超声波探伤作业指导书

SOP of UT (Ultrasonic Testing)

1 目的

1 Purpose

使超声波探伤人员能够掌握探伤的各作业程序，确保超声波探伤结果的准确性、符合性。

To help UT operators master the operation procedures and guarantee the accuracy and conformity of UT results.

2 范围

2 Scope of Application

适用于公司所有经锻造的法兰、锻件的超声波检测；适用于 PXUT-240B,PXUT-320C 型等 A 型脉冲反射式超声波探伤仪。

Applicable to UT of forged flanges and pieces made by the Company, as well as Type A pulse reflection ultrasonic fault detector, such as PXUT-240B and PXUT-320C.

3 引用标准

3 Normative References

NB/T47013.3 承压设备无损检测　第 3 部分 超声检测

NB/T47013.3 Nondestructive Testing of Pressure Equipments - Part 3: Ultrasonic Testing

EN10228-3 锻钢件无损检测第 3 部分 铁素体、马氏体钢锻件超声波检测

EN10228-3 Non-destructive Testing of Steel Forgings - Part 3: Ultrasonic Testing of Ferritic or Martensitic Steel Forgings

BS EN10228-4 锻钢件无损检测第 4 部分 奥氏体钢和奥氏体钢-铁素体不锈钢锻件超声波检验

BS EN10228-4 Non-destructive Testing of Steel Forgings – Part 4: Austenitic Steel: Ultrasonic Testing of Ferritic Stainless Steel Forgings

BS EN473 无损检测检验人员的资格鉴定和认证—— 一般规则

BS EN473 Qualification and Certification of NDT Personnel- General Principles

ASTM A388/A388M 大型钢锻件超声检测标准

ASTM A388/A388M Ultrasonic Testing Standard of Large Steel Forgings

ASTM A745/A745M 奥氏体钢锻件超声波检验

ASTM A745/A745M Ultrasonic Examination of Austenitic Steel Forgings

注：如客户需按另外的标准检测时，则客户指定的探伤标准探伤并验收，但需经探伤人员的确认。

Note: The testing standards designated by customer should be prioritized in testing and acceptance once such standards are confirmed and accepted by the testing personnel.

4 术语和定义

4 Terms and Definitions

GB/T12604.1 和 NB/T47013.1 界定的以及下列术语和定义。

Those defined in GB/T12604.1 and NB/T47013.1 and the following terms and definitions:

4.1 底波降低量 BG/BF

4.1 Decrease of bottom wave BG/BF

锻件检测时，在靠近缺陷处的完好区域内第一次底面回波波幅 BG 于缺陷区域内的第一次底面回波波幅 BF 的比值，用 dB 值来表示。

The ratio between the first bottom wave amplitude BG in intact area close to defect and the first bottom wave amplitude BF in defective area when testing the forged piece, represented by dB.

4.2 密集区缺陷

4.2 Defect of dense area

锻件检测时，在显示屏扫描线上相当于 50mm 声程范围内同时有 5 个或 5 个以上的缺陷反射信号，或是在 50mm*50mm 的检测面上发现在同一深度范围内有 5 个或 5 个以上的缺陷反射信号，其反射波幅均大于某一特定当量空直径额缺陷。

There are 5 or more defective reflection signals in the 50mm acoustic distance range on the display scanning line, or there are 5 or more defective reflection signals in the same depth range on the testing surface sized 50mm*50mm when testing the forged piece. The reflection amplitude is higher than the empty diameter defect of specific equivalent.

4.3 基准灵敏度

4.3 Reference sensitivity

将对比试块人工反射体回波高度或被检工件底面回波高度调整到某一基准时的灵敏度。

Adjust the echo height of artificial reflector of reference block or bottom echo height of workpiece under test to the

sensitivity of certain benchmark.

4.4 扫查灵敏度

4.4 Scanning sensitivity

在基准灵敏度的基础上，根据表面状况、检测缺陷要求及探头类型等适当提高 dB 数（增益）进行实际检测的灵敏度。

On basis of reference sensitivity, increase the dB (gain) properly to the actual testing sensitivity based on the surface condition, defect testing requirements and probe type.

