path for zone testing of bars have been added (see 8.12 and Appendix C);

--- The sensitivity calibration requirements have been modified (see 8.13; 6.1.2 of the 2007 edition);

--- The notes in the acceptance grade table have been deleted (see Table 3 of the 2007 edition);

--- The external dimensions and tolerances of the longitudinal-wave reference blocks have been modified (see Appendix A; Appendix A of the 2007 edition);

--- The depth of artificial reflectors in reference blocks for zone testing has been added (see Appendix B).

This document is proposed by and under the jurisdiction of the China Nonferrous Metals Industry Association.

This document was drafted by the National Technical Committee 243 on Nonferrous Metals of Standardization Administration of China (SAC/TC 243).

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The previous editions of this document that have been replaced are as follows:

--- GB/T 5193-1985; GB/T 5193-2007.

Method of ultrasonic inspection for wrought titanium and titanium alloy products

1 Scope

This document specifies the principle, test conditions, instruments and equipment, test pieces, reference blocks, test procedures, evaluation of test results, test records and report for ultrasonic inspection of wrought titanium and titanium alloy products.

This document applies to ultrasonic inspection of wrought titanium and titanium alloy products with a cross-sectional thickness of 6 mm to 500 mm. Products of other specifications may be inspected by reference to this document.

2 Normative references

The following documents are indispensable for the application of this document. For the dated references, only the edition cited applies. For the undated references, the latest edition of the referenced document (including any amendments) applies.

GB/T 9445 Non-destructive testing — Qualification and certification of NDT personnel

JB/T 10061 General technical conditions for A-type pulse-reflection ultrasonic flaw detectors

3 Principle

Ultrasonic waves generated by the sound source propagate into the test piece in a certain direction and at a certain velocity. When encountering interfaces with different acoustic impedance on both sides, part of the sound wave is reflected. The reflected ultrasonic waves are received by the inspection equipment and processed and analyzed to evaluate whether there are defects in the test piece and the characteristics of the defects. This document is mainly used to detect internal defects in wrought titanium and titanium alloy products, such as cracks, porosity, porosity and other discontinuities in the exposed or unexposed-to-surface structure.

4 Test conditions

4.1 The working area shall be free from strong electromagnetic interference and kept clean. Dust and foreign impurities shall be avoided from contaminating and damaging the inspection conditions.

4.2 Inspection personnel shall receive technical qualification training and obtain Level 1 or above NDT personnel qualification in accordance with the relevant requirements of GB/T 9445 or corresponding standards. Personnel who issue and interpret inspection reports shall hold Level 2 or above NDT personnel qualification.

5 Instruments and equipment

5.1 Flaw detector

The pulse-reflection ultrasonic flaw detector shall be capable of producing, receiving and displaying high-frequency electrical pulses satisfying the required frequency and sensitivity, and shall operate over bandwidths of 2.25 MHz to 10 MHz and 1 MHz to 20 MHz. Gates, distance-amplitude correction curves, alarm systems, recorders and other electronic auxiliary equipment for detection and processing may be used as needed, and their performance shall meet the requirements of JB/T 10061.

5.2 Search units

The applicable inspection methods and recommended products to be inspected for search units are given in Table 1.

Table 1 Search units, recommended products and inspection methods

Search unit type	Search unit diameter mm	Search unit frequency MHz	Inspection method	Recommended products
Straight beam	12~32	2.0~5.0	Water-immersion or contact testing	Flat products with thickness 20 mm~500 mm; Round products with diameter 70 mm~500 mm
Focused search unit	6~20	5.0~15.0	Water-immersion testing	Flat products with thickness 6 mm~80 mm; Round products with diameter 6 mm~80 mm
Focused search unit	12~60	5.0~15.0	Water-immersion testing	Flat products with thickness 80 mm~500 mm; Round products with diameter 80 mm~500 mm
Dual-element search unit	8~10	2.5~5.0	Contact testing	Flat products with thickness 6 mm~20 mm
Note a: When agreed by both supplier and customer, search				

units with frequencies lower than 2.0 MHz or special shapes may be used. Note b: For round products with diameter 6 mm~80 mm, water-immersion focusing type is recommended.				

5.3 Couplants

5.3.1 For water-immersion testing, water may be used as the couplant. A wetting agent may be added to the water. The water shall be free of visible air bubbles or other suspended matter that would interfere with the ultrasonic inspection.

5.3.2 For contact testing, water, machine oil, glycerin, transformer oil, water glass and other couplants may be used.

5.4 Inspection system

For automated water-immersion testing, the inspection system shall ensure that the variation of the water path during the inspection process does not exceed ±6 mm; the variation range of the incidence angle does not exceed ±1°; and the deviation of repeated testing of the same regular reflector does not exceed ±1.5 dB.

