PROFICIENCY TESTING PROGRAMME IN ULTRASONIC TESTING

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Abstract: In India, National Accreditation Board for Testing and Calibration Laboratories (NABL), under Department of Science and Technology (DST), is a recognized body to provide accreditation to the laboratories involved in testing and calibration. One of the requirements of accreditation is their participation in the Proficiency Testing. NABL identified Atomic Fuels Division, Bhabha Atomic Research Centre as a Nodal Laboratory to carry out this programme for the laboratories, which are engaged in providing services in the field of ultrasonic testing. Test samples in the form of stainless steel plate 25mm thick, containing artificial defects such as notches and side drilled holes were prepared. The participating laboratories examined these samples by angle beam technique and reported their observations in the prescribed format. The results of investigations of these laboratories were evaluated. This paper highlights various aspects related to this Proficiency Testing Programme in ultrasonic testing of stainless steel plates such as test samples used, procedure followed for examination, marking scheme evolved and evaluation procedure adopted to categorize the performance of participating laboratories.

Introduction: In India, National Accreditation Board for Testing and Calibration Laboratories (NABL), under Department of Science and Technology (DST), is a recognized body to provide accreditation to the laboratories involved in testing and calibration. The International Standard ISO/IEC 17025:1999 titled 'General Requirements for The Competence of Testing and Calibration Laboratories', specifies all the requirements that the testing and calibration laboratories have to meet, if they wish to demonstrate that they operate quality system, are technically competent and are able to generate technically valid results. One of the requirements of accreditation of testing and calibration laboratories is their participation in the Proficiency Testing. One of the techniques employed by laboratories providing services in the field of Non-Destructive Testing (NDT) of materials and components is Ultrasonic Testing. The accuracy and reliability of ultrasonic testing results depend a great deal on factors such as the capability of instruments and accessories used during examination, calibration blocks, calibration and testing procedures and proficiency of operators. NABL identified Atomic Fuels Division, Bhabha Atomic Research Centre as a Nodal Laboratory to carry out this programme for the laboratories, which are engaged in providing services in the field of ultrasonic testing. Test pieces in the form of stainless steel plate samples containing artificial defects were prepared. A detailed procedure containing the examination requirements, recording criteria, evaluation procedure and the recording format was drafted. Defect parameters useful for evaluation of test results were identified. Prior to using these samples for proficiency testing, all the test pieces were examined by two teams of nodal laboratory. This was necessary to check the homogeneity of test pieces as well as to arrive at an acceptable error band for various defect parameters. This paper gives details of the plate samples used during proficiency testing and the procedure adopted for ultrasonic examination. The marking scheme evolved for assessment of test results of various participating laboratories and the criteria followed for categorization of performance are also discussed.

Test Pieces for Proficiency Testing: Test pieces were prepared from AISI 304 stainless steel plates of size 300mm long, 145mm wide and 25mm thick. Artificial defects in the form of notches and side drilled holes were machined in these test pieces. Prior to machining, the test pieces were examined by ultrasonic testing to detect the presence of any natural defects like laminations, stringers, surface cracks, etc. After confirming that no such defect exist in the test pieces, machining of artificial defects was carried out. All test pieces contained seven artificial defects. Out of these, five defects were in the form of notches and the reaming two were side drilled holes. One of the notches is intended to be used as reference defect standard for calibration prior to examination. The notches were of different lengths and depths and were machined at various locations in the plate. However all of them were machined on one face, parallel to either

major or minor axis of the plate. Side drilled holes of different depth and diameter were machined at two opposite faces of the plate All the defects were big enough to be detected, if the examination is carried out using proper instruments by a qualified and competent operator. A reference point (0, 0) was marked at one end of the plate and all the measurements were taken with respect to the reference point. The major axis of the plate (300mm long) is assigned as X-axis and the minor axis of the plate (145mm long) is assigned as Y –axis. After the defects are machined on the test pieces, their actual locations and length was measured for all the plate samples. Table 1 gives these values for one of the plate samples PTP 01:

Table 1: Defect positions in Plate No. PTP 01

Defect No.	Defect Type	Oriented Parallel to	Defect Location from reference point (0,0)				
			Depth from Scanning surface (mm), through thickness depth	Location X/Y (mm)	Start (mm)	End (mm)	Length (mm)
1	Notch	Y	Opp. Surface, 1.25mm deep	X = 45	Y = 25	Y=50	25
2	Notch	Y	Opp. Surface, 1.75 mm deep	X = 260	Y = 40	Y=75	35
3	Notch	Y	Opp. Surface, 0.75mm deep	X = 50	Y = 91	Y = 121	30
4	SDH	X	10mm, 1.5 mm dia.	Y = 66	X = 0	X = 30	30
5	Notch	X	Opp. Surface , 0.5mm deep	Y = 25	X =200	X = 240	40
6	SDH	X	15mm, 2 mm dia	Y = 83	X =280	X = 300	20
7	Reference Notch	Y	Opp. Surface, 0.75 mm deep	X = 150	Y = 95	Y = 120	25

(Opp. Surface – Surface opposite to the scanning surface)

Prior to the examination, the plates were fully covered on all the faces, except the one from which the scanning is carried out, to mask all the defects. A small region was left uncovered adjacent to the reference notch so that the examiner can calibrate the system prior to ultrasonic examination.

