



CORPORATE STANDARD

AA 085 01 02

Rev. No. 02

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NON-DESTRUCTIVE TESTING PROCEDURES AND ACCEPTANCE STANDARDS FOR TURBO GENERATOR ROTORS AND STEAM TURBINE ROTORS & SHAFTS

1.0 GENERAL:

This standard stipulates the machining requirements prior to non-destructive testing, the non-destructive testing procedures and the defect assessment standards for high stress ferritic alloy steel rotor & rotor shaft and the records required by BHEL prior to approval for despatch from supplier's works.

2.0 PERSONNEL REQUIREMENT:

Personnel performing non-destructive examination and evaluation shall be qualified to the recommended practice SNT-TC-1A or any other recognised practice.

3.0 SUMMARY OF PROCEDURE:

1. Machining requirements for Non-destructive testing.
2. Non-destructive Testing Procedure.
3. Defect Assessment and Acceptance Standards.
4. Records.

4.0 MACHINING REQUIREMENTS FOR NON-DESTRUCTIVE TESTING:

The surface condition of the rotor forging prior to examination shall comply with the following requirements:

- 4.1 The bore and journal surfaces shall have a finish of 1.6 micron. or better for close visual examination. Preferably the bore shall be honed.
- 4.2 The remainder of the surface shall have a finish of 6.3 micron or better produced by a broad nosed tool, for ultrasonic examination
- 4.3 Local grinding or enlargement of the bore to remove defects shall not be done without the consent of BHEL. Note the requirements for the bore surface applies only to through bores.

5.0 NON-DESTRUCTIVE TESTING PROCEDURE:

All results of non-destructive examination shall be presented in the Forging Manufacturing record (Appendix B)

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**5.1 Visual Inspection:**

The external surfaces of the rotor shall be visually examined for defects. The bore of the rotor, when specified, shall be examined by means of a suitable boroscope giving a magnification of X2 to X4 and assessed in accordance with clause 6 of this document.

5.2 Magnetic Particle Inspection At Forging Supplier's Works:

This test shall be carried out in accordance with the requirements of ASTM E 709.

5.2.1 Rotor And Shaft Bores:

Where there is a full length axial bore, the bore surface shall be subject to magnetic particle inspection.

The magnetic field shall be produced by passing direct current or full wave or half wave rectified alternating current through a conductor threaded longitudinally through the bore.

The continuous method, whereby magnetic particles are applied while magnetisation continues, shall be used wherever possible. Otherwise by agreement with BHEL, the residual method may be applied using direct current magnetisation.

The bore shall then be examined with a boroscope and assessed in accordance with clause 6 of this document. The rotor shall then be half turned, the bore cleaned out, re-sprayed and examined.

On completion of the examination, the bore shall be cleaned and the forging shall be free from residual magnetism prior to despatch.

5.2.2 Rotor External Surfaces:

In the case of generator and monobloc turbine forgings, all re-entrant changes in section present at the hardening and tempering stage of manufacture shall be subjected to magnetic particle inspection for detection of circumferential and longitudinal cracks.

5.2.3 Recording Of Flaws:

Results of the examination shall be recorded in the Forging Manufacturing Record.

5.3 Ultrasonic Flaw Detection:**5.3.1 Ultrasonic Flaw Detection Equipment:**

All ultrasonic equipment shall meet the requirements and capabilities laid down in ASTM E 317.

5.3.1.1 Sensitivity:

The sensitivity shall be set in accordance with Appendix A. If either metallurgical conditions or equipment characteristics prevent the above conditions from being met the test sensitivity shall be the subject of discussion between the supplier and



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5.3.1.2 Linearity Of Time Base And Amplifier:

Linearity of time base shall be equal to or better than 1%.
Linearity of amplifier shall be equal to or better than 3%.

5.3.1.3 Resolution:

The resolution of the equipment and probe combined shall be such as to show separately indications from two or more nearby reflecting surfaces when the difference in beam path lengths between them does not exceed twice the wave-length.

5.3.1.4 Calibrated Attenuator:

The calibrated attenuator shall be accurate to within ± 1 dB over its full range.

