# Effect of the different artificial flaw type in qualification purposes from the point of view of the inspection company

Krunoslav Markulin, Matija Vavrous, INETEC - Institute for Nuclear Technology Ltd. Mika Kemppainen, Iikka Virkkunen, Kaisa Miettinen, Trueflaw Ltd. Raimo Paussu, Jani Pirinen, Fortum Power and Heat Oy

## ABSTRACT

A comprehensive in-service inspection programme of the primary circuit components assures their safe and reliable operation with resultant benefit to the overall nuclear safety. Qualification of inservice inspection of nuclear power plant primary components is a powerful tool which provides confidence that a given in-service inspection is fit for its purpose.

Through the process of qualification the estimate of the defect detection and sizing capabilities including defect characterization is provided. For that purpose, representative specimens with different type of defects are manufactured in order to make sure that in-service inspection will have capabilities to successfully address potential degradation and deterioration of primary circuit components.

Moreover, in order to reliably simulate real inspection conditions, qualification specimens need to fully correspond to the intended areas of control, they need to be made of the same or similar material from which the subject component is made of and finally need to have the same constructional elements including the welded joints. Implementation of the defects in such specimens is of great importance and could affect the chemical composition, structure, physical and mechanical properties which later on affect the inspection system capabilities to locate, characterize, size, evaluate and adjudge defect types and detectable defect sizes with previously identified accuracy.

This article will introduce defects manufactured in three different ways to be used in qualification purposes and their comparison from the view point of the inspection company, i.e. detectability and sizing capability including advantages and disadvantages of the different defect types will be presented and analyzed coupled with experience from the actual specimens.

### **INTRODUCTION**

In nuclear industry periodical maintenance through application of non-destructive testing is essential activity for ensuring the safe and reliable operation of plant components and nuclear power plant as a whole unit. Maintenance activities as in-service inspections and non-destructive testing performed during outages are important to efficiency of outage and entire operation of the plant.

Constant demand is that maintenance and in-service inspections is performed in more efficient manner with less expense of time. In order to keep high level of quality of in-service inspection and high level of reliability of non-destructive testing, one of the tools used are qualification proceedings.

Through qualification process, validation is performed if selected in-service inspection with related non-destructive testing methods has sufficient capabilities to meet requirements defined with applicable standards and codes.

Within qualification process, practical trials are key segment to verify inspection capability. To make practical trials worthwhile, used qualification samples must be representative. Representative covers similarity to inspected component and defects that will realistically represent types of degradation that exists on actual component in real operating conditions. Methods of creating, manufacturing or implementing the artificial defects that will be used for qualification and assessment of inspection is critical because on success of selection and implementation of defects success of qualification will be affected.

## **DEFECTS FOR QUALIFICATION**

Nowadays, number of different flaw manufacturing techniques are available to the flawed test pieces needed for qualification. Over the years, more techniques have become available and each technique has developed. At the same time, both the inspection techniques and qualification practices have developed. This has resulted in increase of the quality of the test flaws and test pieces.

At first, most samples contained mechanically machined flaws, i.e. flat bottom holes, saw cuts and later EDM (electro-discharge machined) notches. These can be easily manufactured to tight tolerances. However, as NDE methods and requirements developed, it soon became apparent that their representativeness was not good enough for service induced cracks. The techniques were developed to decrease the opening to minimum and to introduce surface roughness and out-of-plane surface forms. EDM notches are widely used, e.g., for signal calibration due to their very high repeatability and cost effectiveness. EDM notches are sometimes the only flaw production technology applicable. Also, the EDM notches do not cause any changes in surrounding microstructures that might affect the inspection.

To offer better representativeness, various welded flaw simulations have been developed. These are manufactured, in simple terms, by either implanting an existing crack by welding to the test piece, or by inducing cracking of the weld by carefully chosen weld parameters. The welded in flaws offer better simulation of the tortuous crack paths of real service-induced cracks. They can be manufactured with low cost, especially during test block manufacturing. In particular, for large cracks they offer good compromise between representativeness and cost.

Finally, to offer even better representativeness and to avoid microstructural alterations that might affect the inspection, new techniques have been developed. These employ a true damage mechanism, which is accelerated and controlled to allow artificial production of service induced flaws. These cracks offer very good representativeness for wide range of service induced cracks and NDT techniques. They also do not cause microstructural alterations, because there's no welding involved. Especially, the delicate crack tips are retained and crack opening is typically much smaller than it is for other techniques.

Figure 1 shows the development of different flaw manufacturing techniques on time scale. In many cases, a combination of different flaw manufacturing types is used for a given qualification project.





