SMiRT-12 / K. Kussmaul (Editor)

GD16/2

APPLICATION OF COMPUTER MODELLING TO QUALIFICATION OF ULTRASONIC INSPECTIONS

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ABSTRACT

Performance demonstration of ultrasonic inspections is now increasingly called for where their capability must be justified. It is now a requirement (Appendix VIII) of the ASME Code, Section XI, for ISI of Nuclear Plants. In the UK, Performance Demonstration is a requirement for the inspections of the pressurised water reactor being built at Sizewell 'B'. A large investment was made in facilities and testpieces for these demonstrations. As the contractor for the automated shop inspections of the reactor, Babcock Energy had to design ultrasonic techniques that would be certain to meet the stringent performance specification. To do this, extensive use was made of computer models of ultrasonic inspection. The models have been used for transverse flaws in nozzle welds and inner radii. The paper describes the models and their application to design of ultrasonic techniques. Future applications of modelling to improving the cost effectiveness of performance demonstration programmes being developed in the USA and Europe are discussed.

1. THE NEED FOR QUALIFICATION OF ULTRASONIC INSPECTIONS

The PISC II programme highlighted the considerable variability in performance in both defect detection and sizing which exists between ultrasonic examination carried out to different procedures. Analysis of the results has shown that many factors influence performance. In some cases it has been possible to improve in-service inspection codes on the basis of this analysis. In the ASME Section V code for example, Article 4 on NDE of nuclear reactor vessel welds has been amended to reduce recording thresholds to levels found more successful in the PISC II trials. Other factors are more difficult to codify. Detection rates for smooth cracks were generally poorer on the nozzle weld plate 3 than on the butt weld plate 2. For maximum effectiveness, examination procedures for nozzle welds (and any other areas of complex geometry) must be tailored to the specific plant geometry. In view of the wide range of possible configurations, inspection codes can only give general guidance on how to perform such examinations effectively.

An alternative approach is now incorporated in the ASME Section XI code for ISI of nuclear plant. Appendix VIII, now defines requirements for "Performance Demonstration" of ultrasonic examination. In future, examination procedures need not meet specific requirements (on the number of beams to be used, for example) but instead will have to be demonstrated to be able to detect and size representative defects in a mock-up of each type of weld to be examined.

The same trend is apparent in other countries. In Europe serious consideration is being given to the development of economic methodologies for inspection performance qualification. Compliance with established ultrasonic examination standards is not being regarded as sufficient evidence of examination capability.

2. UK EXPERIENCE OF PERFORMANCE DEMONSTRATION

In the United Kingdom, Performance Demonstration is required for the manufacturing and in-service inspections of the pressurised water reactor being built at Sizewell 'B'. This "Validation" programme is similar to the performance demonstration programmes envisaged by Appendix VIII. Full scale mock-ups of reactor vessel components and welds each containing several implanted defects were procured for this programme. Inspection contractors are conducting ultrasonic examinations on these mock-ups using the same procedures, equipment and personnel as apply to inspections of the reactor vessel and other components. The size and number of test specimens required and the extent of the examinations to be validated has been such as to necessitate the setting up of a dedicated facility : the Inspection Validation Centre.

As the contractor for the automated shop inspections of the reactor vessel, Babcock Energy had to design ultrasonic procedures which would be capable of meeting the stringent specification set by the utility, Nuclear Electric. This was in many respects more onerous than the current requirements of Appendix VIII. In particular, for the weld inspections, there was a requirement to guarantee detection of planar flaws over a defined range of tilts and skews with respect to both longitudinal and transverse thoughwall orientations. This requirement applied throughout the volume of all reactor vessel welds and in particular applied to the nozzle-shell welds.

To meet this challenge, Babcock Energy developed, in collaboration with Nuclear Electric, a computer modelling approach to the design and development of ultrasonic techniques. The successful demonstration of performance which was achieved in the validation trials with procedures designed by modelling provides considerable confidence in the validity of this modelling approach. As will be discussed further below, establishment of a valid inspection coverage model opens the possibility of reducing the extent and hence the cost of future performance demonstration exercises.