6 Test pieces

6.1 The surface roughness of the product to be inspected shall be $Ra \leq 3.2$ μm. If machining is required, the surface may be machined with a round-nose tool, ground or polished. The surface shall be free of machining or grinding particles, oil, grease, cutting fluid mixture. For products with higher inspection requirements, higher surface roughness requirements may be required.

6.2 The product to be inspected shall have a normal geometric cross-section, such as round, square, polygonal, etc. Flat products shall ensure the flatness of all surfaces.

7 Reference blocks

7.1 The reference block shall be made of titanium and titanium alloy materials with the same or similar acoustic properties and surface condition as the product to be inspected. The difference in sound transmission characteristics between the two shall be within 12 dB. If the sound transmission characteristic difference is less than or equal to 12 dB, the instrument sensitivity shall be increased during inspection to compensate for the sound transmission

characteristic difference. If the sound transmission characteristic difference is greater than 12 dB, the reference block shall be replaced with one that meets the requirements.

7.2 When inspecting flat products, flat test blocks shall be used. The machining technical conditions of the reference blocks shall comply with the provisions of Appendix A.

7.3 When inspecting curved products, reference blocks with the same geometric shape shall be used. The difference shall not exceed ±20% of the curvature radius of the product to be inspected. Small-diameter bars shall be made of bar stock with the same or similar curvature radius. For round bars above 120 mm, reference blocks for zone testing may be made with reference to Appendix B.

7.4 The surface roughness of the reference block shall be similar to that of the product to be inspected.

7.5 For longitudinal-wave calibration, the reflector shall be a flat-bottom hole. Its buried depth shall be determined according to the product shape and cross-sectional thickness "T" and the values in Table 2.

Table 2 Buried depth of flat-bottom holes

Unit: millimeters

Product to be inspected	Range	Flat-bottom hole buried depth
Round product diameter	6~13	1/2T, T-3
	>13~50	1/2T, 6
	>50~130	1/2T, 1/4T, 6
	>130~500	1/2T, 1/4T, 1/8T, 10
Flat product thickness	6~13	1/2T
	>13~50	T-5, 1/2T, 6
	>50~130	T-10, 1/2T, 6
	>130~250	1/2T, 1/4T, 1/8T, 10
	>250~500	1/2T, 1/4T, 1/8T, T-10
Note: For products with diameter or thickness greater than 120 mm, when zone water-immersion testing is performed, the longitudinal-wave calibration reflectors may be determined by zone number. See Appendix B.		

7.6 For shear-wave calibration, the reflector may be a flat-bottom hole, transverse hole or groove. The specific type and dimensions of the artificial reflector shall be determined by both parties through negotiation.

8 Test procedures

8.1 Generally, longitudinal wave method shall be used for inspection. If necessary, shear wave or other wave types may be adopted through negotiation between the supplier and customer.

8.2 Before inspection, appropriate reference blocks shall be used to calibrate the instrument so that the reflected signal amplitude of the artificial defect in the test block is within 40%~80% of the full screen height, to ensure that the inspected product can be inspected in accordance with the standard requirements. When the metal path is greater than or equal to three times the near-field distance, the large flat-bottom hole calculation method may be used to adjust the testing sensitivity. When using the large flat-bottom hole calculation method to adjust the testing sensitivity, calculate the gain ΔdB according to formula (1), then move the bottom wave of a good part of the workpiece to the selected reference baseline and gain ΔdB on this basis.

$$\Delta dB = 20\lg(\pi\Phi^2 / 2\lambda X) \quad \text{..... (1)}$$

Where:

ΔdB —— gain value to be increased, in decibels (dB);

Φ —— acceptance equivalent flat-bottom hole diameter, in millimeters (mm);

λ —— ultrasonic wavelength in the test piece, in millimeters (mm);

X —— test piece thickness, in millimeters (mm).

8.3 When using a flat-bottom hole with small buried depth to adjust the instrument gain to an appropriate position, after the flat-bottom hole echo amplitude reaches a certain height, move the search unit in the scanning direction. The distance between the search unit movements when the wave height drops to 50% of the original wave height is the effective beam diameter.