4.5 缺陷自身高度

4.5 Defect height

缺陷在工件厚度方向的尺寸。

Dimensions of defect at the direction of workpiece thickness

4.6 回波动态波形

4.6 Echo dynamic waveform

探头移动距离与相应缺陷反射体回波波幅变化的包络线。

The envelope line between probe movement distance and echo amplitude change of defective reflector

4.7 工件厚度

4.7 Workpiece thickness

即锻件检测方向厚度。

The thickness at the testing direction of forged piece

5 人员：

5 Testing personnel:

5.1 超声波检测人员应具有 II 级或III级资格证书，并负责出具检测报告，并对报告的正确性负责。

5.1 UT personnel should hold Class II or III qualification certificates, issue the test report and bear liabilities for the correctness of report.

5.2 超声波检测人员应具有一定的金属材料、设备制造安装、焊接及热处理等方面的基本知识，应熟悉被检工件的材质、几何尺寸及透声性，对检测中出现的问题才能做出分析、判断和处理。

5.2 UT personnel should have the basic knowledge about metal materials, equipment manufacturing, installation,

welding and thermal treatment, master the material, dimensions and acoustic transmission property of workpiece under test, and be capable of analyzing, judging and handling the issues in test.

6 超声检测仪器

6 UT Instruments

6.1 探伤仪

6.1 Flaw detector

探伤仪应符合为 A 型脉冲反射式探伤仪，必须经过专门检验机构检定，并在有效期内使用。

Type A pulse reflection detector used should be within valid period and pass the inspection of specific testing institute.

6.2 探头

6.2 Probe

6.2.1 直探头

6.2.1 Straight probe

6.2.1.1 探头标称频率应在 1MHz～5MHz 范围内。

6.2.1.1 Nominal frequency of probe should be within 1MHz~5MHz.

6.2.1.2 双晶直探头晶片面积不小于 150mm^2;单晶直探头晶片有效直径应在为 φ10mm～40mm 范围内。

6.2.1.2 The crystal area of double-crystal straight probe should not be lower than 150 mm^2; the effective diameter of crystal of single-crystal straight probe should be within φ10 mm~40 mm.

6.2.2 斜探头

6.2.2 Angle probe

6.2.2.1 探头有被检工件应保持良好的接触，遇有一下情况时，应采取曲面试块调节检测范围和基准灵敏度：

6.2.2.1 The probe should have good contact with the workpiece under test. The test range and reference sensitivity should be adjusted by using curved-surface block in any of the following cases:

a) 在凸表面上纵向（轴向）扫查时，探头楔块宽度大于检测面曲率半径的 1/5；

a) The width of probe wedge should be over 1/5 of curvature radius of testing surface when doing longitudinal (horizontal) scanning on the convex surface;

b）在凸表面上横向（周向）扫查时，探头楔块长度大于检测面曲率半径的 1/5。

b) The length of probe wedge should be over 1/5 of curvature radius of testing surface when doing horizontal (circumferential) scanning on the convex surface.

6.2.2.2 探头标称频率主要为 2MHz~5MHz 之间，探头晶片面积为 80mm^2~625 mm^2。

6.2.2.2 The nominal frequency of probe is 2MHz~5MHz and probe crystal is sized 80mm^2~625 mm^2.

6.2.2.3 原则上应采用折射角 45°（K1）的探头，但根据工件几何形状和内外径比例的不同，也可采用其他的折射角（K 值）探头。

6.2.2.3 The probe with refraction angle of 45° (K1) should be used in principle, but the probes with other refraction angles can be selected depending on the shapes and ratio of inner and outer diameter.

6.3 对比试块

6.3 Reference block

6.3.1 单晶直探头检测采用 CS-2 试块调节基准灵敏度，如确有需要也可以采用其他对比试块。

6.3.1 Reference sensitivity of single-crystal straight probe is adjusted via Block CS-2, or other reference blocks can be used as needed.

6.3.2 双晶直探头对比试块，当工件厚度小于 45mm 时，应采用 CS-3 对比试块。

6.3.2 Reference Block CS-3 should be used for adjusting reference sensitivity of double-crystal straight probe when workpiece thickness is lower than 45mm.