5.3.2 Ultrasonic Testing Of Rotors And Rotor Shafts:

5.3.2.1 Testing Sequence:

The supplier is expected to test the forging as early as possible in the manufacturing cycle at the maximum frequency and sensitivity which the surface condition and grain size permits.

Ultrasonic tests shall be made in accordance with the specification at stages;

1. Prior to gashing and heat treatment in a rough machined condition.
2. As early as possible after heat treatment in a rough machined and preferably unbored condition.
3. After completion of all machining.

The results at each stage are to be reported to BHEL. The supplier is expected to incorporate a refining treatment in the annealing cycle to minimise grain interference at stage 1. IN THE CASE OF TURBINE ROTOR FORGINGS HEAT TREATED IN THE

UNGASHED OR PART GASHED CONDITION BHEL SHALL BE GIVEN THE OPPORTUNITY TO WITNESS THE STAGE 2 TEST IN PREFERENCE TO, OR SUPPLEMENTARY TO, STAGE 3.

"End to end" tests (clause 5.3.2.2) shall be carried out at stage 2 above and reported to BHEL.

5.3.2.2 Coverage:

The minimum coverage shall include a 360° radial test and an end to end test through the body and shafts using longitudinal wave probes. as follows:

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Journals : 360°, 4 -5 MHz combined double longitudinal wave probe.
 Body and Shaft End : 360°, 2 MHz single longitudinal wave probe.
 Faces : ("End to end" test)

100% of the cylindrical surface should be scanned for back echo loss (keeping back echo at 100%). Any loss on back echo beyond 15%, then it should be tested with 7°, 14° & 21° longitudinal wave probes.

In the event of attenuation preventing the use of 2 MHz this shall be brought to the attention of BHEL without delay or suitable remedial action taken by the supplier. When using a combined double probe within the near zone region a suitable test block shall be available for setting of test sensitivity. From this an amplitude/depth curve shall be constructed for assessment purposes.

5.3.2.3 Probe Manipulation:

Uniform contact between the probe and forging shall be maintained and a full surface coverage ensured (i.e. scanning overlap shall be at least a quarter of the probe diameter). Speed of examination shall not exceed 150 mm per second. Particular attention shall be paid to the observation of "travelling indications" on the screen since these may indicate the presence of radial/axial defects.

5.3.2.4 Attenuation:

After final heat treatment attenuation readings shall be taken at three equally spaced circumferential positions at both ends and the middle of the rotor body in the following manner:

Set the first back wall echo at 40 mm and record the calibrated attenuator reading, then set the second back wall echo at 40 mm and again record the calibrated attenuator reading. The difference between these two readings shall be entered on the record sheet.

These readings shall be made at both 2 and 4 MHz. If values greater than 15 dB are recorded at either frequency, this shall be brought to the attention of BHEL for further investigation before the forging can be accepted.

5.3.2.5 Frequency of Calibration Of Test Equipment:

The frequency of calibration of the testing equipment (i.e. dynamic checking) shall be:

- i) At the beginning of testing of new size.
- ii) At the start of each shift.
- iii) After each 4 -hours of testing.
- iv) At the end of each shift.
- v) Whenever malfunctioning is suspected



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6. 0 DEFECT ASSESSMENT AND ACCEPTANCE STANDARDS:

6.1 General:

Any defects found by any method shall be fully investigated by the appropriate method to fully delineate their dimensions and positions. Acceptable and unacceptable defects shall be assessed in accordance with Clauses 6.2 to 6.4 and Tables 1 and 2. Defects in the unacceptable category shall be referred to BHEL.

Any unacceptable defects found at any preliminary examination stage shall be brought to the attention of BHEL even if the machining carried out by the supplier would remove the defect.

Categories described in Table 1 shall apply to regions of the finally machined forgings as follows:

6.2 Unbored Rotors:

Table 1 applies

Category 1-Blade fastening regions of turbine rotors, base of winding slot of generator rotors and journal surfaces.

Category 2-Remainder.

6. 3 Bored Rotors:

Table 1 applies.

Category 1-Bore surface and region within 50 mm radially of the bore for the length of the body + 250 mm at each end. blade fastening regions of turbine rotors, base of winding slots of generator rotors and journal surfaces.

Category 2-Remainder.

6.4 Bored And Unbored Shafts:

Table 1 applies

Category 1-Journal surfaces.