Procedure for carrying out Ultrasonic Examination: A detailed procedure to be used during proficiency testing for carrying out ultrasonic examination of stainless steel plate samples was prepared by the Nodal Laboratory. The procedure covered all the aspects of ultrasonic examination such as equipment and probe to be used, calibration procedure, reference standard, scanning and recording, evaluation and reporting of indications, etc. The participating laboratories were required to carry out examination from one surface of the plate. This surface of the plate was left completely uncovered contrary to the opposite surface, which was covered to hide the artificial defects. Participating laboratories were instructed to carry out the examination, recording, evaluation and reporting strictly as per the procedure prepared for this proficiency testing. It was required to carry out angle beam examination only, using 4 MHz, 45 deg. shear wave transducer. Scanning was to be carried out from one surface along X and Y axis of the plate in two opposite directions. A reference defect standard in the form of 3% wall thickness deep (0.75mm) notch was used to draw a Distance Amplitude Correction (DAC) curve by taking readings at ½ and 1 skip distances. DAC line was considered as a reference line for evaluations of all the recordable indications. Any indication more than 20% of reference level was required to be recorded and evaluated. The parameters of defect which were required to be reported include location of defect from the reference point, depth of defect from the scanning surface, start and end points of defects with respect to the reference point, length of the defect and the amplitude of reflected signal from the defect in terms of reference level. The laboratories were required to report the data in the prescribed format provided to them during the examination.

Ultrasonic Examination at Nodal Laboratory: Before the start of Proficiency Testing Programme, all the plate samples were examined by the two teams of Nodal Laboratory. The examination was carried out as per the procedure used during Proficiency Testing. The defects in the plate samples were evaluated and the details recorded in the prescribed format. The following table gives the data record for one of the samples (PTP 01) examined by Team 1:

Table 2: Data record for examination of Plate No. PTP 01 by Team 1

Defect No.	Probe Location Index Pt. mm		Probe Movement along X/Y	Probe direction towards/away from 0	Beam Path		Amplitude		Flaw Location mm			Length mm		
	X	Y			Div.	mm	% FSH	%Ref	X	Y	Depth	Start	End	Length
1	20	32	X	Away	3.6	36	140	147	45	32	Opp. Surface	25	50	25
1	70	33	X	Towards	3.6	36	133	140	45	33	"	25	49	24
2	235	56	X	Away	3.6	36	170	180	260	56	"	39	74	35
2	284	60	X	Towards	3.6	36	170	180	259	60		40	75	35
3	25	105	X	Away	3.6	36	100	105	50	105	"	94	123	29
3	75	104	X	Towards	3.6	36	95	98	50	104	"	93	123	30
4	8	29	Y	Away	5.6	56	25	43	8	69	10.5	0	30	30
4	8	102	Y	Towards	5.6	56	20	35	8	62	10.5	0	30	30
5	215	49	Y	Towards	3.6	36	60	63	215	24	Opp. Surface	201	241	40
6	291	50	Y	Away	5.0	50	20	29	291	85	14.5	281	301	20
6	293	117	Y	Towards	5.0	50	20	29	293	82	14.5	281	301	20

From the above table it can be seen that, all the defects, except defect No.5, are reported twice, once while scanning away from zero and then while scanning towards zero. Since defect No. 5 is near the edge of the plate, not enough space is available for probe movement to pick-up this defect, while scanning away from zero. The parameters such as probe location, direction of probe movement, beam path, amplitude of indication in terms of full screen height (% FSH) and the extent (length) of indication are recorded during the examination. Other parameters like flaw location and depth are calculated from beam angle and beam path while amplitude in terms of reference level is calculated from the calibration curve (DAC).