8.4 Water-immersion testing shall meet the following requirements:

a) For water-immersion calibration and inspection, the water temperature, reference block and inspected product shall be allowed sufficient time to reach temperature stability.

b) For longitudinal-wave inspection, adjust the incident angle so that the reflected signal amplitude is maximized, so that the longitudinal wave is perpendicular to the incident surface. During inspection, the determined angle variation shall meet the requirements of 5.4.

c) The pulse repetition frequency shall not be lower than 600 Hz.

d) The optimal water path shall be selected according to the metal path of the search unit and the inspection. The variation of the water path during inspection shall meet the requirements of 5.4.

e) The inspection spacing shall not be greater than 70% of the effective beam diameter.

f) For distance-amplitude correction, electronic distance-amplitude correction method is recommended. If the minimum echo signal amplitude is not lower than 20%, the distance-amplitude curve displayed on the fluorescent screen may also be used. This curve is drawn using a distance-amplitude calibration block. When the noise level does not obscure the required reflected signal, the highest sensitivity of the distance-amplitude calibration block may be used for inspection, and appropriate metal path correction shall be performed.

8.5 Contact testing shall meet the following requirements:

a) For contact testing and calibration, good coupling shall be ensured.

b) The inspection spacing shall not be greater than 50% of the search unit crystal diameter or 50% of the effective beam diameter, whichever is smaller.

8.6 The measurement of bottom echo loss shall be performed on surfaces where the inspected products are parallel to each other.

8.7 The allowable background noise shall not exceed 50% of the reflected height of the reference flat-bottom hole in the reference block. If the background noise exceeds the reference level, the involved cross-section shall be re-inspected comprehensively to ensure that the product meets the specified requirements.

8.8 The scanning speed during inspection shall not be greater than the scanning speed that can distinguish the flat-bottom hole in the reference block. For manual scanning of products without alarm system, the recommended scanning speed shall not be greater than 127 mm/s. For manual or automatic scanning of products with alarm system, the recommended scanning speed shall not be greater than 500 mm/s.

8.9 The parameters determined at the instrument control knob setting position and during calibration shall not be changed during the product inspection period. The control of pulse width shall not affect the vertical linearity of the instrument and shall provide appropriate resolution.

8.10 The inspection surface shall comply with the provisions of Table 3.

Table 3 Inspection surfaces

Product to be inspected	Inspection surface a
Bar	Entire circumference
Forging billet	All surfaces except end faces
Plate	Double surface or single surface
Forgings and extruded profiles	Surface inspection as required by drawings and order
Note a: If shear wave or refracted wave is used to inspect the adjacent surface, all flat products may be inspected from one side or both sides. These inspections, calibration and calibration parameters shall be decided by both parties through negotiation.	

8.11 For water-immersion or contact testing, zone inspection may be performed. In this case, each zone shall be calibrated separately.

8.12 For zone water-immersion testing, each inspection zone shall contain at least two flat-bottom holes with buried depths at the start and end of the inspection zone. During inspection, the gate range of each zone shall be extended by 10 mm to both ends (except for the first zone). The recommended inspection zones, search units and water paths for some standard bars are given in Appendix C.

8.13 Before each inspection, after inspection and after continuous work for 2 hours, a sensitivity calibration check shall be performed. If there is a permanent stability record (C-scan or A-scan), the calibration interval may be extended to 8 hours. If the equipment status changes during the inspection, the equipment shall be recalibrated immediately and the product inspected since the last calibration shall be re-inspected. If the sensitivity is found to be lower than the original inspection sensitivity by 1.5 dB, all products inspected since the last calibration shall be re-inspected; if the sensitivity is found to be higher than the original inspection sensitivity by 2 dB, the products in which defects were found since the last calibration shall be re-inspected.

9 Evaluation of test results

9.1 The ultrasonic quality requirements for longitudinal-wave inspection are divided into four grades according to Table 4. The applicable grade shall be specified in the material product standard or order.

Table 4 Ultrasonic quality requirements for longitudinal-wave inspection

Grade	Equivalent diameter of single discontinuity / mm
AA	0.8
A1	1.2
A	2.0
B	3.2

9.2 The reflected signal of any discontinuity shall not be greater than the reflected signal of the reference flat-bottom hole at the same depth as the discontinuity.

9.3 When checking the bottom echo loss, when compared with the same or similar same-type non-defective product, if a non-saturated bottom echo loss greater than 50% occurs, and at the same time, the signal increases between the incident surface and the bottom surface (at least twice the normal background noise signal), the product is unacceptable.

9.4 The noise level exceeding the requirements of 8.7 is unacceptable.

9.5 If it is evaluated that the reflected signal exceeds the specified standard, but the defects can be eliminated during the manufacturing process, such products may be determined by the supplier and customer through negotiation.

9.6 When special reference blocks are used or inspection is performed at grades not listed in Table 4, the acceptance criteria shall be determined by both parties through negotiation.