Category 2-Remainder

7.0 RECORDS:

Supplier shall provide all certificates and data as specified in the purchase order, purchase specification and testing procedure as specified in this standard at the time of notification for final inspection or earlier. In addition, the forging procedure and heat treatment details shall also be furnished.

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**TABLE-1 (Clauses 6.1, 6.2, 6.3 & 6.4)**

CATEGORY	UNACCEPTABLE DEFECTS	DEFECTS TO BE REFERRED TO BHEL
1 Ultrasonic	Defects giving indications > 2mm dia equivalent flaw size Defects with probe movement in excess of that consistent with a 2 mm dia equivalent flaw size at the same depth. Defects giving "travelling" indications indicative of radial orientation. Groups of defects giving indications which cannot be separated at the testing sensitivity and with maximum reflection	Any condition of continuous clusters as indicated by multiple indications of smaller amplitude than the limits listed for unacceptable defects, at the testing sensitivity; Discrete linear defects oriented in the direction of forging and without radial dimension giving indications
1 Visual/ Magnetic	>1 mm dia equivalent flaw size. Inclusions larger than 3 mm; Groups* of inclusions within which individual defects exceed 3 mm length. Dispersed inclusions exceeding 2 in any 150 mm length of bore	<2 mm dia equivalent flaw size. Discrete thread like inclusions larger than 3 mm.
2 Ultrasonic	Defects giving indications > 4 mm** dia equivalent flaw size. Defects with probe movement in excess of that consistent with a 4mm dia equivalent flaw size at the same depth. Defects giving "Travelling" indications indicative of radial orientation. Groups of defects giving indications which cannot be -separated at the testing sensitivity and with maximum reflection	Any condition of continuous clusters as indicated by multiple indications of smaller amplitude than the limits listed for unacceptable defects, at the testing sensitivity; Discrete linear defects oriented in the direction of forging and without radial dimension giving indications
2 Visual/ Magnetic	>1 mm dia equivalent flaw size. Inclusions larger than 6mm; Groups* of inlcusion within which individual defects exceed 6 mm length. Dispersed inclusions exceeding 3 in any 150 mm length of bore.	< 4 mm dia equivalent flaw size. Discrete thread like inclusions larger than 6 mm.

Cracks and porosity are unacceptable in either category.



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* A group is defined as any number of defects separated by less than 2 x length of the longest. In the case of defects in the same plane separated by less than 2 x the longest they shall be regarded as a single defect of length equal to the overall length of the group.

** Defects giving indications 2-4 mm dia equivalent flaw size in size shall not exceed 30 Nos. in the entire body of the forging and also shall not exceed 10 Nos. in any place. Allowable defects shall be separated by a minimum distance equal to 15 times the size of the larger of the adjacent defects.

APPENDIX -A (See cl. 5.3.1.1) SENSITIVITY SETTING

A.1 INTRODUCTION:

This appendix lays down the procedure to be used when setting test sensitivity, recording flaw indications and assessing flaws. The approach is based on the DGS diagram, which after due allowance is made for the attenuation measured in the forging under test, ensures reproducibility and standardization of sensitivity from one forging to another. If DGS diagram for the particular probe and equipment to be used is available, it may be used in place of universal DGS diagram. In that case there is no need for calculation of near zones/frequency.

A. 2 SCANNING SENSITIVITY PROCEDURE:

A. 2.1 Solid Rotors:

A.2.1.1 Reference Sensitivity:

Operation 1

Refer to the DGS diagram noting the gain reading in dB (G) of the back wall echo at its distance from the probe in terms of near zones.

Operation 2

Note the gain reading in dB (G) at which a 1.5 mm (1/16th) diameter equivalent flat bottomed hole occurs on the AXIS of the forging.

Operation 3

Set the back wall , echo amplitude to half screen height using the uncalibrated gain control.

Operation 4

Increase the sensitivity using the calibrated attenuator by the difference between gain readings (1) and (2)

Operation 5

If the attenuation value through the section exceeds 2 dB after subtracting 6 dB for natural losses (see 5.3.2.4 Attenuation) the sensitivity shall be reduced by HALF this value using the calibrated gain control. This is to offset the losses due to attenuation in the material between the axis of the forging and the back wall.

