解説記事

Establishment and Implementation of Performance Demonstration System for Ultrasonic Examination in Korea

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Abstract *–Korea Electric Power Research Institute (KEPRI) and Korea Hydro and Nuclear Power Company (KHNP) developed Korean Performance Demonstration (KPD) system for ultrasonic examination applicable to pressurized light-water reactor and pressurized heavy-water reactor power plants in accordance with ASME Sec. XI App. VIII. In order to develop the KPD system, following works were completed. 1)Surveying the welds on piping of all nuclear power plants in Korea, 2)Surveying the bolting configuration of all nuclear power plant in Korea, 3)Determining the number and type of test specimens, 4)Designing the test and the practice specimens, 5)Developing quality assurance procedures for the fabrication of test specimens and system management, 6)Developing generic procedures for manual ultrasonic test, 7)Fabrication and fingerprint of test specimen. After establishing the KPD system, round robin tests were conducted to evaluate the accuracy and reliability of examination results by comparing traditional ASME code and performance demonstration method. KEPRI/KHNP had successfully developed the KPD system to fulfill the performance demonstration requirements of ASME Sec. XI, Appendix VIII, and are executing the performance demonstration test for ultrasonic examination system.*

I. INTRODUCTION

Ultrasonic examination is recognized as a vital in-service inspection method for nuclear power plant piping welds. In the early 1980s, many leaks in the piping systems of boiling water reactors in the USA were discovered in piping weld area which had been examined ultrasonically and found to be defect free. Efforts to demonstrate the effectiveness of in-service inspection most often resulted in demonstrating its' shortcoming. This led to a recognition of the need to demonstrate the performance of the inspections used for key components of all nuclear power plant piping welds. This scheme requires that particular procedure, equipment and personnel combinations are capable of detecting and sizing flaws of the concerned area. KEPRI and KHNP always understood that the safety of nuclear power plants is dependant upon the integrity of its materials, and developed the Korean Performance Demonstration system in order to improve the in-service inspection results. The performance demonstration system developed in the U.S. is not adequate to apply directly to the nuclear power plants in Korea as, instead of the Boiling Water Reactors (BWRs) used in U.S., Korea has the Pressurized Heavy Water Reactors (PHWRs). Therefore, the KPD system was developed to be applied to the Pressurized Water Reactors (PWRs) and Pressurized Heavy Water Reactors (PHWRs). The target components of the KPD system were the piping and stud/bolt system for the first phase, and target reactor types were the PWR and PHWR. Ministry of Science and Technology (MOST) bulletin 2004-13 was published to implement the performance demonstration for the ultrasonic examination of nuclear power plant piping weld from July 2004.

II. SURVEY RESULTS OF KOREAN NUCLEAR POWER PLANT CONFIGURATIONS

A survey on the configurations of the welds for piping and the stud/bolt was performed in order to design and fabricate the test specimens, which are the most important tasks for establishing the KPD System. These survey components were supplied by Westinghouse, Framatome, CE, and AECL. Centrifugal casting stainless steel piping, which is one of the components of reactor coolant systems in domestic PWR plants, was excluded in this survey because the code requirements were still in the course of preparation. The materials of all target pipings in Wolsong nuclear power plant unit 1 through 4 are ferritic steel. The survey results for the piping are shown in Table 1.

Table 1. The results of survey for piping in domestic PWR/PHWR plants

Reactor type	PWR		PHWR
Material type	Austenitic	Ferritic	Ferritic
Min. diameter	2.0 in	4.0 in	6.0 in
Min. thickness	0.22 in	0.337 in	0.56 in
Max. diameter	24 in	42 in	20 in
Max. thickness	1.6 in	4.4 in	1.77 in

According to the survey results, the mockup matrix of the PWR plants can be utilized for the performance demonstration program of the PHWR plants because the detailed data for all Wolsong units are in the range of those data on the PWR plants as shown in Table 1.

The essential variables mentioned in the examination category B-G-1 of the ASME code such as material specification, head configuration, hole diameters of bore, and stud/bolt lengths were surveyed and are listed in Table 2.