6.3.3 斜探头对比试块，为了调整灵敏度，可利用被检工件壁厚或长度上的加工余量部分制作对比试块。在锻件的内外表面，分别沿轴向和周向加工平行的 V 形槽作为标准沟槽。V 形槽长度为 25mm,深度为锻件壁厚的 1%，角度为 60°。也可采用其他等效的反射体（如边角反射等）。

6.3.3 The margin part at the thickness or length direction of workpiece under test can be prepared into reference block of angle probe for adjusting the sensitivity. The axial and circumferential V-slot at the inner/outer surface of forged piece should be used as standard slot. The V-slot is 25mm long, with depth up to 1% of wall thickness of forged piece and angle of 60°. Other equivalent reflectors (such as corner reflection) can also be used.

7 灵敏度的确定

7 Determination of Sensitivity

7.1 单晶直探头基准灵敏度的确定

7.1 Determination of reference sensitivity of single-crystal straight probe

使用 CS-2 或 CS-4 试块，依次测试一组不同检测距离的 φ2mm 平底孔（至少 3 个），制作单晶直探头的距离-波幅曲线，并以此作为基准灵敏度。当被检部位的厚度大于或等于探头的 3 倍近场区长度，且检测面于底面平行时，也可以采用底波计算法确定基准灵敏度。

Test 1 group of φ2 mm flat-bottom holes (at least 3) by using Test Block CS-2 or CS-4 respectively, prepare the distance – amplitude curve of single-crystal straight probe and take it as the reference sensitivity. The reference sensitivity can also be determined via bottom wave calculation method if thickness of testing position is higher than or equal to 3 times that of length of near-field region and the testing surface is in parallel with the bottom surface.

7.2 双晶直探头基准灵敏度的确定

7.2 Determination of reference sensitivity of double-crystal straight probe

使用 CS-3 试块，依次测试一组不同检测距离的 φ2mm 平底孔（至少 3 个）。制作双晶直探头的距离-波幅曲线，并以此作为基准灵敏度。

Test 1 group of φ2mm flat-bottom holes (at least 3) by using Test Block CS-3, prepare the distance – amplitude curve of double-crystal straight probe and take it as the reference sensitivity.

7.3 斜探头基准灵敏度的确定

7.3 Determination of reference sensitivity of angle probe

从锻件外圆面将探头对准内圆面的标准沟槽，调整增益，使最大反射高度为满刻度的 80%，将该值标在面板上，以其为扫查灵敏度;不改变仪器的调整状态，再移动探头测定外圆面的标准沟槽，并将最大的反射高度也标在面板上。将上述两点用直线链接并延长，绘出距离-波幅曲线，并使之包括全部检测范围。内圆面检测时扫查灵敏度也按上述方法确定，但探头斜楔应与内圆曲率一致。

Align the probe from outer circular surface of forged piece to the standard slot of inner circular surface, adjust the gain until the max. reflection height reaches 80% of full scale, mark this value on the panel as the scanning sensitivity; Move the probe to measure the standard slot of outer circular surface without changing the adjustment status of instrument, and mark the max. reflection height on the panel. Connect the two points above and prolong it, draw the distance – amplitude curve and cover all range of testing. When testing the inner circular surface, the scanning sensitivity can also be determined according to the method above, but the probe wedge should be consistent with the curvature of inner circle.

7.4 扫查灵敏度一般应比基准灵敏度高 6dB。

7.4 Scanning sensitivity should be 6 dB higher than the reference sensitivity.

8 检测

8 Testing

8.1 检测前应由检验员填写书面申请单，应写明构件名称、厚度、材料牌号、探伤标准及验收标准。

8.1 The testing personnel should fill the written applicant and write the component name, thickness, material designation, testing standard and acceptance standard before start of testing.

8.2 检测表面状态

8.2 Status of testing surface

扫查表面应无油漆、氧化皮，干耦合剂、凸凹不平或其他任何能降低耦合效果、妨碍探头自由运动或导致错误结论的物质，检查表面应有足够均匀的轮廓和平滑度，以保持较好的声耦合。表面粗糙度不大于 6.3um.

The scanning surface should be free from paint, scale, dry coupling agent, rough and uneven surface or any other substance can may weaken the coupling effects, affect free movement of probe or lead to wrong conclusion. Besides, the testing surface should have sufficient outline and smoothness to maintain good acoustical coupling. The surface roughness should not be over 6.3 um.

