

No. 69 Guidelines for non-destructive testing of marine steel castings

(June 2000)
(Rev.1
May 2004)
(Rev.2
Oct 2020)

TABLE OF CONTENTS

- 1. General**
 - 1.1 Scope
- 2. Qualification of Personnel involved in NDT**
 - 2.1 Qualifications
- 3. Casting Condition**
 - 3.1 Heat Treatment
 - 3.2 Surface Condition
- 4. Extent of Inspections**
 - 4.1 Zones to be examined
- 5. Inspection Procedures**
 - 5.1 Visual Inspections
 - 5.2 Surface Inspections
 - 5.3 Volumetric Inspections
- 6. Acceptance Criteria**
 - 6.1 Visual Inspection
 - 6.2 Surface Inspection
 - 6.3 Volumetric Inspection
- 7. Reporting**
- 8. Rectification of Defects**

Annex 1

Extent and methods of non-destructive testing to be applied to typical hull steel castings.

1. General

1.1.1 This document is intended to give general guidance on the extent, methods and recommended quality levels applicable to the non-destructive testing (NDT), of marine steel castings, except in those cases where alternative criteria have been otherwise approved or specified.

1.1.2 Although no detailed guidelines are given for machinery components, the requirements in these guidelines may apply correspondingly considering their materials, kinds, shapes and stress conditions being subjected.

1.1.3 Castings intending to be examined by NDT methods are identified in Annex 1 to this document. The list of castings is not definitive. Criteria for the inspection of other castings not listed in Annex 1 will be subject to agreement.

1.1.4 UR W8 or this Recommendation do not include every cast component type that may be subject to Classification. In such cases where the particular component or type is not included, appropriate national/international standards, or other Society requirements may be applied, to determine the appropriate testing regime and defect acceptance criteria.

1.1.5 These guidelines complement and reference the requirements of the following UR's - UR W8, UR W22, UR W29, UR A1 and UR W34, and contain general guidance for the non-destructive testing methods, the extent of testing and the minimum recommended quality levels that should be complied with unless otherwise approved or specified.

1.1.6 Castings should be examined in the final delivery condition

1.1.7 Where intermediate inspections have been performed the manufacturer should provide reports of the results upon the request of the Surveyor.

1.1.8 Where a casting is supplied in semi-finished condition, the manufacturer should take into account the quality level of final finished machined components.

1.1.9 Where advanced ultrasonic testing methods are applied, e.g. PAUT or TOFD, reference is made to UR W34, for general approach in adopting and application of these advanced methods. Acceptance levels regarding accept/reject criteria are specified in the applicable section in this Recommendation.

2. Qualification of Personnel involved in NDT

2.1 Qualifications

2.1.1 Personnel engaged in visual examination are to have sufficient knowledge and experience, however, may be exempted from formal qualifications specified in this Recommendation.

2.1.2 Personnel carrying out NDT should be certified to a recognised national or international certification scheme, e.g. ISO 9712:2012, or an employer based scheme such as SNT-TC-1A: 2016, or ANSI/ASNT CP-189: 2016. Where employer based schemes are applied, personnel qualification to these schemes may be accepted if the written practice is reviewed and found acceptable by the Society. The written practice should align with the main requirements with those of ISO 9712 (apart from the impartiality requirements of a certification body).

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2.1.3 Personnel responsible for the NDT activity including approval of procedures should be qualified and certified to Level III.

2.1.4 The NDT personnel's certificates and competence should comprise all industrial sectors and techniques being applied by the manufacturer or its subcontractors. Certificates should be made available to the Society for verification, when requested.

2.1.5 The operator carrying out the NDT and interpreting indications, should, as a minimum, be qualified and certified to Level II in the NDT method(s) concerned.

However, operators only undertaking the gathering of data using any NDT method and not performing data interpretation or data analysis may be qualified and certified as appropriate, at level I.

The operator should have adequate knowledge of materials, weld, structures or components, NDT equipment and limitations that are sufficient to apply the relevant NDT method for each application appropriately.

3. Casting Condition

3.1 Heat Treatment

Non-destructive testing applied for acceptance purposes to support final casting certification should be made after the final heat treatment of the casting. Where intermediate inspections have been performed the manufacturer should provide reports of the results upon request of the Surveyor.

3.2 Surface Condition

3.2.1 Castings should be examined in the final delivery condition free from any material such as scale, dirt, grease or paint that might affect the effectiveness of the inspection. A thin coating of contrast paint is permissible when using magnetic particle techniques. For surface inspection NDT methods, the surface quality should be a minimum value of $R_a \leq 6.3 \mu\text{m}$

3.2.2 Ultrasonic testing should be carried out after the castings have been ground, machined or shot blasted to a suitable condition, with a minimum value surface quality of $R_a \leq 12,5 \mu\text{m}$. The surfaces of castings to be examined should be such that adequate coupling can be established between the probe and the casting and that excessive wear of the probe is avoided.