Table 2. Survey results of stud/bolt

Reactor type	PWR	PHWR
Length	45.4 ~ 79.31 in	9.5 ~ 26.5 in
Diameter	2.3 ~ 6.0 in	2.25 ~ 3 in
Bore diameter	0.661 ~ 1.25 in	N/A

In reviewing the geometric conditions contained in the PWR and PHWR plants, it is clear that they are very similar to the conditions in US plants of the same type. Examples of abnormal conditions provided by the plant survey results are:

- Weld crowns wider than twice the pipe thickness
- Weld crowns which limit the coverage of the required inspection volume
- A number of ID counter bore transitions are within 4mm of the weld root
- Sharp counter bore conditions exist, which provide a signal response that requires evaluation.
- CANDU units contained the similar types of geometric conditions as the PWR units.

III. TEST SPECIMEN MATRIX, NUMBER AND DESIGN

The specimen matrixes and numbers to be used in the KPD program were decided by plant survey results, as mentioned above, and satisfy ASME code, 1995 edition and 1996 addenda. The bases of specimen sets and numbers are:

- Specimens are divided into Austenite and Ferrite
- Ferrite specimens include clad specimen
- Candidate number for each performance demonstration test is 15(maximum)
- 3 detection sets and 3 sizing sets for practice
- Practice specimen must satisfy the same manufacturing specification

The code requires the use of the minimum and maximum thickness and diameters. It also requires a minimum of four different pipe sizes. The austenite piping set shall include specimens not thicker than 0.1 in. more than the minimum thickness, nor thinner than 0.5 in. less than the maximum thickness for which the examination procedure is applicable. The ferrite piping set shall include specimen not thicker than 0.1 in. more than the minimum thickness, nor thinner than 1.0 in. less than the maximum thickness for which the examination procedure is applicable.

The KPD selected 0.237″ minimum thickness, 1.531″ maximum thickness, 2.0″ minimum diameter and 24″ maximum diameter for austenite specimens to meet the ASME code. It is composed of 5 different diameters. The KPD also selected 0.337″ minimum thickness, 4.125″ maximum thickness, 4.0″ minimum diameter and 50″ maximum diameter for ferrite specimen to meet the ASME code. It is composed of 4 different diameters. The specimens have wide crown, counterbore, ground flush, diameter shrinkage, etc. This paper does not contain the flaw distribution and number because of security concerns.

IV. ESTABLISHMENT OF QA PROGRAM

The QA program of the KPD system was developed based on the QA program of the performance demonstration system established by EPRI. This QA program provides QA requirements for the specimen fabrication process and the performance demonstration process, and reflects the requirements of eighteen (18) criteria for QA in 10 CFR Appendix B and ASME NQA-1. For QA of the specimen fabrication process, eighteen (18) procedures were established, and for QA of the performance demonstration process, twenty (20) procedures were established.

V. FABRICATION AND FINGERPRINT OF TEST SPECIMEN

V.A. Fabrication

After finishing the test specimen design, KEPRI and KHNP started to fabricate the test specimens at the beginning of December 2002 and obtained all the test specimens at the end of 2003. Before manufacturing the actual test specimen, the trial specimens, that are representative of the entire test specimens, had been made to measure, evaluate, and analyze the flaw(location, length and depth, etc) by means of destructive method. Figure 1 shows 4 pieces from a specimen out of 4 trial specimens and Figure 2 shows the sectional view of a flaw. Flaw depth, opening width and flaw tip were measured by the SEM(Scanning Electron Microscope)'s accompanying analytical software. From this analysis of the KPD piping trial specimen, it was verified that fabrication vendor was able to meet the requirements of the KPD manufacturing specification.