8.3 耦合

8.3 Coupling

耦合方式一般可采用直接接触法，耦合剂可用机油作为耦合，检测完毕，必须清除耦合剂。

Direct contact method can be used as general coupling. Engine oil can be used for coupling of coupling agent and such agent must be removed once testing is done.

8.4 扫查方式

8.4 Scanning mode

8.4.1 栅格扫查

8.4.1 Grid scanning

栅格扫查要让探头沿着来回移动。

The probe is moving constantly during grid scanning.

Fig. 1 Fig. 2

8.4.2 直探头扫查（图 1）

8.4.2 Scanning of straight probe (Fig. 1)

扫查沿一侧表面和外周表面方格栅格线扫查，栅格线间距应等于法兰厚度，最大 200mm.

Do scanning of grid line at the one surface and periphery surface and the spacing of grid line, which should be equal to flange thickness, should be 200mm as the maximum.

8.4.3 斜探头扫查（图 2）

8.4.3 Scanning of angle probe (Fig. 2)

扫查沿一侧表面和外周表面方格栅格线扫查，栅格线间距应等于径向厚度，最大 200mm.

Do scanning of grid line at the one surface and periphery surface and the spacing of grid line, which should be equal to radial thickness, should be 200mm as the maximum.

8.4.4 扫查速度

8.4.4 Scanning speed

手工扫查速度不超过 150mm/秒。

Manual scanning speed should not exceed 150mm/s.

8.5 检测时机

8.5 Scanning time

超声波检验应在最终性能热处理后，或在所要求的超声波检验能够进行的最后制造阶段时间。

UT should be carried out after the final performance and thermal treatment, or in the final manufacturing stage as required.

注：对于要打中心孔的圆柱锻件和矩形锻件，建议打中心孔前进行超声波探伤。

Note: It is recommended to carry out UT before drilling of central holes (if any) of cylinder forged pieces and rectangular forged pieces.

8.6 波形显示分类：

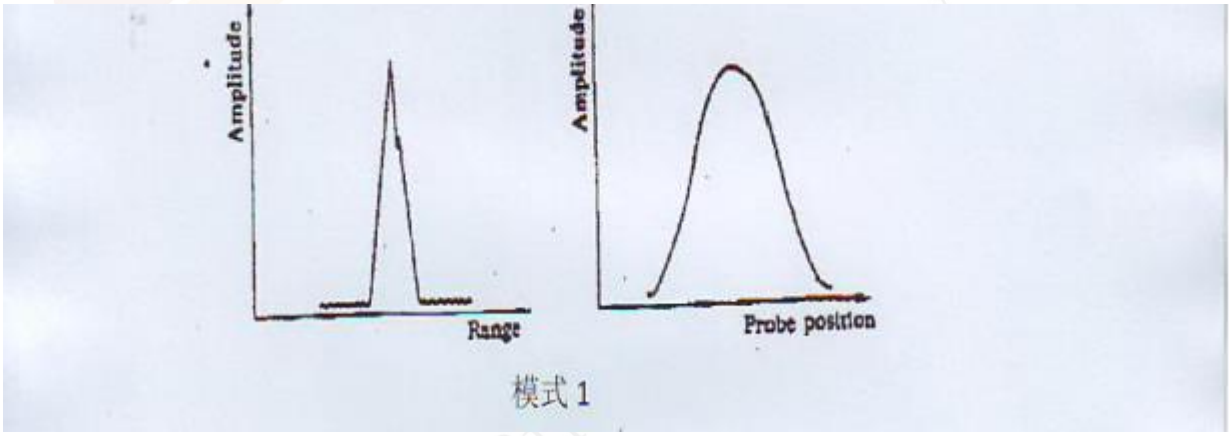
8.6 Classification of waveform display:

8.6.1 模式 1

8.6.1 Mode 1

A 扫描显示明显的单个波峰，随着探头的移动，波幅均匀的上升到最高点后又均匀的回落到零。

Scanning A shows the obvious single wave crest. As probe moves, the waveform increases evenly to the top point and then falls to zero point evenly.