4. Extent of Inspections

4.1 Zones to be examined

4.1.1 Zones to be examined in nominated castings are identified in Annex 1. Testing should be made in accordance with an inspection plan approved by the Society. The plan should specify the extent of the testing, the testing procedure, the quality level or, if necessary, level for different locations of the castings.

4.1.2 In addition to the areas identified in Annex 1, surface inspections should be carried out in the following locations:

- at all accessible fillets and changes of section,

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- in way of fabrication weld preparation, for a band width of 30mm,
- in way of chaplets,
- in way of weld repairs,
- at positions where surplus metal has been removed by flame cutting, scarifying or arc-air gouging.

4.1.3 Ultrasonic testing should be carried out in the zones indicated in Annex 1 and also at the following locations:

- in way of all accessible fillets and at pronounced changes of section,
- in way of fabrication weld preparations for a distance of 50mm from the edge,
- in way of weld repairs where the original defect was detected by ultrasonic testing.
- in way of riser positions,
- in way of machined areas particularly those subject to further machining such as bolt hole positions.

4.1.4 In the case of castings such as rudder horns, which may have a large surface area still untested after the above inspections have been applied, an additional ultrasonic inspection of the untested areas should be made along continuous perpendicular grid lines on nominal 225 mm centres, scanning from one surface only.

5. Examination Procedures

5.1 Visual Inspection

5.1.1 Steel castings nominated for NDT should be subjected to a 100% visual examination of all accessible surfaces by the manufacturer and made available to the Surveyor. Viewing conditions at the inspected surfaces should be in accordance with a nationally or internationally recognised standard. Unless otherwise agreed, the visual and surface inspections should be carried out in the presence of the Surveyor.

5.2 Surface Inspection

5.2.1 The testing procedures, apparatus and conditions of magnetic particle testing and penetrant testing should comply with recognised national or international standards. Magnetic particle testing is preferable to penetrant testing except in the following cases;

- austenitic stainless steels,
- interpretation of open visual or magnetic particle indications,
- at the instruction of the Surveyor, where a particular need for penetrant testing has been identified.

5.2.2 For magnetic particle testing, attention is to be paid to the contact between the casting and the clamping devices of stationary magnetisation benches in order to avoid local overheating or burning damage in its surface. Prods should not be permitted on finished machined items. Note that the use of solid copper at the prod tips must be avoided due to the risk of copper contamination into the casting. The pole of the magnets should have close contact with the component.

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5.2.3 AC magnetisation method should normally be used, as it is more sensitive for detecting surface indications. Where DC magnetisation method is used, this should be in agreement with the Classification Society, and the reason for use clearly stated.

5.2.4 When indications have been detected as a result of the surface inspection, acceptance or rejection should be decided in accordance with Section 6.

5.3 Volumetric Inspection

5.3.1 Volumetric inspection in accordance with these guidelines is normally to be carried out by ultrasonic testing using the contact method with normal (0°) beam and/or angle beam technique. The testing procedures, apparatus and conditions of ultrasonic testing should comply with the recognised national or international standards.

5.3.2 In some cases, due to the shape, nature, complexity of casting, or defect type or orientation, there may be a need for radiographic testing. In such cases, radiographic testing may be carried out on the basis of prior agreement with the Classification Society. Where radiographic testing is to be applied, national or international standards for both the testing method, and the quality or severity level to be applied, should be agreed with the Classification Society.

Guidance on standards:

- ASTM E446 – 15
- ASTM E186 – 15 (2019) e1
- ASTM E280 – 15 (2019) e1
- ISO 4993:2015

These examples are suitable national or international standards as appropriate to the radiographic testing of castings, and casting thickness.

A suitable quality level for marine castings would normally be severity level 2 or 3 (of the above standards), depending on the location zone and type of casting. Other severity levels may be applied, and should be agreed with the Classification Society

5.3.3 Only those areas shown in the agreed inspection plan should be tested, however, the inspections may reveal indications that require further evaluation or an extension of testing. In such cases, this should be agreed with the Classification Society. The plan should include those locations nominated in section 4.2.3 together with the scanning zones identified for the relevant casting in Annex 1.

5.3.4 Ultrasonic scans should be made using a 0° probe of 1 - 4MHz (usually 2MHz) frequency, and angle probes, where required. Whenever possible scanning is to be performed from both surfaces of the casting and from surfaces perpendicular to each other.