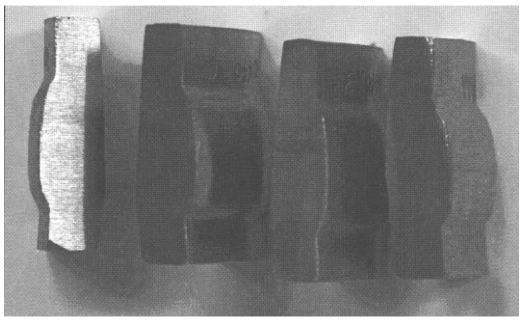

Figure 1. Trial specimens

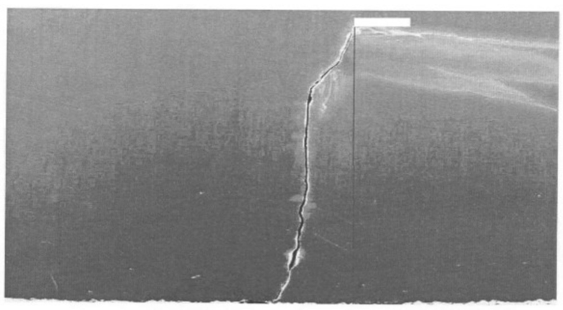

Figure 2. Sectional view of a flaw

V.B. Fingerprint

To verify that all the specimens have the intended flaws and no other extraneous signal exists, fingerprint for all specimens was performed. Figure 3 shows the on-going fingerprint using automated UT scanner and figure 4 shows the results of the UT for the specimens.

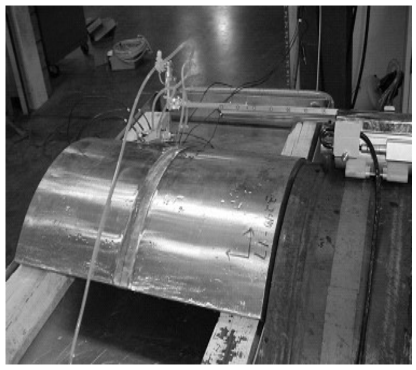

Figure 3. Fingerprinting of the specimen

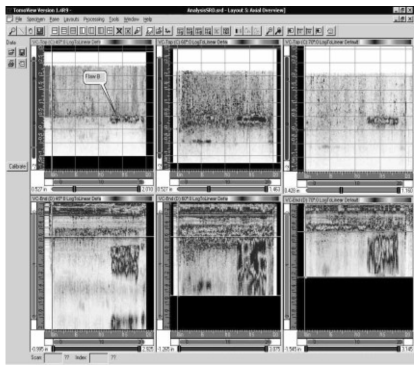

Figure 4. Results of the fingerprint

VI. SPECIMEN MANAGEMENT SOFTWARE

The KPD system adopted a sample management software to manage grading unit of the sample and to organize each sample set for testing. This software includes a test set making module and a test set verifying module according to the ASME Sec. XI, Appendix VIII. All the samples are divided into many grading units and each grading unit provides the flaw information such as flaw length, type, depth and geometric configurations.

Each test set has to meet the requirements of the ASME Sec. XI, Appendix VIII, Supplement 2, 3 and 12, and each test set has to be made based on grading units. The KPD sample set management module has a function to verify the code requirement, and the program manager can review the verification result and modify the test set.

The KPD grading software is designed for grading the detection, length and through-wall sizing of a flaw. The grading software grades the demonstration test with the code requirements, evaluates the ability of detecting flaws, and calculates the Root Mean Square(RMS) error value of the flaw length and depth. Performance Demonstration Qualification Summary(PDQS) for candidates who passed the test will be issued by the project manager.

VII. ROUND ROBIN TEST

6 persons from 3 in-service inspection vendors were participated in round robin test. 2 persons from each company are composed of one person with has more than 100 months field experience and the other person with less than 100 months experience. The tests were done by below sequence.