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A.2.1.2 Testing Sensitivity: Operation 6

Increase the sensitivity on the calibrated gain control by 12 dB so that a flaw on the axis of the forging, giving an echo 12 dB less than that from a 1.5 mm diameter equivalent flat bottomed hole will coincide in amplitude with half screen height. This shall be the scanning sensitivity and shall be recorded in the report.

A.2.2 Bored Rotors: A.2.2.1 Reference Sensitivity:

Operation 1

Refer to the DGS diagram noting the gain reading in dB(G) of the back wall echo from the bore at its distance from the probe in terms of near zones.

Operation 2

Note the gain reading in dB(G) at which a 1.5 mm diameter equivalent flat bottomed hole occurs at the back wall depth (i.e. on the bore surface).

Operation 3

Set the back wall echo amplitude to half screen height using the uncalibrated gain control.

Operation 4

Increase the sensitivity by the difference between gain readings (1) & (2) using the calibrated attenuator.

Operation 5

Refer to Fig. 2 and obtain the correction factor required to offset the effect of the curvature of the bore.

Using the calibrated gain control reduce the gain accordingly.

A.2.2.2 Testing Sensitivity:

Operation 6

Increase the sensitivity on the calibrated gain control by 12 dB so that a flaw on the bore of the forging giving an echo 12 dB less than that from a 1.5 mm diameter equivalent flat bottomed hole will coincide in amplitude with half screen height. This shall be the scanning sensitivity and shall be recorded in the report,



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A. 3 RECORDING OF FLAW INDICATIONS:

The Forging Manufacturing Record Report Sheet shall be used. Appendix B.

Discrete defects less than 1 mm diameter equivalent flaw size are considered non-relevant.

The following conditions shall be recorded.

- A.3.1 All flaw indications 1 mm diameter equivalent flaw size or greater. Record position, orientation, reflection amplitude relative to the reference sensitivity and its flaw size equivalent.
- A.3.2 Defects with probe movement shall be recorded as at A 3.1 but the size indicated by probe movement shall also be recorded.
- A.3.3 Groups of defects giving indications which cannot be separated at the testing sensitivity and with maximum reflection 1 mm diameter equivalent flaw size or greater.
- A.3.4 Any condition of continuous clusters as indicated by multiple indications of smaller amplitude than A 3.3 at the testing sensitivity.
- A.3.5 Sizes of groups shall be recorded.
- A.3.6 Defects giving "travelling" indications indicative of radial orientation.

A. 4 ASSESSMENT OF FLAWS:

Large defects having dimensions of the order of the probe diameter and greater shall be assessed by measuring probe movement in four directions at right angles over which the echo falls to 50% of the original amplitude. Allowance is necessary for orientation where "travelling" of the indication suggests radial orientation.

Note:

Measurement of probe movement shall be taken using, the probe axis as a datum. For single small defects which are not measurable by probe movement and which do not exhibit evidence of the "travelling" condition the equivalent diameter of the defect in terms of an; equivalent flaw size shall be established.

A.5 LIMITATIONS OF TESTS:

Where, in the case of rotor forgings it is not possible to attain the specified sensitivity at the pre-heat treatment test . stage (Stage 1) the highest practical sensitivity shall be used and the limitation noted on the report. The sensitivity used shall be recorded relative to the specified reference sensitivity.

Any other limitations shall similarly be recorded.