5.3.5 The backwall echo obtained on parallel sections should be used to monitor variations in probe coupling and material attenuation. Any reduction in the amplitude of the back wall echo due to material properties should be corrected. Attenuation in excess of 30dB/m could be indicative of an unsatisfactory annealing heat treatment and may render the effectiveness of the testing as unsuitable. In such cases of excessive attenuation, this should be investigated, and suitable mitigation measures carried out for effective ultrasonic testing to continue, where possible.

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5.3.6 Machined surfaces, especially those in the vicinity of riser locations and in the bores of stern boss castings, should also be subject to a near surface (approximately 25mm) scan using a twin crystal 0° probe.

Additional scans on machined surfaces are of particular importance in cases where boltholes are to be drilled or where surplus material such as 'padding' has been removed by machining thus moving the scanning surface closer to possible areas of shrinkage.

Additionally, it is good practice to examine the machined bores of castings using circumferential scans with 70° probes in order that axial radial planar flaws such as hot tears can be detected. Fillet radii should be examined using 45°, 60°, or 70° probes scanning from the surfaces/direction likely to give the best reflection, primarily to determine the presence of any cracks within the radiused areas, and as an additional scan to confirm any indications that may have been detected with 0° probe(s) within this area.

5.3.7 In the examinations of those zones nominated for ultrasonic examination the reference sensitivity for the 0° probe should be established against a 6mm reflector. Sensitivity can be calibrated either against 6mm diameter flat bottomed hole(s) in a reference block (or series of blocks) corresponding to the thickness of the casting provided that a transfer correction is made, using the DAC (distance-amplitude-correction) method, or by using the DGS (distance-gain-size) method.

5.3.8 The reference sensitivity of angle probes (where required for testing) should be established against an appropriate 6mm reflector (e.g. reference reflectors angled perpendicular to the sound beam) for the DAC method, or equivalent using the DGS method.

5.3.9 The DGS diagrams issued by a probe manufacturer identify the difference in dB between the amplitude of a back wall echo and that expected from a 6mm diameter disk reflector. By adding this difference to the sensitivity level initially set by adjusting a back wall echo to a reference height e.g. 80%, the amended reference level will be representative of a 6mm diameter disk reflector. Similar calculations can be used for evaluation purposes to establish the difference in dB between a back wall reflector and disk reflectors of other diameters such as 12 or 15 mm.

5.3.10 Having made any necessary corrections for differences in attenuation or surface condition between the reference block and the casting, any indications received from the nominated zones in the casting that exceed the 6mm reference level should be marked for evaluation against the criteria given in 6.3 below. Evaluation should include additional scans with angle probes in order that the full extent of the discontinuity can be plotted.

6. Acceptance Criteria

6.1 Visual Inspection

6.1.1 All castings should be free of cracks, crack-like indications, hot tears, cold shuts or other detrimental indications. Thickness of the remains of sprues or risers should be within the casting dimensional tolerance.

6.1.2 Additional magnetic particle, penetrant or ultrasonic testing may be required for a more detailed evaluation of surface irregularities at the request of the Surveyor.

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6.2 Surface Inspection

6.2.1 The following definitions relevant to indications apply:

- Linear indication = an indication with a largest dimension three or more times its smallest dimension (i.e. $l \geq 3w$).
- Non-linear indication = an indication with a largest dimension less than three times its smallest dimension (i.e. $l < 3w$).
- Aligned indication = three or more indications in a line, separated by 2mm or less edge-to-edge, which results in a unique indication, defined as follows:
 - a) Non-linear indications form an alignment when the distance between indications is less than 2mm and at least three indications are aligned. An alignment of indications is considered to be a unique indication and its length is equal to the overall length of the alignment.
 - b) Linear indications form an alignment when the distance between two indications is smaller than the length of the longest indication.
- Open indication = an indication visible after removal of the magnetic particles or that can be detected by the use of penetrant testing.
- Non-open indication = an indication that is not visually detectable after removal of the magnetic particles or that cannot be detected by the use of penetrant testing.
- Relevant indication = an indication that is caused by a condition or type of discontinuity that requires evaluation. Only the indications which have any dimension greater than 1.5mm should be considered relevant for the categorization of indications.

6.2.2 For the purpose of evaluating indications, the surface should be divided into reference band length of 150 mm for level MT1/PT1 and into reference areas of 22500mm² for level MT2/PT2. The band length and/or area should be taken in the most unfavourable location relative to the indications being evaluated.

6.2.3 The following quality levels recommended for magnetic particle testing (MT) and/or penetrant testing (PT) are;

Level MT1/PT1 - fabrication weld preparation and weld repairs.

Level MT2/PT2 - other locations nominated for surface inspection in Annex 1.