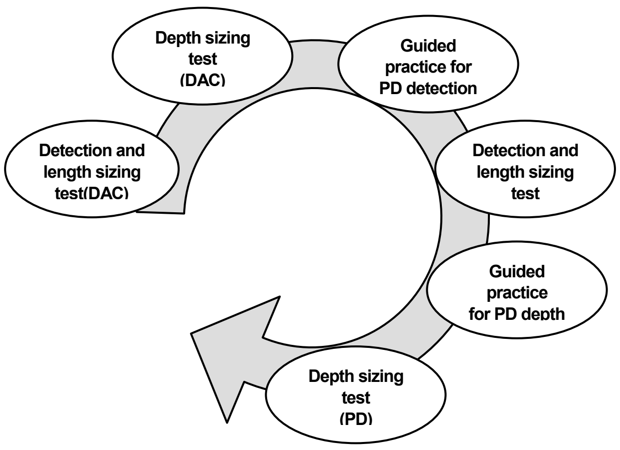

Figure. 5 Flow chart for round robin test

VII.A. Test Specimen

The test sets for the detection and length sizing were composed of 7 austenitic specimens and 4 ferritic specimens. These 11 samples contained 7 thermal fatigue cracks and 5 mechanical fatigue cracks in view of flaw type, and 11 circumferential cracks and 1 axial crack in view of flaw orientation. 6 wide weld crowns, 6 counterbores and 2 cladding conditions were included in these samples for geometry restriction. Table 3 shows the length distribution in samples.

Table 3. Flaw length distribution

Length of flaw	Number
1.0″ ~ 2.0″	3 flaws
2.0″ ~ 3.0″	3 flaws
3.0″ ~ 4.0″	1 flaws
Greater than 4.0″	5 flaws

The test sets for the depth sizing were composed of 4 austenitic specimens and 4 ferritic specimens. These 8 samples contained 4 thermal fatigue cracks and 4 mechanical fatigue cracks in view of flaw type and all flaws were the circumferential cracks. The numbers of specimens and flaws were chosen only for round robin test(not for PD test). 5 counterbore and 2 cladding conditions were included in these samples for geometry conditions and all samples are flat topped. Table 4 shows the depth distribution in samples.

Table 4. Flaw depth distribution

Depth of flaw	Number
0 ~ 30% of thickness	2 flaws
30 ~ 60% of thickness	4 flaws
60 ~ 100% of thickness	2 flaws

VII.B. Round Robin Test Results

The length sizing of conventional ASME method uses 6 dB drop method; Adjust the signal response from the flaw indication to 80% Full Screen Height(FSH) and scan along the length of the flaw in each direction until the signal response reduced to 40% FSH. However, 12 dB drop method are used for the length sizing in Korean PD System; Adjust the signal response from the flaw indication to 80% FSH and scan along the length of the flaw in each direction until the signal response reduced to 20% FSH. Figure 6 shows the results of Korean PD method are more precise than the results of the conventional ASME method and also fit to the ideal line.

The conventional depth sizing method of Korean ISI vendors before starting the PD system is 6dB drop method