### **DESCRIPTION OF SAMPLES WITH DEFECTS**

For present study, four different samples were selected, each containing different artificial flaws. The first three (designated YC033, YC035 and YC036), the representative component was control rod drive housing. For the fourth sample (designated YC015), the representative component was reactor pressure vessel and, in particular, the inner cladding for the RPV wall. The different samples are shown in Figures 2 and 3. Example surface images for thermal fatigue flaw type is shown in Figure 4.

# YC033 (pipe / flange)

Test block is a cut off from a real control rod housing. This is the worst case considering flaw manufacturing population. There is very limited access to inside surface of weld.

Grinding of openings and seeing inside was not so easy. Welding of solidification crack was possible only by welding using mirror. Tiny hands of lady welder made it possible to get inside and see the mirror while welding and feeding filler metal. The test blocks contains solidification cracks and EDM notches. Due to the manufacturing difficulties, the quality of the solidification cracks is questionable.

## YC035 (small pipe / reducer)

Test block is a cut off from real control rod housing. The test block contains thermal fatigue cracks and EDM notches.

# YC036 (small pipe / flange)

Test block is a cut off from real control rod housing. The test block contains solidification cracks and EDM notches.



Figure 2. Test pieces YC033, YC035 and YC036, which represent various inspection targets in the control rod drive housing.



Figure 3. Test pieces YC015 and YC030, which represent the reactor pressure vessel cladding area.



## Figure 4. Example thermal fatigue flaw surface image found in one of the test pieces.

## INSPECTION COMPANY ASSESSMENT

A pulse-echo and phased-array probes with nominal frequencies ranging from 1 to 4 MHz were used for nondestructive testing of defects manufactured for qualification of automated examination of different nuclear power plant primary components. Nondestructively tested qualification specimens were typically made of austenitic titanium stabilized stainless steel, designated by 08X18H10T similar to AISI 321 or W 1.4541, or 22K material (carbon steel), or low alloyed chrome-molybdenum vanadium steel of grade 12X2MΦA or 15X2MΦA. Consequently pulse-echo and phased-array probes were designed for examination of these materials.

The available specimens had the range of different defect values and length dimensions provided the good source for determination of the detection and measurement accuracy, with the great number of defects manufactured in three different ways which is sufficient for extensive analysis. The following observations have been drawn after extensive ultrasonic data analysis of numerous specimens.

As the material surrounding the EDM notch is left in the original state and the width of EDM notch is usually much greater than the width of true crack, an ultrasonic echoes from such geometric reflectors provides clear tip signals without noise that may affect the depth sizing and consequently result in the easiest detectability and sizing capability of NDE procedure when compared to the other defect types used for qualification purposes. Figure 5 shows the ultrasonic response from such geometric reflector of nominal depth 5 mm located on opposite surface to the scanning one. A clear tips signals are typical for such reflectors and represent 1 - upper tip response seen as OD surface reflection, 2 - corner trap response and 3 – upper tip response seen directly.



Figure 5. Typical ultrasonic echo from the EDM notch

However, because ultrasonic echo received from EDM notch is not well correlated with the echo received from true crack, its use in evaluation of inspection system capabilities in true crack detection and length and depth sizing is questionable. The reason for that lay in the fact that the ultrasonic

echoes received from true cracks which have rough surfaces tightly closed or irregular surfaces with extremely sharp edges with specific crack profile cannot be well compared to smoothly machined EDM notch profile having constant width and depth dimensions.

On the other hand, the constant width and depth dimensions is the main advantage of this type of reflectors as it result in constant and repeatable ultrasonic echo along EDM notch length. This advantage is very useful in calibration and calibration verification of ultrasonic testing systems. Further advantage of using the EDM notches, which are standardized across the industry, is the easier comparison of the results of qualifications and later on inspections performed at different sites.

Echoes from in-situ produced thermal fatigue cracks reflectors also provides very clear tip signals without surplus noise, as shown in Figure 6, and as a result detection probability and sizing ability is very similar to one achieved in ultrasonic examination of EDM notches. In opposite to EDM notches profile, the in-situ produced thermal fatigue cracks, as well as welded solidification cracks, have profile which is not constant in depth and width along each defect length, so the ultrasonic echoes received from such defects, especially in application of automated examinations are more comparable to echoes received from true cracks, so inspection company realize these as crack like flaws.