The allowable numbers and sizes of indications in the reference band length and/or area are given in Table 1. The required quality level should be shown on the

manufacturer's inspection plan. Cracks and hot tears should not be accepted.

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Table 1 Allowable number and size of indications in a reference band length/area

Quality Level	Total maximum number of all indications	Type of indication	Maximum number of each type of indication	Maximum dimension, (e.g. width, length, diameter) of single indication, mm ²
MT1/PT1	4 in 150 mm length	Non-linear	4 ¹⁾	5
		Linear	4 ¹⁾	3
		Aligned	4 ¹⁾	3
MT2/PT2	20 in 22500 mm ² area	Non-linear	10	7
		Linear	6	5
		Aligned	6	5
Notes: 1) 30 mm minimum (measured in any direction) between relevant indications, 2) In weld repairs, the maximum dimension is 2mm.				

6.3 Volumetric Inspection

6.3.1 Acceptance criteria for ultrasonic testing are identified in Table 2 as UT1 and UT2. As stated in 4.2.1 the quality levels applicable to the zones to be examined should be identified on an inspection plan. The following quality levels are nominated for the castings identified in Annex 1.

Level UT1 is applicable to:

- fabrication weld preparations for a distance of 50mm,
- 50mm depth from the final machined surface including boltholes,
- fillet radii to a depth of 50mm and within distance of 50mm from the radius end,
- castings subject to cyclic bending stresses e.g. rudder horn, rudder castings and rudder stocks - the outer one third of thickness in the zones nominated for volumetric inspection by Annex 1,
- discontinuities within the examined zones interpreted to be cracks or hot tears.

Level UT2 is applicable to:

- other locations nominated for ultrasonic testing in Annex 1 or on the inspection plan.
- positions outside locations nominated for level UT1 inspection where feeders and gates have been removed.

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- castings subject to cyclic bending stresses - at the central one third of thickness in the zones of nominated for volumetric inspection by Annex 1.

6.3.2 For near surface testing (to an approximate depth of 25 mm) twin crystal 0° (normal beam) probe should be used, plus a 0° probe (usually single crystal beyond a depth of 25 mm) for the remaining volume.

6.3.3 Ultrasonic acceptance criteria for other casting areas not nominated in Annex 1 should be subject to special consideration based on the anticipated stress levels and the type, size and position of the discontinuity.

6.3.4 Table 2 describes the acceptance criteria for both methods of applied sensitivity (DGS and DAC)

6.3.5 DGS and DAC methods may be used for determining sensitivity. The DAC method for normal beam probes may be based on a 6.0mm diameter reflector or flat bottomed hole (FBH). A DAC curve should be produced using reference blocks containing 6.0mm FBH reflectors over a range representative of the inspection thickness, after adjustment for transfer and attenuation losses,

6.3.6 For quality level UT 1, any discontinuity producing a signal amplitude in excess of the 6.0 mm DAC curve is unacceptable.

6.3.7 For quality level UT2, the sensitivity may be based on actual size FBH (of 12mm and 15 mm) or based on equivalent 6mm FBH, and the sensitivity adjusted to obtain equivalent amplitudes, as described in 6.3.8.

6.3.8 For use of FBH of 6mm for setting sensitivity, adjustment of signal amplitudes (measured in dB above 6mm DAC) can be determined for 12mm and 15mm FBH reflectors: to be DAC + 12dB and DAC + 16dB (plus any compensation for transfer and attenuation losses). This is illustrated in Figure 1. The increase in dB to the indicated levels represent the equivalent FBH sizes (for 12 mm and 15mm), and their respective corresponding ultrasonic response amplitudes.

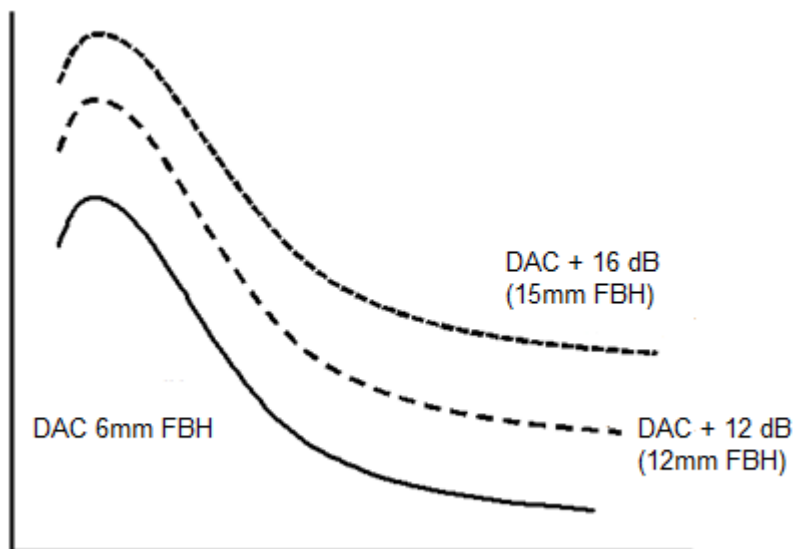


Figure 1 DAC curve produced from 6.0mm FBH reflector and DAC curves adjusted to represent equivalent 12.0mm and 15.0mm FBH reflectors.