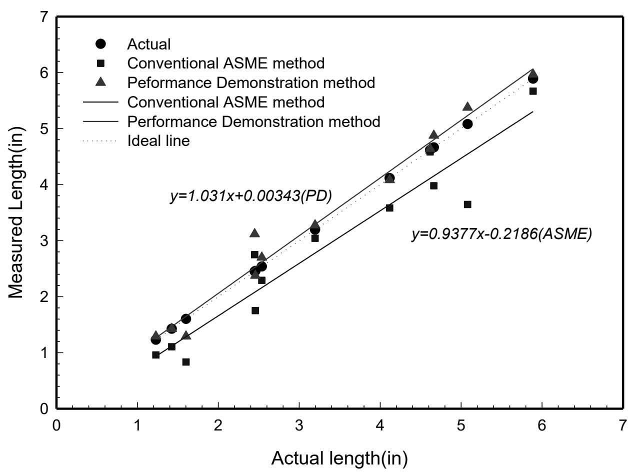

Figure. 6 Estimated flaw length comparison

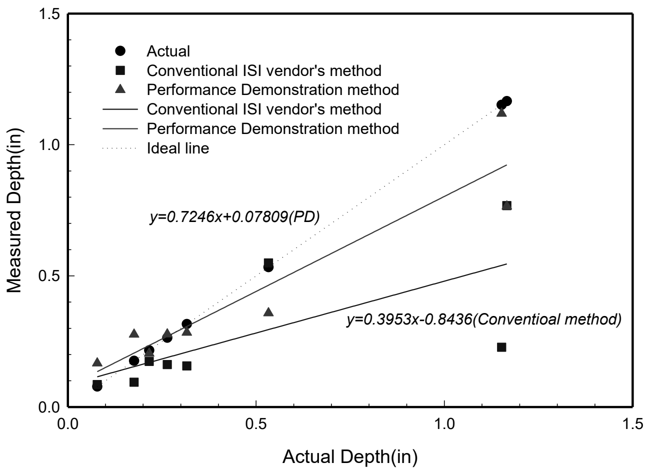

Figure. 7 Estimated flaw depth comparison

but the depth sizing of Korean PD system uses tip diffraction methods(AATT: Absolute Time Arrival Technique or RATT: Relative Time Arrival Technique). Tip diffraction methods rely upon obtaining a direct signal response from flaw tip. Figure 7 shows the results of our PD method are more precise than the results of the conventional ISI vendor's method.

VIII. IMPLEMENTATION STATUS OF PERFORMANCE DEMONSTRATION

VIII.A. Performance demonstration evaluation criteria

The performance demonstration tests following the ASME Code Section XI Appendix VIII are composed of the detection, length sizing and depth sizing. In the detection test, austenitic or ferritic piping specimens have the flawed grading units and unflawed grading units. In one flawed grading unit, there is a circumferential defect or an axial defect and the examinee must detect it correctly. At least one or a maximum of 10% of the flaws shall be oriented axially. Piping specimens shall include the limited access condition and geometric condition following the code. The mechanical fatigue crack and thermal fatigue crack are used considering failure mechanism. For the length sizing test, the detected circumferential crack must be measured and the RMS error of the results following Eq.1 should be within 0.75″.

$$RMS = \sqrt{\frac{\sum_{i=1}^{n}(m_i - t_i)^2}{n}} \quad \text{..... (1)}$$

here, m_i = measured flaw length or depth
t_i = true flaw length or depth
n = number of flaws measured

For the depth sizing test, the 2″ window region of each specimen containing a flaw to be sized is identified to the candidate. The candidate shall determine the maximum depth of the flaw. The Root Mean Square(RMS) error of the estimated flaw depths should be within 0.125″.

VIII.B. Implementation status

From April 2004, the performance demonstration for the austenitic/ferritic piping welds has been implemented in Korea. 59 persons took the detection and length sizing test by the manual UT. Among those, 52 persons from 6 different companies have been qualified. For depth sizing test by manual UT, 40 persons took the test and 34 persons have been qualified until the end of 2006. For detection and length sizing tests by automatic UT, 28 persons took test and 25 persons from 4 different companies have been qualified until October 2006.

The average numbers of miss call and false call per a person are 1.8 and 1.2, respectively during the test by the manual UT. The average miss call and false call are 1.5 and 0.7, respectively during the test by automatic UT. The RMS error values of length sizing by the manual and automatic

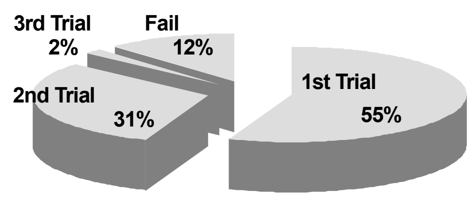

Fig. 8 Length passing rate (Manual UT)

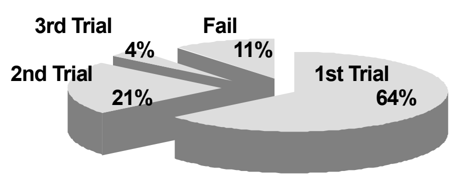

Fig. 9 Length passing rate (Automatic UT)

UT during the test are shown on Fig. 8 and 9. The average RMS error values are 0.43″ for the manual UT and 0.42″ for the AUT. To pass the length sizing test, the RMS error value must be below 0.75″. The numbers of miss call and false call by the automatic UT are a little smaller than by the manual UT but the length RMS error values are quite the same. Fig. 8 and 9 show the passing rates to the trials. Passing rate after the 1st trial by the automatic UT was higher than by the manual UT but around 85% of the candidates passed the test after the 2nd trial regardless of the manual or automatic UT.

