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Bayesian analysis of flaw sizing data of the NESC III exercise

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Abstract

Non-destructive inspections are performed to give confidence of the non-existence of flaws exceeding a certain safe limit in the inspected structural component. The principal uncertainties related to these inspections are the probability of not detecting an existing flaw larger than a given size, the probability of a false call, and the uncertainty related to the sizing of a flaw. Inspection reliability models aim to account for these uncertainties. This paper presents the analysis of sizing uncertainty of flaws for the results of the NESC III Round Robin Trials on defect-containing dissimilar metal welds. Model parameters are first estimated to characterize the sizing capabilities of various teams. A Bayesian updating of the flaw depth distribution is then demonstrated by combining information from measurement results and sizing performance.

Keywords: Inspection reliability; NDT; Bayesian modelling; Probability models for flaw sizing; NESC

1. Introduction

In-service inspection of pressure retaining equipment plays a major role in monitoring the performance of pressure vessels and auxiliary components in the nuclear industry. Much research effort is dedicated to areas related to the inspection, flaw evaluation and repair of in-service pressure equipment. Unfortunately, inspections such as non-destructive examinations (NDE) are never perfect. The principal uncertainties related to these inspections are flaw characterisation, probability of not detecting an existing flaw, probability of a false call and uncertainty related to the sizing of a flaw.

These considerations have led to the introduction of the concept of inspection reliability, that is the attempt to measure and model the capability of a given inspection system to find flaws, to correctly size them and to reject false calls. Such measures of inspection capability are needed, for instance, in structural reliability modelling to properly account for uncertainties related to flaw detection and sizing.

The parameters for the inspection reliability models should be estimated from the most accurate data available. The most representative data would naturally be those obtained from the "real" inspections at the plant. There are however obstacles to obtaining such data. Even if the inspection records are available, there is no knowledge of the true distribution of the number and sizes of flaws in the inspected structures, and thus parameter estimation from field data is practically impossible. In some rare cases, structural components where significant flaws have been detected have been removed from the plant and investigated thoroughly to obtain reliable information on the true size of the flaws.

The most significant information that has been used as a basis for developing detection probability distributions comes from Round Robin Trials (RRT). In these exercises, structural components containing known (usually artificially manufactured) flaws are inspected by several inspection teams. After the completion of the inspection rounds, the components are destructively examined to determine the true flaw sizes and investigate indications of unintended flaws. In these cases, the results can be used to determine parameters for detection and sizing models.

In this paper we first give a short summary of the NESC III inspection blind RRT and then present an analysis of

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the through-wall sizing results. The modelling principle follows the one presented in Simola and Pulkkinen [1], and is based on the use of Bayesian inference. This is a natural approach to express uncertainties and to use accumulating information to update the confidence on the existence/non-existence or the size of a flaw. We also give some background to Bayesian modelling and statistics, and justification of its application to the field of inspection management.

2. NESC III exercise

The NESC-III Blind RRT was organised and managed by the Joint Research Centre (JRC) in Petten, The Netherlands. A dedicated pipe mock-up was manufactured containing two different types of circumferential dissimilar metal weld: Weld A (austenitic 308L) and Weld B (Inconel 182), and a number of intentional defects were manufactured in each weld. The weld and material configurations are listed in Fig. 1. Most of the defects were in the weld material, with some located in the buttering. JRC circulated this component to the different participating inspection teams according to an agreed inspection schedule. The teams then had 2 weeks to carry out their inspections and could choose whether to inspect only one weld or both. During circulation, the component was equipped with an anti X-ray device. JRC therefore performed no invigilation of the inspections from the external surface. However, teams could also choose to inspect the welds from the internal surface; in this case the inspections were invigilated by JRC staff. The dimensions of the mock-up are shown in Fig. 2.

Seven teams from six different European countries participated in the NESC-III trials. The inspections were carried out in the period between August 2003 and June 2004. A total of 17 inspection data sets were handed in to the JRC for the two welds. Only two teams inspected the component from the inner surface. The main ultrasonic techniques applied by the inspection teams were pulse echo (longitudinal and shear wave), focused probes, phased array and time of flight diffraction.

The teams were requested to carry out a full volumetric inspection of at least one of the two welds (and could choose whether to inspect from the inner or outer surface). They were requested to look for circumferential defects (outer surface breaking defects, in Weld A only; embedded defects; inner surface breaking defects) and axial defects (inner surface breaking, in weld B only). The detection target for both welds was set to 5×10 mm and the sizing targets were set at ± 3 mm for through-wall extent sizing and $+10/-5$ mm for length sizing. In this paper we use for simplicity the expression "flaw depth" with the meaning of through-wall flaw size.

The austenitic weld (A) contained a total of 10 intended defects, with a through-wall size ranging between 3.8 and 18.7 mm and the Inconel 182 weld (B) contained a total of 8 intended defects, with a through-wall size ranging between 2.9 and 18 mm. Destructive examination was performed by JRC in Petten. A total of four defect manufacturing types were inserted in the NESC-III RRT mock-up: (1) PISC Type A (sharp edge EDM notch), (2) lack of sidewall fusion (LOF), (3) technique "A" (smooth flaw technique), and (4) technique "B" (simulation of stress corrosion cracking).

A more detailed description of the NESC III exercise and its results can be found in [2].

3. Models for flaw sizing and updating flaw depth distribution

Inspection Round Robin Trials, such as the PISC and NESC exercises [3,4], produce data on sizing accuracy of known flaw sizes. These can be statistically analysed to provide results on the performance of different inspection

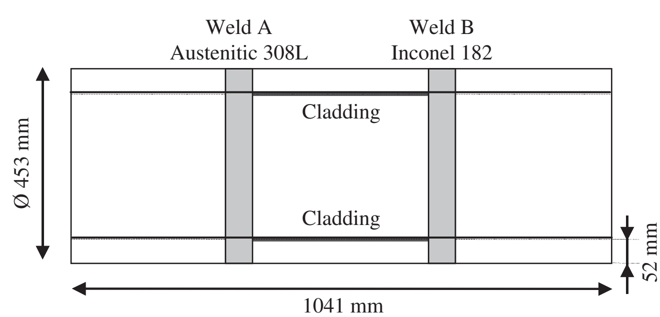

Fig. 2. Schematic and dimensions of NESC-III component.

ID	Description	Weld A	Weld B
#1	Ferritic base material	SA508	SA508
#2	Austenitic base material	304L	304L
#3	Buttering	309L + 308L	Inconel 182
#4	Weld filler	308L	Inconel 182
#5	Cladding material	309L	309L

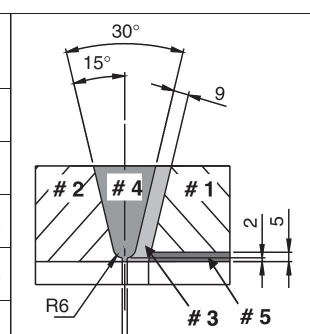

Fig. 1. Materials and weld configuration of NESC-3 component.