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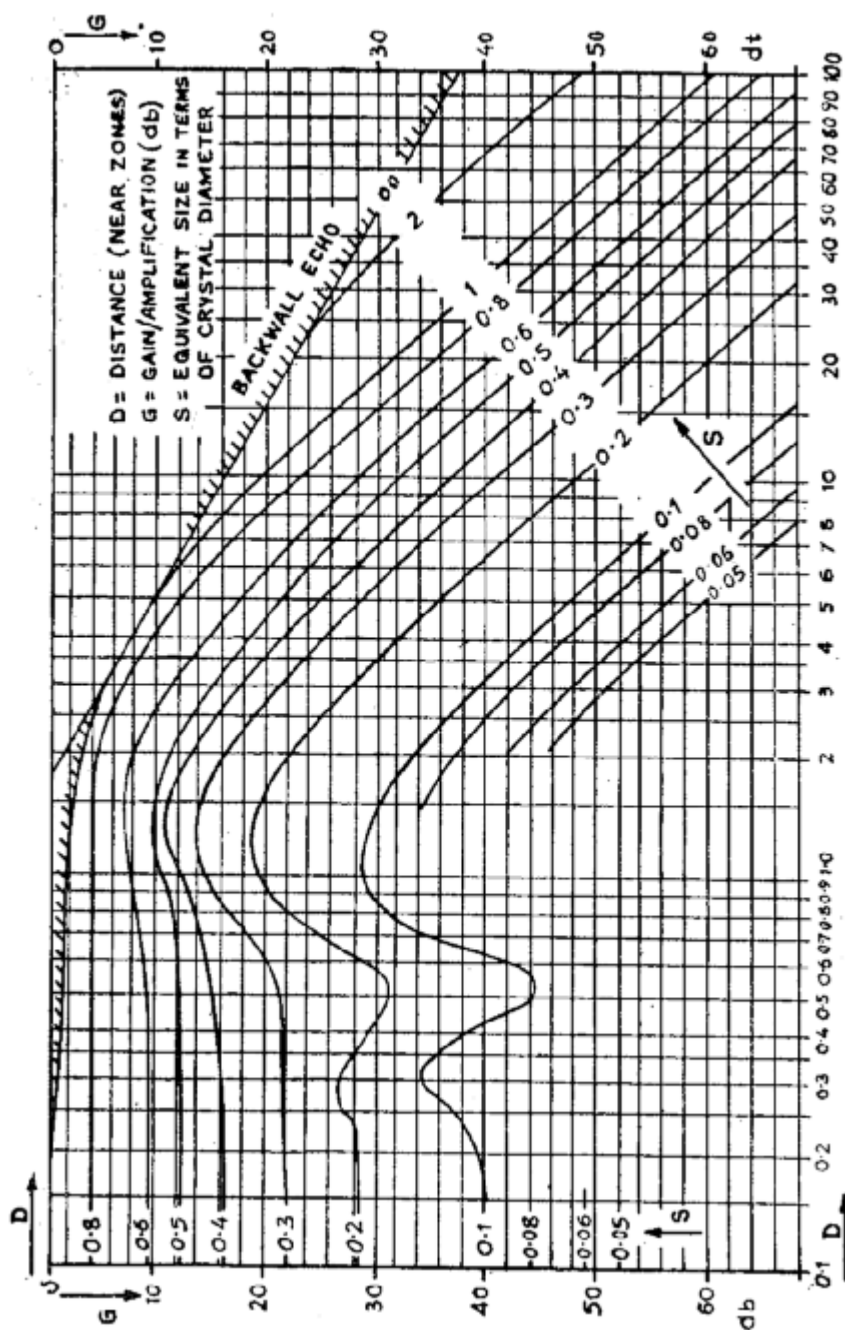
APPENDIX - A

Fig.1

APPENDIX A (Cont.d)

