Intercomparison of Techniques for Pressure Tube Inspection and Diagnostics

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1. Introduction

This document describes a summary of sample inspection results performed on the KOR-1 pressure tube sample. The sample inspections were performed by seven participants. This study is to intercompare inspection and diagnosis techniques for characterization of pressure tube. As a part of this study, a KOR-1 pressure tube sample was prepared by KEPRI from pressure tube material in Zr-2.5% Nd alloy, and circulated to seven participants. A round-robin series of tests, in the laboratories of seven participants, was performed and seven sample inspection reports from participants were issued. KEPRI who is the originating investigator of KOR1 pressure tube sample have prepared this sample summary report, and the summary report include basically the following:

- The FLAW CHARACTERIZATION TABLE of KOR1 sample and supporting documentation.
- The CROSS REFERENCE TABLES for each investigator, which is the SAMPLE INSPECTION TABLE that cross reference to the FLAW CHARACTERIZATION TABLE.
- Each Sample Inspection Report as Appendices.

2. Description of Sample

2.1 Applied Requirement of Flaw Design and Fabrication

For this study, a KOR-1 pressure tube sample was prepared from pressure tube material in Zr-2.5% Nb alloy. Artificial flaws in KOR1-sample were designed and fabricated as per the requirements of working material issued on July 1999 and the Canadian standard CSA N285.4-94. Defects, such as fretting damage and crack-like notch, typical of those that can arise in CANDU reactors were introduced into pressure tube sections. They were duplicate real defects of concern as realistically as possible. The punch mark was considered at 12:00 o'clock looking at the face on the end with the punch mark. Axial distance was measured in mm from the same face (not from the punch mark itself).

2.2 Type and Dimension of Flaws

The dimensions of KOR-1 pressure tube sample are 100mm I.D. and 605mm length by 4.1 mm wall, unirradiated. A piece of real pressure tube from field NPP, including some unintentional scratched on the inner and external tube surfaces, was used for KOR1 sample fabrication. For samples with an outside covering, the covering was started 50 mm from the end to allow for an extension tube to be clamped on. All flaws on the inner and external tube surfaces were simulated with an EDM notch with a rectangular and semi-elliptical profile. Blind flaws were created on the outside of samples by covering with a plastic sleeve. All the as-built flaw dimensions are based on profilometry results. Additionally, a few scratches were unintentionally made on internal and external surface of KOR-1 sample tube during handling, and these were verified and taken picture by fiberscope. Some of these indications were reported by seven participants during round-robin-test.

3. Applied Inspection Methods

For this study, two kinds of inspection method, ultrasonic and eddy current techniques were mainly used by seven participants to characterize the artificial flaws of KOR-1 pressure tube sample. Six of seven participants applied one NDE method(UT) to inspect KOR1 sample, and one participant applied two kinds of NDE method(UT & ECT) and produced two inspection results. To measure the actual flaw dimension of KOR1 sample by using profilometry, replicas were taken to measure the real size of flaws.

4. INSPECTION RESULTS

4.1 Flaw Detection Results

Flaw detection results are based on the total number of flaws detected by seven participants and two kinds of NDE method. The numbers of flaws in KOR1 are total 12. Total eight inspection results from seven laboratory were used for this analysis. Six laboratories produced every one result individually, and one laboratory produced two results. Five among the seven participants detected all flaws in KOR-1 pressure tube sample, one participant using UT detected 10 flaws out of 12, and two participants using ET detected 6 flaws out of 12, and 4 flaws out of 12. The round-robin test result of KOR-1 shows that the average detectability of UT method is 97%, and that of UT method is 61% respectively. UT method showed the better flaw detectability than ECT method. Six participants reported additional indications, these indications were verified by fiberscope as unintentional scratches whose depth were approximately 0.1mm above. Generally round-robin test result of KOR-1 showed very good delectability of flaws.

The average detectability of OD flaws by two NDE methods is 78%, and that of ID flaws is 94% respectively. Detectability of ID flaw is higher than that of OD flaws.
UT method showed the better flaw detectability than ECT method for OD and ID flaws. Notably, ECT method showed bad detectability on OD flaws of sample tube in comparison to UT method, but two NDE methods showed nearly equal detectability on ID flaws.

