

Qualifying the Effectiveness of Non-Destructive Examination

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1.0 Introduction

One of the most important inputs required for structural integrity assessment of engineering components is the knowledge about the presence or absence of any significant flaw and its characteristics. What type and size of flaw is significant for safe operation of component depends on variety of factors such as material of construction, operating parameters, environmental degradation, etc. Non-Destructive Examination (NDE) plays a vital role in detection and characterization of flaws in engineering components. Ultrasonic testing is one of the most widely used NDE techniques for this purpose during fabrication and in-service inspection of components. It is predominantly used for flaw characterization and for thickness measurement and is finding increasing applications for material properties characterization. Ultrasonic testing for flaw detection is often carried out with respect to a reference flaw. In a sense, the reference flaw represents the size of the significant defect that is required to be detected. During examination of a component, if any flaw of this size or higher is observed then it is characterized in terms of its geometry (size, shape and orientation) and nature (lamination, slag, porosity, crack, etc.). There are several techniques, both conventional and advanced, which are being used for these tasks. One of the important links which is often missing in NDE including the routine ultrasonic examination is to come out with the uncertainty associated with various aspects of testing such as detection, sizing and characterization. This information is vital to the design engineers so that they can incorporate sufficient safety margin in design or conservatism in their fitness-for-service assessment. Often there is doubt that: whether the testing procedure has missed any significant flaw? What is the uncertainty involved in flaw characterization? Whether the operator or the test system is proficient enough to ensure effective inspection? Over the years, several tools and methodologies have been evolved to address these issues. This paper deals with these aspects for qualifying the effectiveness of NDE techniques in general and ultrasonic testing in particular.

2.0 Uncertainty in NDE

ISO defines Uncertainty as: *A parameter, associated with the result of the measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.* Some of the important steps involved in coming out with the uncertainty value include: identifying what is being measured, listing of factors that may affect measurement, quantifying them, combining these factors using mathematical tools and finally coming out with the uncertainty value. In NDE, there are three main components of uncertainty, viz. (i) **Uncertainty in detection**, which includes limit of detection and false calls, (ii) **Uncertainty in classification of flaw** in terms of its nature (planar or volumetric, metallurgical origin) and (iii) **Uncertainty of measurement** in terms of its size. Each of these affects the overall effectiveness of NDE for the intended purpose.

Detection uncertainty relates to whether or not a flaw has been detected. Since no engineering component is free from flaw, one has to define the size of significant flaw that should be detected to come out with the uncertainty in detection. There can be four possible outcomes while dealing with uncertainty in flaw detection: (i) A flaw is present and the NDE detects it (True Positive), (ii) No significant flaw exists and the NDE also does not report any flaw indication (True Negative), (iii) A significant flaw exists and the NDE does not detect it (False Negative) and (iv) No significant flaw exists and the NDE indicates a presence of flaw (False Positive). While the first two cases are acceptable, the third one leads to a safety concern and the last one may lead to a healthy component being retired from service resulting in economic penalty. The above cases are the foundation for the concept of 'Probability of Detection' (POD). PODs try to assess a minimum flaw size that will be reliably detected by NDE technique. This is done by plotting the accumulation of flaws detected against the flaw size of all the flaws 'detected' or that produce a response over some threshold. Ideally all flaws over some critical size will be detected and flaws smaller than that are not detected. The tool most commonly used for POD description is the POD curve. POD is often expressed in terms of probability that a particular size of flaw is detected with some confidence level. For example it may be expressed as: A 3.0 mm deep crack has a 90% probability of detection with 95% confidence level.

Uncertainty in flaw classification relates to whether the nature of flaw has been identified correctly. This is very significant for some NDE techniques such as ultrasonic wherein such assessment is based on interpretation of signals received from the flaw. The skill of the operator plays a vital role in this regard. With the availability of signal processing tools there is now a higher confidence level on flaw classification as compared to the one obtained by conventional means.