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The bottom curve (DAC) represents a sensitivity based on 6mm FBH, and the two additional curves (DAC + 12 and DAC + 16dB) above this represent the equivalent sensitivities converted for larger FBH's (12mm and 15mm).

When scanning using these curves, and applying Table 2 acceptance criteria, for UT2, any indication below DAC +12mm should be disregarded, and any indication above DAC +16mm should be rejected.

Any indication between these two curves should be evaluated according to its size, as per Table 2.

Table 2 Ultrasonic Acceptance Criteria for steel castings – Using DGS or DAC system

Quality Level	Allowable disc shape according to DGS ¹⁾ [mm] or diameter of FBH according to DAC ^{2), 3)} Curve [mm]	Maximum number of indications to be registered ⁴⁾	Allowable size of all relevant indications [mm] ^{5),6)}
UT1	>6	0	0
UT2	12-15 >15	5 0	50 0
Notes: 1) DGS: distance-gain size. 2) DAC: Distance Amplitude Correction 3) The corresponding DAC level to each of the FBH reflectors is at 100% DAC 4) grouped in an area measuring 300 x 300 mm 5) measured on the scanning surface 6) the measured indication is regarded as the longest dimension, as measured in the scanning process			

6.3.9 The maximum number of indications to be registered and the maximum length of indications permissible for quality level 2 (as stated in Table 2) apply to normal probes.

6.3.10 For quality level UT 2, any discontinuity producing a signal amplitude in excess of the 15.0 mm DAC curve should be regarded as unacceptable.

6.3.11 Any signal between 12 + 15 curve should be evaluated for length of defect, and referred to table 2 for acceptance

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7. Reporting

7.1 General

All reports of non-destructive examinations should include the following items;

- (1) Date of testing.
- (2) Name(s), signature(s) and qualification level of inspection personnel.
- (3) Type of casting.
- (4) Product number and unique identification.
- (5) Grade of steel.
- (6) Heat treatment.
- (7) Stage of testing.
- (8) Locations for testing.
- (9) Surface condition.
- (10) Test standards used- including reference to the appropriate tables for acceptance purposes
- (11) Results, including documentation regarding the repair and testing history (as appropriate);
- (12) Statement of acceptance / non-acceptance.
- (13) Locations of reportable indications.
- (14) Details of weld repairs including sketches (where applicable).

7.2 In addition to the items listed in 7.1, reports of surface inspections should include at least the following items:

- for penetrant testing; the penetrant system used,
- for magnetic particle testing: method of magnetising, test media and magnetic field strength and magnetic flux indicators (where appropriate).
- viewing conditions (as appropriate to the penetrant or magnetic technique and media used)
- testing details and procedure number
- details of any test restrictions

7.3 In addition to the items listed in 7.1, reports of ultrasonic inspection should include at least the following items:

- flaw detector, probe type, size, angle and frequency (and any adaptations to probes for curved surfaces), calibration and reference blocks, sensitivity method (including reflector size, transfer correction), maximum scanning rate (mm/s), and couplant.

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8. Rectification of Defects

8.1 Indications that exceed the requirements of Table 1 and Table 2, should be classed as defects, and should be repaired or rejected as appropriate, according to Classification Society Rules.