The cause of fail for the detection and length sizing are shown on Fig. 10 and Fig. 11. Miss call (55%) is the principal reason for fail by the manual UT. For the automatic UT, the reason why the candidates failed are by miss call(33%) and false call(34%) and evenly matched. Fig. 12 shows the RMS error values of depth sizing by the manual UT during the test. The average RMS value is 0.120″ and cut off value to pass the test is 0.125″. However, the average RMS error value of passing candidate is 0.069″. Passing rates for the depth sizing test by the manual UT are shown on Fig.13. 85% of the candidates passed the test after the 2nd trial and this rate is the same as the passing rate of detection/length sizing test by the manual and automatic UT.

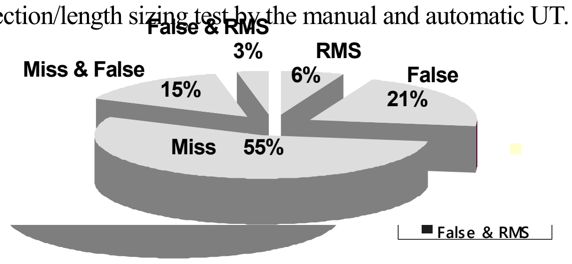

Fig. 10 Cause of fail (Manual UT)

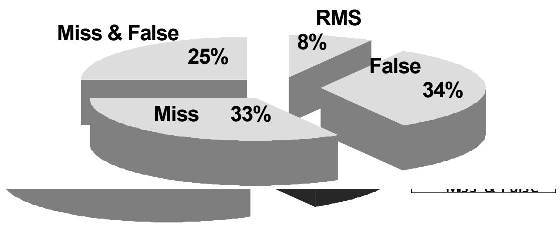

Fig. 11 Cause of fail (Automatic UT)

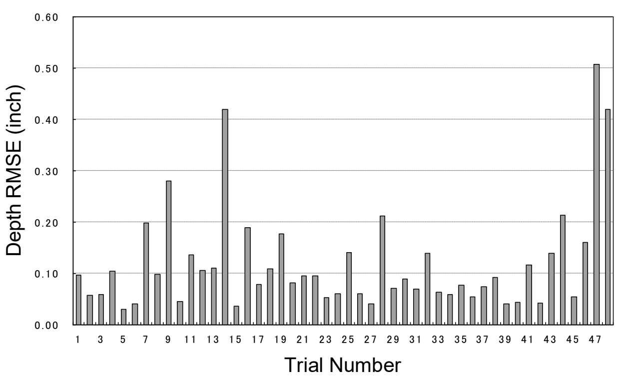

Fig. 12 Depth RMS error (Manual UT)

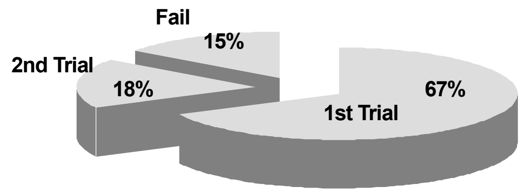

Fig. 13 Depth passing rate (Manual UT)

IX. SUMMARY

KEPRI/KHNP had successfully developed the KPD system to fulfill the performance demonstration requirements of ASME Sec. XI, Appendix VIII, and have executed the performance demonstration test for ultrasonic examination system. 52 persons(detection/length sizing by the manual UT), 34 persons(depth sizing by the manual UT) and 25 persons detection/length sizing by the automatic UT) have been qualified from April 2004. The improvement of the reliability for the ultrasonic examination for nuclear power plant piping weld in Korea is expected by accomplishing the performance demonstration. By the enforcement of the performance demonstration the following results are expected.

- Improvement of the reliability of in-service inspection results
- Standardization of inspection due to the usage of standard non-destructive testing procedures
- Providing qualified inspection personnel steadily because the education and examination for the performance demonstration are conducted in Korea
- Improvement of the level of non-destructive testing techniques

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