Uncertainty in measurement relates to the in-accuracy involved in sizing the flaw dimensions such as depth from scanning surface, length of flaws and its through thickness dimension. This has an important bearing on fitness-for-service assessment of flaw. These assessments are done based on fracture mechanics which decides if a particular size of flaw in component can lead to catastrophic failure under the operating conditions. Any gross undersizing in flaw dimensions may lead to safety concern while gross oversizing can lead to economic penalty wherein a healthy component may be retired from service. It is therefore important not only to size the flaw dimensions very accurately but also report the uncertainty involved in measurement to help the designer provide appropriate safety margins in design or conservatism in their assessment while taking decision regarding safe operation of the component. The sizing accuracy or its uncertainty is analyzed by comparing the NDE estimates with the true value found out by destructive means (sometimes by other methods such as profilometry of replica). There is an uncertainty involved in direct measurement as well, which needs to be accounted for. Sizing inaccuracy can be expressed in various forms. The simplest way is to plot the true flaw size with the NDE estimates. A straight 45° line represents an ideal condition. One can also incorporate tolerances lines in the graph running parallel to the ideal line. There have also been efforts to quantify uncertainty in flaw sizing using mathematical models. These methods identify factors that can lead to uncertainty in sizing and weigh them appropriately before arriving at a particular value. Such analysis is useful in fracture mechanics assessment and also to find out if there has been real growth in the flaw size since the last inspection.

3.0 Performance Demonstration of Certified NDE personnel

Any code or standard demands that NDE of any component shall be carried out by a trained and certified operator. The operator is certified by a recognized certification scheme such as ISNT or ASNT. During the certification examination, the operator has to undertake a practical examination to demonstrate his skill on flaw detection and characterization. This test is usually performed on a test pieces containing flaws of known dimensions. The test pieces cover a limited range of geometry and also a limited range of defect type. This means that the test pieces on which an operator has been qualified may not be directly relevant to a particular inspection he/she is going to perform in the field. Also, many qualification schemes do not require the operator to estimate the through-wall dimensions of the flaw during certification examination, which is a vital flaw parameter while dealing with the actual component. In effect, it means that a trained and certified NDE operator does not necessarily ensure a good quality inspection. The problem is more severe while dealing with some flaws such as intergranular stress corrosion cracking (IGSCC). IGSCC contribute to majority of failures in austenitic stainless steel components. There have been many instances wherein certified operators have either missed such cracks completely during ultrasonic examination or have grossly undersized them. The ASME B&PV Code Sec. XI, which deals with nuclear components, has recommended a Performance Demonstration for certified UT operators before they undertake actual inspection in the plant. The code gives guidelines on the minimum number of samples required for such demonstration, number and type of flaws to be put in the test samples and also the acceptance criteria for performance with respect to detection and sizing of length and through-wall depth...

The **European Network for Inspection Qualification (ENIQ)** relies on one of the following two approaches for qualification of inspection system:

- (i) Practical trials of the inspection conducted on a simplified or representative test pieces resembling the component to be inspected
- (ii) Technical justification, which involves assembling all the evidence available on the effectiveness of the inspection including previous experience of its application, laboratory studies, mathematical modeling, physical reasoning, etc.

The qualification of inspection system (including performance demonstration) can be very costly, time consuming and complex process. Hence, its use tends to be reserved for situations where high level of inspection effectiveness needs to be demonstrated or where there is very little previous experience of an inspection, like use of novel NDE method for a particular application.

4.0 Need for Natural Flawed Specimen

The sensitivity of NDE technique for the intended purpose is demonstrated by using a reference standard. In ultrasonic testing, a reference block (same material and geometry as the component to be inspected) contains artificial defects in the form of flat bottom holes, side drilled holes and notches. The type, number, location and size of reference defects are specified by the referencing code, standard or procedure. Prior to examination, the test system is calibrated on the reference standard to ensure that the sensitivity level of inspection system during actual inspection detects a flaw equal to or more in size than the reference flaw. For some NDE techniques like ultrasonics, the concept of using artificial defects during calibration may lead to poor quality inspection of the component. Ultrasonic is a reflection

