ABSTRACT

The Japanese Performance Demonstration standard, NDIS0603, “Qualification and certification of personnel for performance demonstration of ultrasonic testing system” was issued in 2005. The first Japanese Performance Demonstration (PD) qualification examination for IGSCC crack depth sizing in austenitic stainless steel piping welds for nuclear power plants began in March 2006, and it has been operated by the PD center of the Central Research Institute of Electric Power Industry (CRIEPI).

By the end of FY 2015, 44 examination sessions had been completed and 58 candidates had passed the examination. The total number of tests administered, including retests and recertification, was 104. A certified examiner can perform a crack depth sizing of IGSCC flaws with a high level of accuracy.

The average age of PD qualification holders is increasing. This means that few young UT engineers are joining the NDE role of the nuclear field.

Currently, NDIS0603 is being revised so as to add the Weld Overlay PD (WOL-PD) and the dissimilar metal weld crack depth-sizing PD (DMW-PD). The CRIEPI has initiated to prepare the WOL-PD and DMW-PD examinations. The Japanese regulator has also initiated the process of endorsing NDIS0603.

INTRODUCTION

In 2000, the Japan Society of Mechanical Engineers (JSME) published the first edition of a fitness-for-service (FFS) code. In June 2005, the first Japanese Performance Demonstration (PD) standard, NDIS0603, “Qualification and certification of personnel for performance demonstration of ultrasonic testing system,” was issued. The NDIS0603 is fundamentally similar in structure to the Appendix VIII of Section XI of the ASME Boiler and Pressure Vessel Code, but with some modifications that reflect the Japanese findings of the IGSCC with regard to 316L stainless steel welds. This code was focused on IGSCC crack depth sizing in austenitic stainless steel piping welds for nuclear power plants; however, it was decided that this target would be expanded in the future.

In March 2006, the first Japanese PD qualification examination session was initiated. At the end of FY 2015, 44 examination sessions had been completed, and 58 out of a total of 104 candidates passed the examination.

EXAMINATION RESULTS

Figure 1 shows the history of the number of candidates and successful applicants from March 2006 to the end of FY 2015. This figure shows that the number of candidates performing qualification activities in each period has gradually decreased over the past eight years. It should be noted that the required number of qualified personnel needed to support the Japanese nuclear industry was nearly satisfied within the first 18 months of the start of the PD qualification examination process. After this, the number of candidates during each period stabilized as candidates primarily...
performed the examinations in order to support the future activities within their organizations.

The number of certification holders, however, slightly decreased after 2010. Moreover, there have been very few new applicants appearing for the examination since the Great East Japan Earthquake in 2011, and most of them were for recertification. This means that although highly skilled ultrasound testing (UT) engineers are still working in the nuclear field, a generational change is not being observed.

Figure 2 shows the relation between the root-mean-square error (RMSE) and the average measurement errors of the successful and unsuccessful candidates. Approximately 70% of the successful candidates performed depth measurements on the IGSCC, with average errors of 1 mm or less. This shows that depth sizing of IGSCC flaws can be performed to a high level of accuracy.

**Figure 1** Year-by-year distribution of the number of candidates and successful applicants

**Figure 2** Root-mean-square errors (RMSE) vs. average measurement errors

**SIZING PROCEDURE**

Figure 3 shows the number of applicants as well as all of the candidates for the various types of the crack depth-sizing procedures used in the PD qualification examinations. In this figure, “PA” refers
to the phased array examination that uses either linear or matrix phased array transducers with encoded or automated scanning systems. “Others” refers to the manual scanning techniques that have a conventional A-scan type UT instrument and conventional angle beam tip diffraction techniques. The majority of the candidates used the “PA + conventional” type procedure.

The test results shown in Figure 3 indicate that the “PA + conventional UT” is the most successful procedure with the lowest RMSE. Using only the conventional procedure, a total of three candidates passed the examination in the first examination period. No candidate has recently performed the examination utilizing the conventional UT procedure. At present, the pass rate of the PA procedure is still low but its RMSE of passed candidates is better than that of the “PA + conventional UT” procedure.