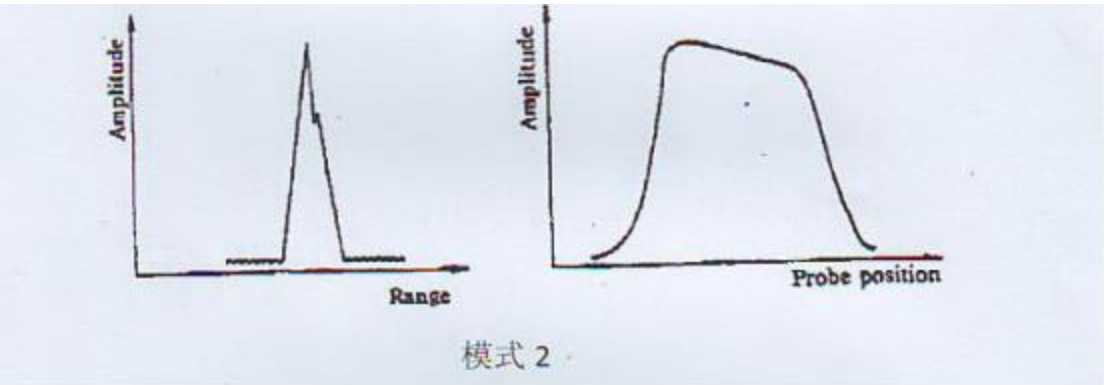
Mode 1

8.6.2 模式 2

8.6.2 Mode 2

A 扫描显示明显的单个波峰，随着探头的移动，波幅均匀的上升到最高点，保持不变或者有小幅度变化，再均匀的回落到零。

Scanning A shows the obvious single wave crest. As probe moves, the waveform increases evenly to the top point, maintains unchanged or has slight changes and then falls to zero point evenly.



Mode 2

8.7 不连续性分类

8.2 Discontinuity classification

A 点状不连续 动态波型如模式 1，和/或尺寸等于或小于降低 6dB 时波束宽度（见图 3）

A Dot discontinuity: Dynamic waveform is shown in Mode 1 and/or size is equivalent to or lower than beam width when it is reduced by 6dB (see Fig. 3)

线状不连续，动态波型如模式 2，和/或尺寸大于降低 6dB 时波束宽度（见图 4）

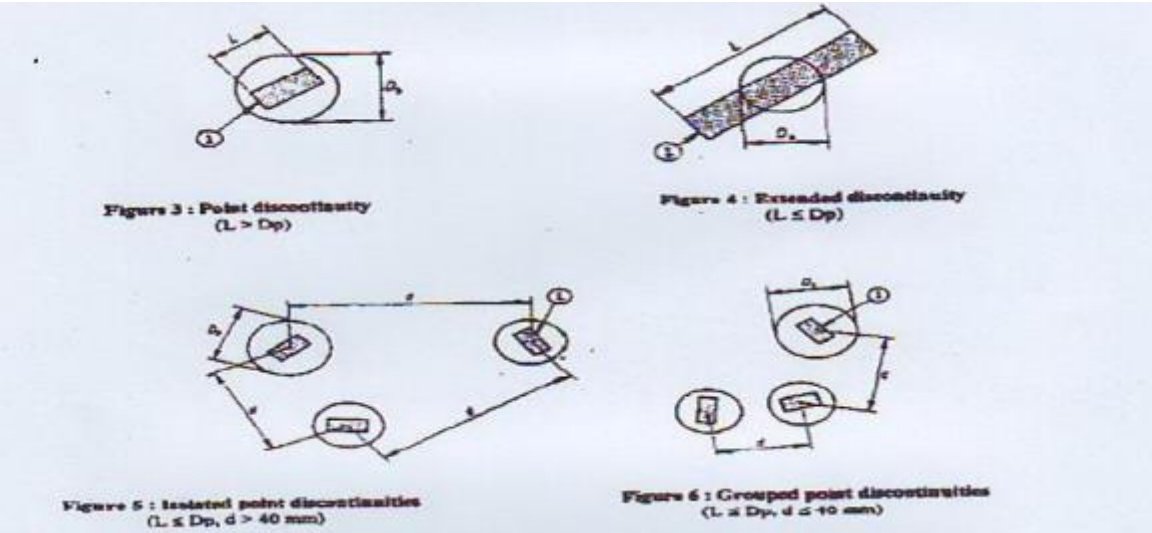
Linear discontinuity: Dynamic waveform is shown in Mode 2 and/or size is higher than beam width when it is reduced by 6dB (see Fig. 4)