Figure 6. Typical ultrasonic echo from the in-situ produced thermal fatigue cracks, side and top view

Because an automated ultrasonic examination has to be performed with qualified scan pattern parameters, for example scan, index, or overlap, these are subject to qualification. An index resolution is parameter highly affected by the defect profile and critical defect length previously specified by the plant owner. From the index dimension, a total length of defect is determined by observing and counting sweeps having proper, discernible echo-dynamic signal as seen on Figure 7.



Figure 7. Bidirectional scan, example defect depth profile and thermal fatigue defect top view

The index dimension is closely correlated to the root-mean-square (RMS) value of depth sizing errors from ultrasonic data. As index dimension increases, defect depth estimation decreases, as well as RMS value of depth sizing errors increases because of defect depth changes along the defect length. In order to estimate defect depth with previously identified accuracy, inspection company NDE procedure has to take above in account during the procedure qualification if the EDM notch is only defect type available. Clearly, this is very important advantage of both the in-situ produced thermal fatigue cracks and welded solidification cracks over the EDM notches when used for qualification and assessment of inspection.

Regardless the shapes of the in-situ produced thermal fatigue cracks and welded solidification cracks are crack like, though ultrasonic echoes are not exactly the same to echoes from true cracks. Echoes from welded solidification cracks are pretty noisy, shown in Figure 8, most probably because of the way they are manufactured, by either implanting an existing crack by welding to the test piece, or by inducing cracking of the weld by carefully chosen weld parameters. This surplus noise requires additional efforts for inspection company to distinguish tips from unwanted noise and, as a result do not accurately represent types of degradation that exists on actual component in real operating conditions.



Figure 8. Typical ultrasonic echo from the welded solidification cracks

Examples of surplus noise can be seen on aid piece flaws where used method of creation of flaws is solidification combined with use of aid piece. This way flaws simulating lack of fusion or thermal fatigue cracking can be achieved. In case that aid piece flaw is simulating lack of fusion defects, aid piece is tack welded against straight surface tightly and pressed tightly surface to surface. Aid piece ends are welded carefully and also the rest of opening. Figure 9 presents response from aid piece lack of fusion flaw.



Figure 9. Typical ultrasonic echo from flaws produced by aid piece simulating lack of fusion defect

Lower and upper tip are present and seen without noise from the side of straight cut surface. The other direction response has higher level of noise due to implanting welding.

Alternatively, similar response is received when aid piece is used for creating a flaw that simulates thermal fatigue cracking. Similar approach to produce fatigue crack into straight cut surface by welding and bending aid piece weld produces crack which is fixed tightly face to face and welded into opening. Figure 10 presents response from aid piece thermal fatigue flaw.



Figure 10. Typical ultrasonic echo from flaw produced by aid piece simulating thermal fatigue defect

Response from such crack is noisier but it includes the tortuous crack path and crack opening can be controlled by manipulation. The noise is low while scanning from straight cut side and higher from the side of opening welding.

The in-situ produced thermal fatigue cracks have been in great extent detected with no material noise similar to one seen at welded solidification cracks and/or other changes visible which could affect the inspection system sizing capabilities and requires additional precautions to be taken during the analysis in order not to miss or misinterpret the defect.



Figure 11. Comparison of ultrasonic echo from the in-situ produced thermal fatigue cracks with the EDM notch

An additional challenge that Inspection Company has to deal with was in certain number of defects a detection of crack tips which found to be hardly detectable, thus when examination was performed with phased array probes, detection and sizing were found to be more efficient.

On the other hand, the approach to qualification which assures more challenging conditions than real operating conditions are welcome and will make sure that in-service inspection will have capabilities to successfully address all potential degradation and deterioration of primary circuit components.

### CONCLUSIONS

Based on achieved results through experimental testing and qualification proceedings characteristically responses for each flaw type used during qualifications were obtained. For each artificial flaw group there is an area of application within qualification sample. Certain flaw types like EDM notch can provide solution due to it's repeatability and ease of manufacturing while flaws made by complex techniques like thermal fatigue provide flaws that are more representative of actual existing degradations from the standpoint of flaws size and crack tips, or can provide a challenge for inspection applications due to difficulty to adequately detect and size such flaws.

Selection of adequate flaw types within test sample is crucial step and overall success of test sample will depend on it. Component that test sample is simulating also plays a role in selection and manufacture of defects.

Qualification as a verification process to assess capability of selected inspection techniques is highly defendant on the tests sample and flaws within it, and only if all aspects of artificial flaws, both from component and degradation side and inspection technique side are taken into account will the test sample be successfully prepared and consequently, qualification will be successful and reflect problems and challenges that can occur during actual application of in-service inspection in real conditions.

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