![Figure 3 Number of candidates relative to the type of flaw-depth sizing procedure](image)

**STATISTICAL ANALYSIS OF SIZING RELIABILITY**

In order to clarify the reliability of the depth sizing, the PD center performed a statistical analysis using 890 depth-sizing data points. Table 1 shows the statistical analysis results of the IGSCC depth-sizing error. The mean error and the standard deviation of the sizings conducted by the successful candidates were 0.33 and 1.87 mm, respectively, while the mean error and the standard deviation for failed candidates were 1.00 and 4.84 mm, respectively.

<table>
<thead>
<tr>
<th>Candidate group</th>
<th>Mean error $\mu$ (mm)</th>
<th>Standard deviation $\sigma$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>0.60</td>
<td>3.53</td>
</tr>
<tr>
<td>Pass</td>
<td>0.33</td>
<td>1.87</td>
</tr>
<tr>
<td>Fail</td>
<td>1.00</td>
<td>4.84</td>
</tr>
</tbody>
</table>

It is not necessary for a UT examiner to be very careful in avoiding making a −4.4 mm critical miss call as successful PD applicants subsequently measure the IGSCC depth during the actual measuring procedure. $P(x)$, which is the probability that a successful PD applicant will make a −4.4 mm critical miss call, is derived from the mean errors and standard deviations of the pass group in Table 1 (0.33, 1.92$^2$) and Equation (1).
\[
P(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]

Equation (1)

\[P(x)\] is calculated to be 0.007 (0.7%) from Equation (1). Furukawa et al. have reported that the maximum probability that a −4.4 mm critical miss call will be made by a successful PD applicant measuring the IGSCC depth sizing is 5% \(^6\,^7\). These results indicate that a successful Japanese PD applicant will measure the crack depth with sufficient precision and reliability.

Table 2 shows the statistical analysis of each final decided technique. As described above, most candidates use the “PA + conventional UT” procedure, but most candidates chose to measure the crack depth using the PA technique as their final decision. Figure 5 contains the probability density curves for all candidates, including both passed and failed ones, calculated from each standard deviation. From Figure 5, it can be presumed that the mode of frequency of the passed candidate is about 0, and the frequency distribution is almost symmetrical. However, the frequency distribution of the failed candidates has been obviously biased toward the positive side. This overestimation could be caused by an examiner’s lack of skill in differentiating the base metal to weld metal interface echo and the IGSCC tip echo. Moreover, the possibility of human error is also unavoidable because the candidate is exposed to the stress of the potential for a −4.4 mm critical miss call, which could cause the candidates to bias their measurements toward a deeper value.

**Table 2 Analysis results for each final decided technique**

<table>
<thead>
<tr>
<th>Candidates Group</th>
<th>Final decided technique</th>
<th>No. of data</th>
<th>Mean error (mm)</th>
<th>Std. dev. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass</td>
<td>Phased array</td>
<td>472</td>
<td>0.30</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>104</td>
<td>0.50</td>
<td>2.18</td>
</tr>
<tr>
<td>Fail</td>
<td>Phased array</td>
<td>311</td>
<td>1.40</td>
<td>4.71</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>142</td>
<td>0.10</td>
<td>5.06</td>
</tr>
</tbody>
</table>

**Figure 5** Distribution of the errors for depth sizing

**THE AGE DISTRIBUTION OF QUALIFICATION HOLDERS**

Figure 6 shows the age distribution of qualification holders. During the first 8 years of the program, over 50% of qualification holders were in their 20s or 30s. But in the last 3 years, the number of qualification holders in their 30s has reduced by approximately 30%. Additionally, the average age of the qualification holders has increased year-on-year. This result means that there are very few new candidates that could be considered to be young, and that the highly skilled qualification holders are aging. This implies that young engineers do not want to join the NDE of the nuclear field and that there may be a possible shortage in the number of NDE engineers.
THE FUTURE PROGRAM (WOL-PD AND DMW-PD SYSTEM)