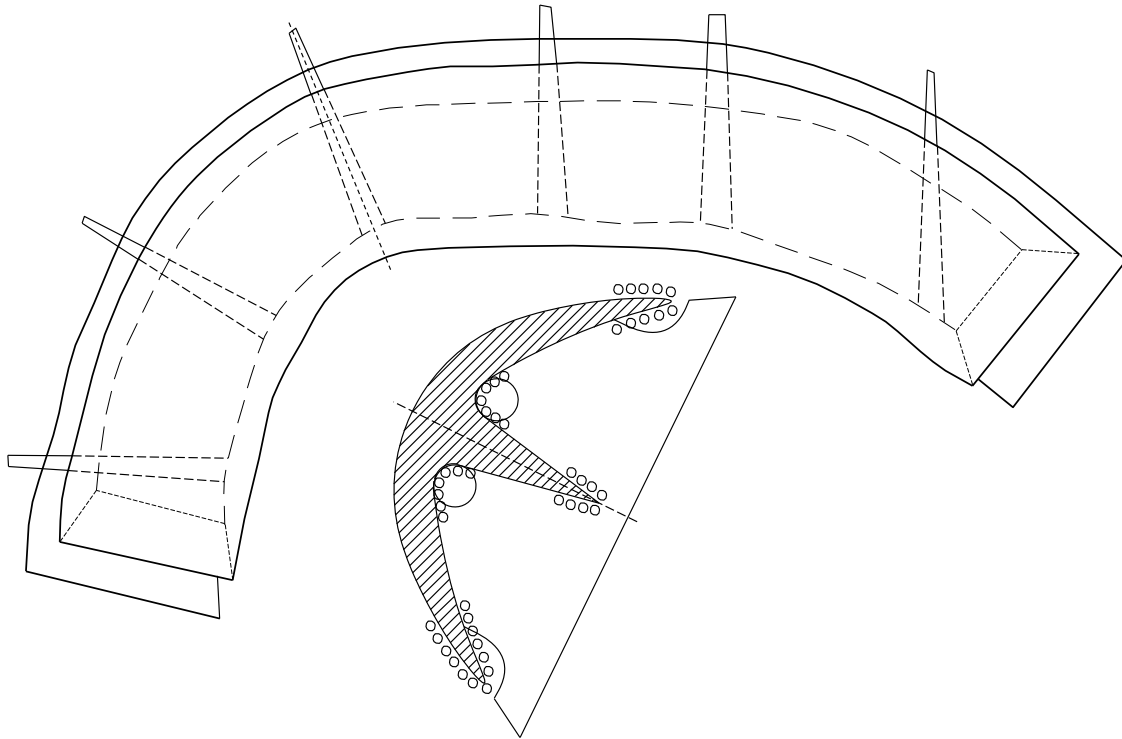
8.2 Generally it may be permissible to remove shallow indications by light grinding, however, all repairs should be undertaken in accordance with Classification Society Rules.

8.3 Complete removal of the defect should be proved by magnetic particle testing or penetrant testing, as appropriate.

8.4 Castings which are repaired should be examined by the same method as at initial inspection, as well as by any additional methods as requested by the Surveyor.

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Annex 1 Extent and methods of non-destructive testing that should be applied to typical hull steel castings

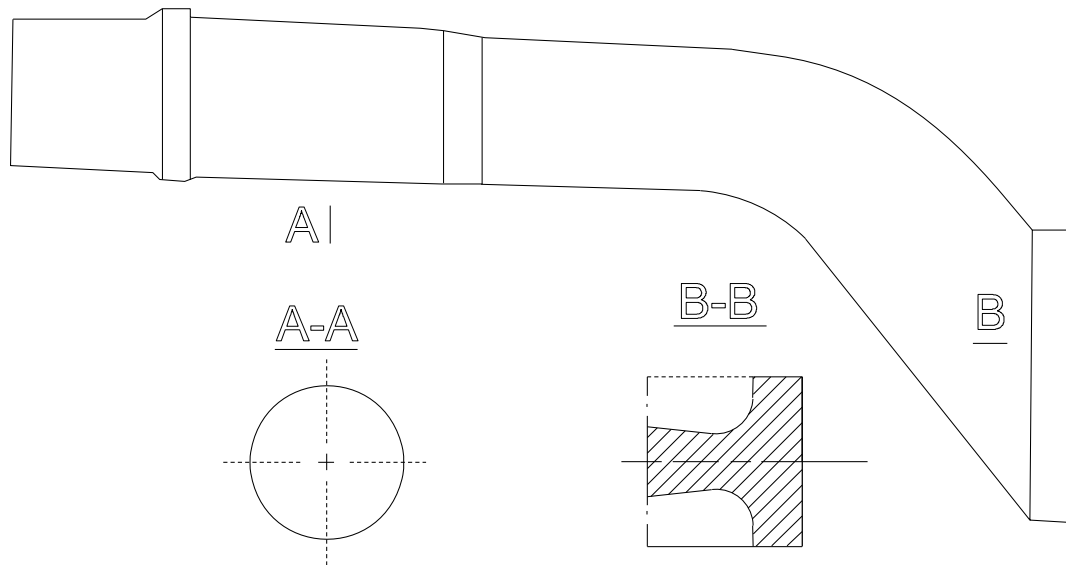


Notes: Location of non-destructive examination

- 1) All surfaces: Visual examination
- 2) Location indicated with (OOO): Magnetic particle and Ultrasonic testing
- 3) The detailed extents of examinations and quality levels are given in Sections 4 and 6.