10 Test records and report

10.1 The inspection record shall include at least the following main contents:

a) Workpiece name, material, heat number, batch number, specification, material grade;

b) This document number and grade;

c) Inspection instrument model, search unit frequency, search unit crystal size, focusing type, etc.;

d) Reference hole diameter, buried depth;

e) Couplant;

f) Inspection scanning sensitivity, defect location and defect indication length, echo height and other detection results;

g) Inspection date, inspection personnel signature, etc.

10.2 The inspection report shall include the appropriate contents of the inspection record and the signature of the issuing reporter.

Appendix A
(Normative)
Requirements for reference blocks

The dimensional tolerance requirements for the machined reference block are shown in Figure A.1.

Unit: millimeters

[Figure A.1 External dimensions and tolerances of longitudinal-wave reference block]

Description:

H —— metal path;

L —— reference block height;

D —— cylindrical outer diameter. When D is 50 mm, it is suitable for the depth range of inspection less than 150 mm; when D is 64 mm, it is suitable for the depth range of 150 mm to 230 mm;

Φ —— flat-bottom hole diameter. Φ ≤ 1.6 mm, tolerance ±0.013 mm; Φ > 1.6 mm, tolerance ±0.03 mm.

Surface roughness: upper and lower surfaces ≤ 1.6 μm, cylindrical surface ≤ 3.2 μm.

Figure A.1 External dimensions and tolerances of longitudinal-wave reference block

Appendix B
(Informative)
Depth of artificial reflectors in reference bars for zone testing

The depth of artificial reflectors in partial specification bars for zone testing is shown in Table B.1.

Table B.1 Depth of artificial reflectors in partial specification bars for zone testing

Unit: millimeters

Sample bar diameter φ	Flat-bottom hole buried depth B
127	5;19;38;57;76
152	5;20;43;66;89
178	5;20;41;61;81;102
203	5;23;46;69;91;114
229	5;20;41;61;81;104;127
254	5;23;46;69;91;114;140
305	5;23;46;69;91;114;140;165
330	5;25;51;76;102;127;152;178
356	5;25;51;79;107;135;163;190
500	5;25;51;76;102;127;152;178;255

Appendix C
(Informative)
Zone testing areas, search units and water path

The zone testing areas, search units and water path are shown in Table C.1.

Table C.1 Zone testing areas, search units and water path

Unit: millimeters

Specification	Water path	Zone No.	Zone start	Zone end	Diameter	Axial focal length	Circumferential focal length / Depth of focus
127	89	1	5	19	19	114	114 / 10
		2	19	38	25	203	132 / 31
		3	38	57	35	300	145 / 53
		4	57	76	45	394	152 / 76
152	76	1	5	20	19	114	114 / 10
		2	20	43	25	203	132 / 31
		3	43	66	35	300	145 / 53
		4	66	89	45	394	152 / 76
178	89	1	5	20	19	114	114 / 10
		2	20	41	25	213	145 / 33
		3	41	61	35	310	160 / 56
		4	61	81	45	404	170 / 79
		5	81	102	60	500	178 / 102
203	76	1	5	23	19	114	114 / 10
		2	23	46	25	213	145 / 33
		3	46	69	35	310	160 / 56
		4	69	91	45	404	170 / 79
		5	91	114	60	500	178 / 102
229	89	1	5	20	19	114	114 / 10
		2	20	41	32	218	152 / 33
		3	41	61	38	312	175 / 56
		4	61	81	45	409	188 / 79
		5	81	104	51	503	196 / 102
		6	104	127	60	597	203 / 127
254	76	1	5	23	19	114	114 / 10
		2	23	46	32	218	152 / 33
		3	46	69	38	312	175 / 56
		4	69	91	45	409	188 / 79
		5	91	114	51	503	196 / 102
		6	114	140	60	597	203 / 127
305	102	1	5	23	19	137	137 / 10
		2	23	46	25	249	178 / 38

		3	46	69	35	353	206 / 64
		4	69	91	45	460	226 / 89
		5	91	114	60	566	236 / 114
		6	114	140	60	671	246 / 140
		7	140	165	60	777	254 / 165
330	89	1	5	25	19	137	137 / 10
		2	25	51	25	249	178 / 38
		3	51	76	35	353	206 / 64
		4	76	102	45	460	226 / 89
		5	102	127	60	566	236 / 114
		6	127	152	60	671	246 / 140
		7	152	178	60	777	254 / 165
356	102	1	5	25	19	152	152 / 13
		2	25	51	25	262	193 / 38
		3	51	79	35	366	221 / 64
		4	79	107	44	483	241 / 91
		5	107	135	60	599	254 / 119
		6	135	163	60	716	262 / 147
		7	163	190	60	833	269 / 175