For evaluation of the results, the parameters from the above table which were considered important are flaw location (X, if the flaw is oriented along Y-axis and Y, if the flaw is oriented along X-axis), depth from scanning surface, start, end and length of the flaw and amplitude in terms of reference level. These parameters were compared with the actual measurements for both the teams of Nodal laboratory and the error involved in measurement of these parameters by these two teams was found out. Such comparison was made for all the plate samples used during proficiency testing. The estimation of error in the ultrasonic measurements made by two teams of Nodal Laboratory for all the defect parameters in all the test plates was an important step for evaluation of results of participating laboratories. The error gives the measure of scatter that is obtained while making measurement of a particular parameter of a defect by two teams of the Nodal laboratory. This was considered as an *'acceptable error band'* while evaluating the results of participating laboratories. For all the parameters of a defect (location, depth, start, end, length), except amplitude, it was possible to compare the results with the actual measurements and hence get the error. However for amplitude of the signal, no reference (actual value) was available. In this case, the amplitude information from both the team is taken as a reference and the dB difference (20 * log {Amplitude1/Amplitude2) was found out. Lower value of dB difference is an indication of low scatter in the amplitude measurement for a particular defect by two teams of Nodal Laboratory.

Conducting the Proficiency Testing Programme: A total of seventeen laboratories participated in this proficiency testing programme. These laboratories belonged to different regions of India. Out of these seventeen laboratories, eight laboratories have NABL accreditation, while the remaining nine laboratories are not accredited to NABL. For the laboratories in Mumbai region the programme was conducted on a single day, wherein all the laboratories were invited at one place for carrying out ultrasonic examination of plate samples. The laboratories examined two samples and reported the results in prescribed format. For the laboratories outside Mumbai, the

plate samples were sealed and sent for examination. The laboratories were informed of their examination schedule in advance so that they could complete the examination and reporting within a stipulated time period a soon as the samples are received.

Evaluation of Test Results of Participating Laboratories: The objective of proficiency testing was to assess the performance of an inspection team from a testing laboratory while carrying out ultrasonic testing of stainless steel plate. In order to evaluate the results, the following were taken into account:

(a) How many flaws in the test samples are detected by the participating laboratory?
(b) Whether the participating laboratory has reported any flaw which does not exists in the test sample?
(c) How accurately participating laboratory has reported various flaw parameters viz. location, depth from scanning surface, start and end points of defect and length of defect with respect to the actual measurement?
(d) How accurately the participating laboratory has reported the amplitude of defect indication with respect to the one reported by two teams of Nodal laboratory?
(e) Whether the participating laboratory is able to evaluate the indications correctly and report the observations in the prescribed recording format?

Credit is given if the laboratory detects the defect present in the sample. However, if the laboratory reports some defect, which is not present (False Call) then the points are deducted. In case of flaw parameters, full credit is given to the participating laboratory if the reported parameter is equal to the actual measured value or falls in the 'acceptable error band' that is decided by the maximum error encountered by the Nodal laboratory. For example, if for a particular defect parameter, the error encountered by both the teams of Nodal Laboratory is zero, then no error band exists for this defect parameter. The Credit for this parameter reported by the participating laboratory will be based on magnitude of error it encounters. In another case, consider that Team 1 of Nodal Laboratory reports a parameter of defect with an error of 3mm and Team 2 reports the same parameter with an error on 0 mm with respect to the actual measurement. The participating laboratory reports this parameter with an error of 1mm with respect to the actual measurement. In this case, full credit is given to the participating laboratory for this parameter even though it encounters an error, as the error in the measurement is less than that encountered by one of the Teams of Nodal Laboratory. This philosophy was followed for all the parameters of defects in the plate samples. In case of amplitude of indication, full credit is given if the amplitude reported by participating laboratory is equal to one of the amplitude readings of two teams of Nodal Laboratory or if it falls within the amplitude readings reported by these two teams.

Marking Scheme: In order to quantify the results of the participating laboratories and decide about the proficiency of its team members in ultrasonic testing of stainless steel plates, the following marking scheme was adopted:

- For each flaw detected: 5 marks
- False call: -5 marks
- Data record: 10 marks
- Each parameter of flaw evaluation viz. X/Y co-ordinate, depth, start, end, length and amplitude carry 10 marks

The marks scored by the participating laboratory while reporting the defect parameters are based on the *error value* involved in their measurements. The error value is the absolute error encountered by the participating laboratory with respect to the actual measurement minus the maximum error encountered by two teams of Nodal laboratory. For example, consider that the error encountered by two teams of Nodal laboratory for a particular defect parameter is 2mm and 0mm respectively, with reference to the actual measurement. The participating laboratory reports this parameter with an error of 3mm with reference to the actual measurement. During evaluation

of test result, the credit points are awarded to the participating laboratory based on the error value of 1mm (3mm -2mm) and not 3mm (absolute error). The following table gives the details of marking scheme evolved for all the defect parameters, except amplitude:

Table 3: Marking scheme for defect parameters (except amplitude)