Fig. A1 Stern Frame

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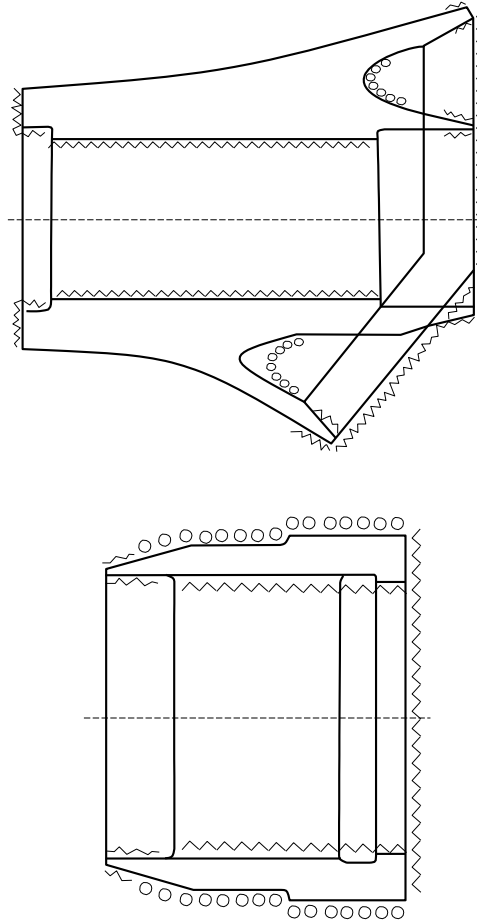


Notes: Location of non-destructive examination

- 1) All surfaces: Visual examination.
Magnetic particle and Ultrasonic testing.
- 2) The detailed extents of examinations and quality levels are given in Sections 4 and 6.

Fig. A2 Rudder stock

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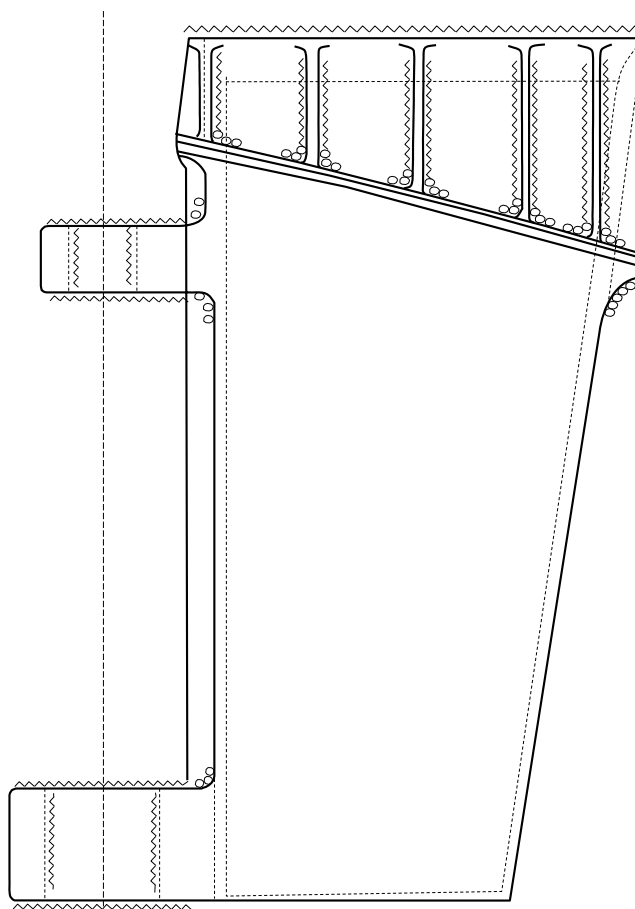


Notes: Location of non-destructive examination

- 1) All surfaces: Visual examination
- 2) Location indicated with (OOO): Magnetic particle and Ultrasonic testing
- 3) Location indicated with (ΛΛΛΛ): Ultrasonic testing
- 4) The detailed extents of examinations and quality levels are given in Sections 4 and 6.