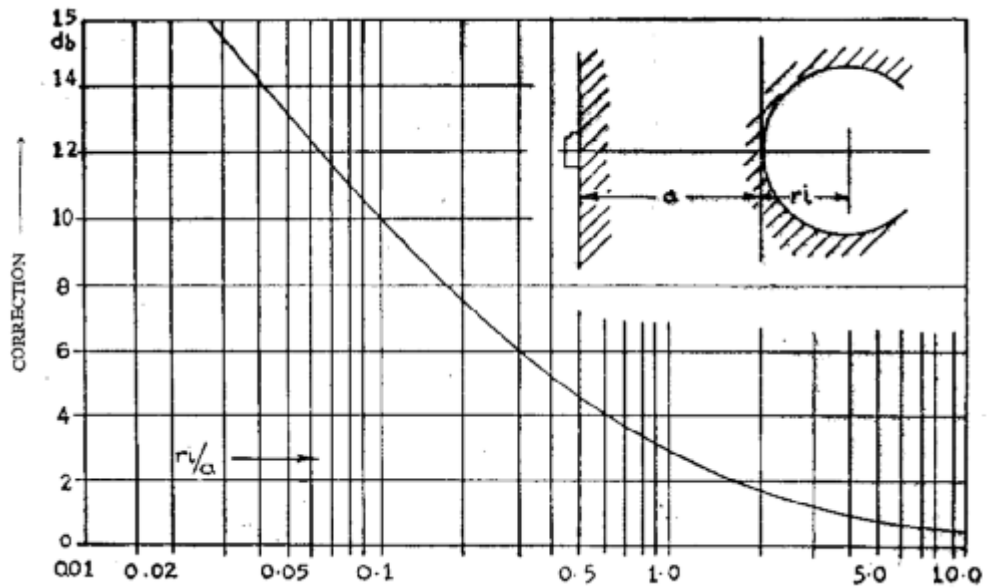


Fig.: CORRECTION FOR CURVED BACKWALL

**APPENDIX – B (See Clause 5)****FORGING MANUFACTURING RECORD**

BHEL Order No.	Description
Supplier's Name	Drawing No.
Supplier's Order No.	Specification
Forging No.	BHEL Serial No.
Cast No.	Date

Attached are the following record sheets relating to the above forging.

Sheet 1 : Ingot and Forging Details

Sheet 2 : Heat treatment Record

Sheet 3 : Non Destructive Test Record

*FATT Curves

*Magnetic Permeability Results

(*Delete if inapplicable)

The records are certified to be correct.

Signed on behalf of supplier



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APPENDIX - B (Cont'd)

Sheet 1

FORGING MANUFACTURING RECORD

INGOT & FORGING DETAILS

Supplier's Indent No.

BHEL Serial No.

Cast No.	Wt.	Steel making -Process	Vacuum Deoxidised?	Vac. Degassed Ladle/Ladle or Ladle/Ingot Mould?

Top or Bottom Poured ?

Order of Pouring .

Ingot Body Dimensions

Form (e.g. Octagonal)

Total weight

Body Weight

Forging weight

Bottom discard weight = %

Top discord weight = %

Position in Ingot if more than one per ingot

Orientation of Forging relative to Ingot:

Steam End = *Top/Bottom End of Ingot * Delete as appropriate

Forging Operations (Details of principal dimensions at each stage)

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**APPENDIX – B (Cont'd)**

Sheet 2

FORGING MANUFACTURING RECORD

HEAT TREATMENT RECORD	
Supplier's Indent No.	
BHEL Serial No.	

Refine Anneal Cycle**Stages at which Treatment Applied (Indicate by tick)****Hardening and Tempering****Stress Relieving**

As Forged

Rough Gashed

Preliminary Rough Machined

Finish Gashed

Part Gashed to Root Diameter =

Rough Bored

All wheels Gashed to Root Diameter =

Orientation of Forgings in Furnace (Indicate by tick)

Hardening	Tempering	Stress Relief	V = Vertical H= Horizontal
			V no rotation
			V rotated in cooling
			H no rotation
			H with rotation
			H ½ turned on soak
			H rotated on cooling



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APPENDIX – B (Cont'd)

Sheet 3

FORGING MANUFACTURING RECORD

Treatment Cycles

	Hardening	Tempering	Stress Relieving
Initial Equalising Temp.			
Time to soaking Temp.			
Soaking Temp. & Time			
Method of Cooling & Time			
Terminal Temp.			
	Rate of Cooling to 450 ° C		

N.D.T. RECORD	(ROTORS)
Supplier's Indent No.	
BHEL Serial No.	

Visual Exam. Of Journals

Bore Examination

Bore Diameter at Time of Inspection

Visual Date

Position, size and Nature of Defects

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**APPENDIX – B (Cont'd)**

Sheet 4

M.P. I of Bore**Date**

Magnetising Equipment

Magnetising Current

No. of Turns

Position, Size and Nature of Defects

M.P.I. of External Surfaces**Date**

Magnetising Equipment

Method

Current/ Field Strength

Result

Ultrasonic Examination**Date****Name of Operator**

Stage of Production

Equipment

Probes

Serial No.

Frequency

Attenuation Measurements

Top Position

Middle Position

Bottom Position

1 2 3

1 2 3

1 2 3

2MHz

4MHz

Testing Sensitivity (Relative to Reference Sensitivity)

Shaft Ends

Body

2MHz

4MHz

Reference Standard**Results of Examination** as laid down in Clause 5