B 单个不连续 相邻不连续最大显示波峰之间距离 d 大于 40mm(见图 5)

B Single discontinuity: The distance d between the adjacent discontinuous max. waveform is higher than 40mm (see Fig. 5)

C 成组不连续 相邻不连续最大显示波峰之间距离 d 等于或小于 40mm(见图 6)

C Group discontinuity: The distance d between the adjacent discontinuous max. waveform is equal to or lower than 40mm (see Fig. 6)



使用符号：

Symbols used

I: 6dB 法测定的不连续的轮廓

I: Discontinuous outline measured via Method 6dB

Dp:不连续性所处深度的波束宽度

Dp: Beam width at the depth of discontinuity

d:两个缺陷间的距离

d: Distance between two defects

L: 6Dd 法测定的不连续的长度

L: Length of discontinuity measured via Method 6Dd

9.记录水平及接受标准

9. Record level and acceptance criteria

9.1 接受标准 EN 10228.3 2 级

9.1 Acceptance criteria EN 10228.3 Class 2

9.2 直探头

9.2 Straight probe

9.2.1 记录水平:等同平底孔（EFBH）Φ2mm,底面回拨衰减比率 R≤0.3

9.2.1 Record level: Equivalent flat-bottom hole (EFBH) is Φ2 mm, attenuation ratio of bottom callback is R≤0.3

9.2.2 可接受水平：单个点状不连续 等同平底孔（EFBH）Φ2mm,线状不连续或成组不连续：d_{eq} Φ2mm

9.2.2 Acceptance criteria: Single spot discontinuity: Equivalent flat-bottom hole (EFBH) isΦ2mm; linear discontinuity or group discontinuity: d_{eq} Φ2mm

9.3 承压设备用钢锻件超声波检测记录标准

9.3 UT standard of steel forgings is adopted for the pressure-bearing equipment

以下为直探头和斜探头的验收标准表 4、表 5、多种质量等级能用作锻件分级，采用何种质量等级由合同双方协定

The forged pieces are classified based on the quality grade in acceptance criteria Table 4 and 5 of straight probe and angle probe. The quality grade should be used as negotiated by both parties

表 4 锻件超声检测直探头缺陷质量分级（1）

Table 4 Classification for Quality Defect of Straight Probe in UT of Forged Piece (1)

等级 Grade	I	II	III	IV	V
单个缺陷当量平底孔直径 Diameter of equivalent flat-bottom hole of single defect	≤φ4	≤φ4+6dB	≤φ4+12dB	≤φ4+18dB	＞φ4+18dB
由缺陷引起的底波降低量 BG/BF Bottom wave reduction due to defect BG/BF	≤6dB	≤12dB	≤18dB	≤24dB	＞24dB
密集区缺陷当量直径 Equivalent diameter of defect in dense area	≤φ2	≤φ3	≤φ4dB	≤φ4+4dB	＞φ4+4dB
密集区缺陷面积占检测总面积的百分比% Proportion of defect area in dense area to total test area %	0	≤5	≤10	≤20	＞20
注 1：由缺陷引起的底波降低量仅适用于声程大于近场区长度的缺陷。 Note 1: Bottom wave reduction due to defect only applies to the defect with beam path over the length of near field region. 注 2：表中不同种类的缺陷分级应单独使用。 Note: The different defect classification in table should be used separately. 注 3：密集区缺陷面积指反射波幅大于等于 φ2 当量平底孔的密集区缺陷。” Note 3: The defect area in dense area refers to the those of dense area with reflection waveform ≥φ2 equivalent flat-bottom hole.					

表 5 锻件超声检测斜探头缺陷质量分级

Table 5 Classification for Quality Defect of Angle Probe in UT of Forged Piece

质量等级 Quality Grade	单个缺陷指示长度 Indication Length of Single Defect
I	≤1/3 壁厚，且≤100mm ≤1/3 wall thickness and ≤100mm
II	≤2/3 壁厚，且≤150mm ≤2/3 wall thickness and ≤150mm
III	大于 II 级者 Higher than Grade II

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批准 Approved By:	王牛 Wang Niu	III	188550	Apr-21, 2023	

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