based technique. The detection of flaw during inspection depends a great deal on the measurable amount of reflection reaching back to the probe. The reference flaws in calibration standard have smooth surfaces and hence good reflectors of incident sound energy. On the other hand, some real flaws like IGSCC has rough surface and exhibit extensive branching. They may be unfavorably oriented and also filled with corrosion products. These factors make them poor reflectors of incident sound wave. As a result, an IGSCC may reflect only a fraction of incident sound energy back to the probe as compared to the artificial flaw of same size in the calibration standard. In an extreme case, this may lead to a real crack being present in the component but not detected during testing. The same logic when applied for depth sizing of such flaws based on comparison of reflected signal amplitude from crack and artificial flaw, can lead to gross undersizing. This anomaly can be overcome by using a calibration standard containing natural flaws instead of artificial reflectors. Such flaws can be generated in laboratory by accelerated tests and then implanted in calibration standard at appropriate places. IGSCC of varying depths are generated in authors' laboratory on 25 mm thick AISI 304 austenitic stainless steel plates. The plates were sensitized at 677 C for 5 hours. A circular groove (almost 20 mm deep and 5 mm wide) was machined at the centre of the plate, in which weld was deposited under restraint. These conditions led to sensitized microstructure and sufficient residual tensile stress in the heat affected zone. The plate was then exposed to ploythionic acid, which caused cracking at room temperature. Several samples with varying degree of IGSCC were generated in laboratory. These plates were examined using a machined notch (10% wall thickness deep) and then a real IGSCC as reference defect standard. It was observed that the depth sizing accuracy of IGSCC by amplitude comparison technique improved considerably when IGSCC was used as reference defect.

5.0 Proficiency Testing, An ISO 17025 requirement

The accreditation of testing and calibration laboratories based on ISO 17025 requires that the laboratories participate in the proficiency testing. 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. NABL identified authors' laboratory as a Nodal Laboratory to conduct proficiency testing in the field of ultrasonic examination for the laboratories that are engaged in providing services to the industries in the filed of ultrasonics. This programme was first of its kind to be conducted in India in the field of NDE. Test pieces containing artificial defects in the form of notches and side drilled holes were prepared from AISI 304 stainless steel plates. The plates were then fully covered on all the faces to mask the defects, except the one from which the scanning is carried out. A detailed procedure for carrying out ultrasonic examination of stainless steel plate samples was prepared by the Nodal Laboratory. Participating laboratories were instructed to carry out the examination, recording, evaluation and reporting strictly as per the procedure prepared for this proficiency testing. Prior to proficiency testing, all the test samples were examined by two teams of Nodal Laboratory. The examination was carried out as per the procedure used during Proficiency Testing. The parameters of the defect which were considered useful for evaluation were (i) location (X/Y from reference point), (ii) depth from the scanning surface, (iii) location corresponding to the start of the defect (X/Y from the reference point), (iv) location corresponding to the end of the defect (X/Y from the reference point), (v) length of the defect (from the start and end points) and (vi) amplitude of the reflected signal in terms of reference level. These parameters reported by both the teams of Nodal laboratory were compared with the actual

measurements and the error involved was found out. Such comparison was made for all the plate samples used during proficiency testing. The error encountered by the Nodal Laboratory was considered as an acceptable error band while evaluating the results of participating laboratory. The first step towards evaluation of results of participating laboratories was computation of errors made during measurement of various defect parameters in the test samples. The measured value of defect parameters was compared with the actual value, and the error was obtained. A marking scheme was evolved to assess the results of examination of participating laboratory. Credit is given based on the detection of defects present in the plate samples and the compliance of reported value of the various defect parameters with the actual value or the value reported by the Nodal Laboratory. Depending on the marks scored by a participating laboratory during the examination of plate samples, their performance was categorized as Satisfactory, Questionable and Unsatisfactory.

6.0 Conclusion

The results of NDE examination are affected by three factors: **the effectiveness of test procedure, the capability of test equipments and the competence of operators**. From the fracture mechanics point of view it is not just important to ensure a high quality NDE but also to qualify its effectiveness taking into consideration the various uncertainties. This information is useful to the designers in fitness-for-service assessment and taking decision regarding the acceptance of component for the intended service. Various tools and mathematical models which are being evolved from time-to-time are useful in this regard.

7.0 References

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