Fig. A3 Stern Boss

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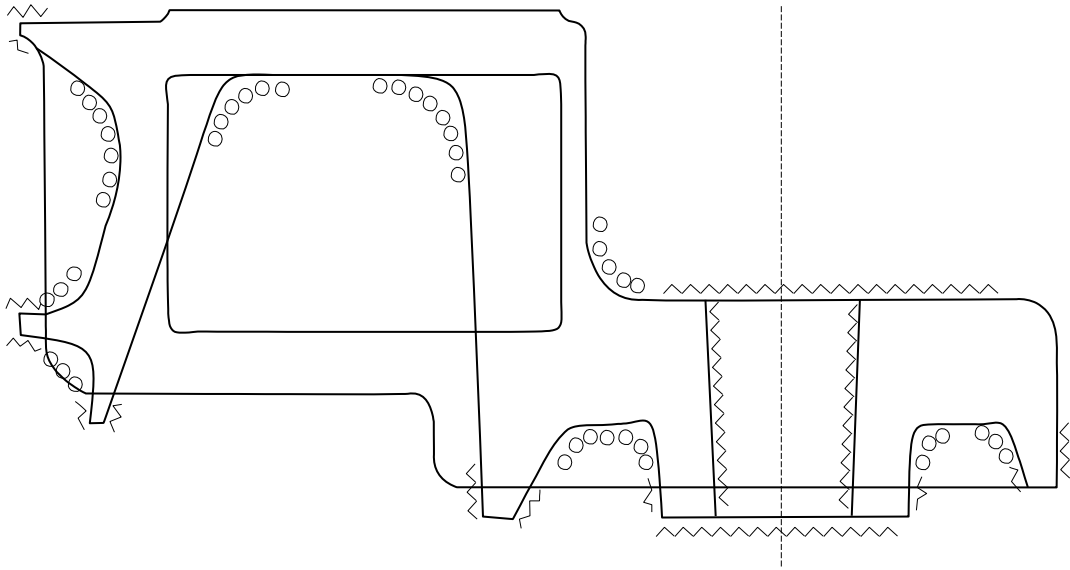


Notes: Location of non-destructive examination

- 1) All surfaces: Visual examination
- 2) Location indicated with (OOO): Magnetic particle and Ultrasonic testing
- 3) Location indicated with (ΛΛΛΛ): Ultrasonic testing
- 4) The detailed extents of examinations and quality levels are given in Sections 4 and 6.

Fig. A4 Rudder Hangings

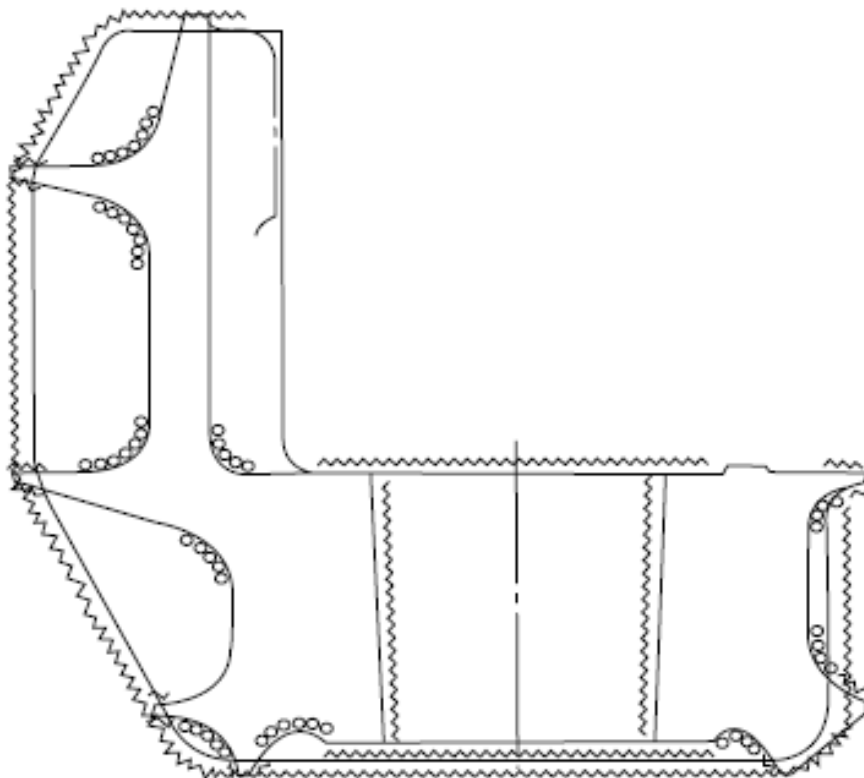
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Notes: Location of non-destructive examination

- | | | |
|----|---|---|
| 1) | All surfaces: | Visual examination |
| 2) | Location indicated with (OOO): | Magnetic particle and
Ultrasonic testing |
| 3) | Location indicated with (AAA): | Ultrasonic testing |
| 4) | The detailed extents of examinations and quality levels are given in Sections 4 | |

Fig. A5 Rudder (Upper Part)

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Notes: Location of non-destructive examination

- 1) All surfaces: Visual examination
- 2) Location indicated with (OOO): Magnetic particle and Ultrasonic testing
- 3) Location indicated with (AAA): Ultrasonic testing
- 4) The detailed extents of examinations and quality levels are given in Sections 4 and 6.

Fig. A6 Rudder (Lower Part)