Error value (mm)	Marks out of 10
Absolute Error ≤ that of Nodal Laboratory	10
Error Value ≤ 2mm	8
Error Value > than 2mm but ≤ 4mm	6
Error Value > than 4mm but < 10mm	4
Error Value ≥ than 10mm	0

In the case of amplitude, if the value reported by the participating laboratory is equal to the value reported by any of the two teams of Nodal laboratory or if it falls within the values reported by two teams of Nodal Laboratory or if the dB difference is less than the one observed between the two teams of Nodal laboratory, then full credit (10 marks) is given to the participating laboratory. In this case also, the dB difference considered while giving the credit points to the participating laboratory is over and above the dB difference between two teams of Nodal laboratory. For example, consider than two teams of Nodal laboratory report the amplitude for a particular defect as 80% and 90% respectively. The dB difference in this case is 1.02dB. The participating laboratory gets full credit, if it reports the amplitude as 80% or 90% or any figure between 80% and 90%. It also gets full credit if it reports the amplitude more than 90% or less than 80%, provided the dB difference with respect to the Nodal laboratory is less than 1.02dB i.e. if the amplitude reading reported by the participating laboratory falls between 71% and 101.%. If the amplitude reading reported by the participating laboratory does not fall within this band, then the credit points are given based on the dB difference value, which is the dB difference of the participating laboratory minus the dB difference of Nodal laboratory. The following table gives the marking scheme adopted for amplitude:

Table 4: Marking scheme for amplitude

dB Difference Value	Marks out of 10
dB Difference < than of two teams of Nodal Laboratory	10
dB Difference Value ≤ 2 dB	8
dB Difference Value > than 2 dB but ≤ 4 dB	6
dB Difference Value > than 4 dB but <10 dB	4
dB Difference Value ≥ than 10 dB	0

With the above marking scheme, maximum marks that can be scored by a participating laboratory comes to 400. The break-up of these marks is given below:

1. Total number of defects (not considering the reference defect) in each plate sample: 6
2. Total marks for all the defects detected @ 5 marks per defect: 30 marks
3. Data record: 10 marks
4. Marks for defect parameters:
   - 4.1 Total number of defects (not considering the reference defect) in each plate: 6
   - 4.2 Defect parameters considered useful for defect evaluation (location, depth from scanning surface, start, end, length and amplitude) for each defect: 6
   - 4.3 Total marks for evaluation of each defect @ 10marks for each parameter: 60 marks
   - 4.4 Total marks for evaluation of all the defect in the plate sample containing 6 defects: 6 x 60 = 360 marks
5. Total marks for proficiency testing: 30 + 10 + 360 = 400

Qualification Criteria: All the laboratories that participated in proficiency testing were required to examine two plate samples. Depending on the marks scored for both the samples, these laboratories were put into the following three categories:

Satisfactory: Laboratory that has scored an average of more than or equal to 80%, with minimum of 70% in both the plates.
Questionable: Laboratory that has scored an average of less than 80% but more than or equal to 70%, with minimum of 60% in both the plates.
Unsatisfactory: Laboratory that has scored an average of less than 70% or less than 60% in any of the plates.
Conclusions: The reliability of any non-destructive examination depends a great deal on the capability of test equipments and accessories used, the effectiveness of test procedure(s) and the competence of inspection personnel who carry out these examinations. Ultrasonic testing is highly operator dependent and its results are greatly influenced by their competence. During proficiency testing programme on ultrasonic testing of stainless steel plates, the only variable was the proficiency of test operators as the type of test equipment and transducer to be used as well as the test procedure to be followed during examination were uniform for all the laboratories. All the operators that participated in this programme were qualified and certified to Level II or higher. Although various fabrication and inspection codes also call for some minimum level of qualification and certification of NDT inspection personnel, this is many a time not adequate. The Syllabus for practical training during certification courses is not well defined. The certification to various 'Levels' also does not guarantee that the certified operator will not miss any unacceptable defect. It is therefore important that the proficiency of operators that carry out examinations should be established. ASME Boiler & Pressure Vessel Code Sec. XI has realized this and has included the need of Performance Demonstration Tests for detection and sizing of fabrication and service-induced defects. Accreditation of test laboratories by a recognized national or international body is an important step towards building the confidence that the test results produced by these laboratories are reliable. It is mandatory for the laboratory that is accredited to participate in the proficiency testing programme. Proficiency Testing Programme in Ultrasonic Testing of Stainless Steel Plates is the first programme of its kind carried out in India in the field of Non-Destructive Testing. It is planned to carry out such programmes for various products by employing different NDT techniques. The need for such programmes for assurance of structural integrity of critical components can not be over emphasized.