In the spring of 2013, the NDIS0603 was revised so as to add the weld overlay PD (WOL-PD). In the spring of 2015, the NDIS0603 was further revised so as to add the dissimilar weld crack depth-sizing PD (DMW-PD). The Central Research Institute of Electric Power Industry (CRIEPI) has now begun preparing a WOL/DMW-PD examination. WOL, however, is not a popular repair method in Japan, and most of the DMW welds that have been applied as counter measures are still working. It can therefore be expected that the number of candidates wishing to take the WOL-PD and DMW-PD certifications is limited. The Japanese WOL-PD and DMW-PD systems, therefore, are planned to be used in a collaboration proposed between the CRIEPI and the EPRI; the Japanese WOL-PD and DMW-PD systems will be performed using EPRI test samples at EPRI examination facilities, and they will be based on Japanese regulations (Table 3). In addition, the EPRI WOL samples have been confirmed to have the crack equivalency required by Japanese regulation 8).

CONCLUSIONS

The CRIEPI PD center has been operating Japanese PD examinations, and it has begun to prepare a WOL-PD examination. The outcome of the Japanese PD is as follows:

✓ The average depth-sizing error for successful candidates is 0.33 mm with a standard deviation of 1.87 mm.
✓ The average depth-sizing error was +1.00 mm for unsuccessful candidates. The reasons for candidate failure included a candidate’s inability to discriminate the crack tip echo as well as overestimating the flaw due to the candidate being wary of the −4.4 mm critical miss call.
✓ The average age of PD qualification holders is increasing. It means that fewer young UT engineers are starting in the role of NDE in the nuclear field.
✓ The Japanese WOL-PD and DMW-PD systems are being prepared in collaboration with the EPRI and their PDI program.

Figure 6 Age distribution of qualification holders
Table 3 Outline of weld overlay performance demonstration (WOL-PD) administration (assumption).

<table>
<thead>
<tr>
<th>Category</th>
<th>SUS-PD</th>
<th>WOL-PD</th>
<th>DMW-PD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Crack Depth Sizing</td>
<td>Detection Length and Depth Sizing</td>
<td>Crack Depth Sizing</td>
</tr>
<tr>
<td>Qualifying Body</td>
<td>CRIEPI PD Center</td>
<td>CRIEPI PD Center (Probably)</td>
<td>CRIEPI PD Center</td>
</tr>
<tr>
<td>Examination Administrator</td>
<td>CRIEPI PD Center Staff</td>
<td>CRIEPI PD Center Staff EPRI PD Administrator</td>
<td>CRIEPI PD Center Staff EPRI PD Administrator</td>
</tr>
<tr>
<td>Examination Location</td>
<td>Japan</td>
<td>EPRI NDE Center (USA)</td>
<td>EPRI NDE Center (Charlotte NC USA)</td>
</tr>
<tr>
<td>Test Specimen</td>
<td>Prepared in Japan</td>
<td>EPRI PDI Test Specimen (Include Japanese Specific)</td>
<td>EPRI PDI Test Specimen (Include Japanese Specific)</td>
</tr>
<tr>
<td>Examination Session</td>
<td>Few times in Year</td>
<td>Any time (need to adjustment)</td>
<td>Any time (need to adjustment)</td>
</tr>
<tr>
<td>Acceptance Criteria</td>
<td>(Depth Sizing) RMSE: &lt;3.2 mm</td>
<td>(Detection) (Length and Depth Sizing) Same as ASME</td>
<td>(Depth Sizing) Same as ASME and Code Case</td>
</tr>
<tr>
<td>Basic Certification</td>
<td>UT Level-2</td>
<td>NDIS0603:2013 Appendix A (SUS-PD)</td>
<td>UT Level-2</td>
</tr>
</tbody>
</table>

REFERENCES