4.2 Flaw Sizing Results

Flaw sizing results are based on the sizing accuracy of artificial flaws in KOR-1 sample except unintentional scratches. For the analysis of round-robin-test result, the sizing accuracy of depth, width, and length of flaw were considered. The flaw sizing accuracy is expressed in root-mean-square(RMS) error. The accuracy of flaw sizing is determined by calculating three linear regression analysis components : regression line slope, correlation coefficient, and the root-mean-square(RMS) error. The RMS sizing error of UT methods(five laboratories applied) is within 1.309mm in length, 0.802mm in width, and 0.258mm in depth, and the RMS sizing error of ECT methods(three laboratories applied) is within 1.656mm in length, 1.003mm in width, and 0.497mm in depth respectively. The UT method was more accurate than ECT method in flaw sizing, and the overall RMS sizing error of UT method is within 0.789mm, and ECT is within 1.052mm respectively.

The overall RMS sizing error of all flaws by seven participants is within 1.584mm in length, 0.843mm in width, and 0.382mm in depth respectively as shown in Figure 1 below. Especially, the depth sizing accuracy showed the best results, and length sizing accuracy showed the worst result.

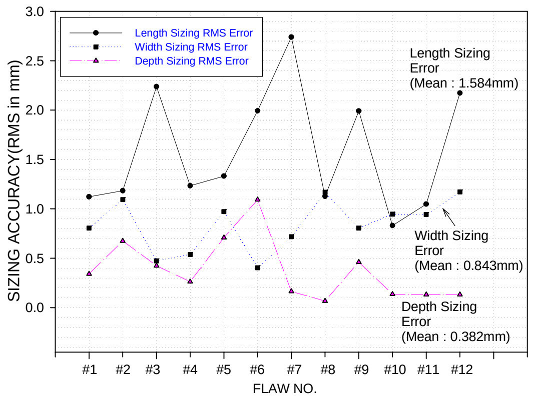

Figure 1 : Sizing RMS Error of three types of Flaw Dimension

The ID flaws were more accurately sized than OD flaws. The RMS sizing error of OD flaws is within 1.584mm in length, 0.843mm in width, 0.386mm in depth, and that of ID flaws is within 1.295mm in length, 1.075mm in width, and 0.113mm in depth respectively.
The wear type flaw among three kinds of flaw in KOR1 sample was more accurately sized than other two flaw type, and inclined flaws show the worst sizing accuracy. The RMS sizing error of wear type flaws is within 0.947mm in length, 0.415mm in width, 0.074mm in depth, and that of inclined flaws is within 1.431mm in length, 0.737mm in width, and 0.725mm in depth respectively. The RMS sizing error of axial & circumferential flaws is within 1.163mm in length, 0.882mm in width, and 0.198mm in depth respectively.

5. Conclusions

A round-robin series of tests by seven participants was performed to intercompare and evaluate detectability and sizing accuracy of applied NDE methods to KOR-1 pressure tube sample. Based on the result obtained from these round-robin-tests, we have elucidated the following results:
(1) Artificial flaws in KOR-1 pressure tube sample were all detected. Two kinds of applied NDE method for the inspection of pressure tube KOR1 sample provides good flaw detectability, and UT method provides better detectability than ECT method. Detectability of ID flaws was higher than that of OD flaws.
(2) Two kinds of NDE method applied for flaw sizing showed very reasonable sizing estimates, and the overall RMS sizing error by seven participants was within 1.584mm in length, 0.843mm in width, and 0.382mm in depth. Generally the sizes of flaw were all overestimated. UT method provides more accurate sizing capability than ECT method. The depth sizing accuracy showed the best result, and length sizing accuracy showed the worst result.
(3) The ID flaws were more accurately sized than OD flaws. The RMS sizing error of OD flaws was within 0.936mm, and that of ID flaws was within 0.828mm.
(4) Wear type flaws among three kinds of flaw were more accurately sized than other two flaw types, and inclined flaws showed the worst sizing accuracy. The RMS sizing error of wear type flaws was within 0.479mm, and that of inclined flaws was within 0.964mm, and that of axial & circumferential flaws is within 0.748mm.

REFERENCES

[1] CAN/CSA-N285.4-94, “Periodic Inspection of CANDU Nuclear Power Plant Components” 1994 Edition
[2] “Manual for NDE on PHWR Pressure Tube, KEPRI, 2001