3. BABCOCK COVERAGE MODEL

The Babcock inspection coverage model provides a three-dimensional, ray-tracing simulation of an ultrasonic examination of an area of complex geometry. This embodies accurate models of all manipulators used to scan probes over the reactor vessel.

The model allows the operator to define an examination volume and a target defect orientation in terms of tilt and skew angles relative to a local throughwall direction. To assess the coverage of an individual beam, the model divides the examination volume into cells, and places a hypothetical defect of the defined tilt and skew within each cell. At each

each point on the scan, the coverage model establishes which cells are hit by the beam axis. For cells which are hit, the model calculates the angle of 'misorientation' between the incident beam and the defect normal. The end result is a coverage 'map' in which the angle of misorientation is plotted for each cell on a diagram of the weld examination volume (Figure 1).

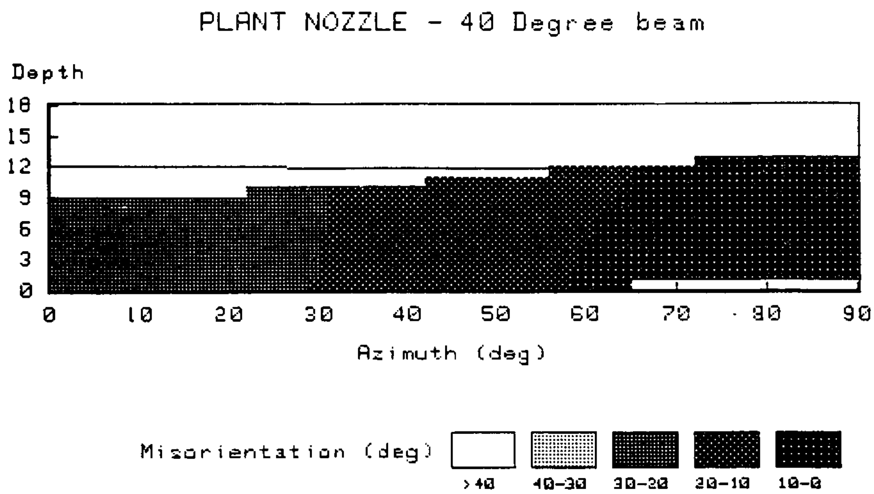

Figure 1 : Example of Coverage Map for 40° Angle Beam Scanning on the Bore of a Tapered Nozzle (15°) in a PWR RPV. Target Defect is Longitudinal in the Throughwall Orientation

4. DESIGN OF ULTRASONIC EXAMINATION FOR PWR NOZZLE-TO-SHELL WELDS

Using this coverage model, an examination procedure giving high reliability of detection has been designed for both longitudinal and transverse defects in PWR RPV nozzle-shell welds. The geometry of these welds is such that it has been necessary to piece together coverage from a variety of examination techniques. Probes had to be scanned on all of the surfaces in the vicinity of the weld including the nozzle bore, the outside vessel surface, the inside vessel surface and associated blend surfaces. The model makes it possible to assess the combined coverage of all these scans.

At positions over a substantial angular range on either side of the nozzle, the model showed that detection of midwall transverse defects of throughwall orientation could not be reliably achieved by single probe techniques. Accordingly a tandem technique was devised and implemented in the model. For certain areas, a wide range of different beam angles was found necessary and here Babcock Variable Angle Probes [2] were used to minimise the extent of scanning.

Once a set of techinques with the required capability had been designed using the model, the coverage maps provided the basis for a detailed technical justification of the inspections. This complemented the results of the validation trials and allowed these results to be extrapolated from the limited set of defects incorporated in the test specimens to the full range of the specification. Thus the model provided confidence that defects would be detectable, not just at the small number of positions where defects were placed in the test specimens, but throughout the weld examination volume over the full range of orientations required by the specification.

5. APPLYING COMPUTER MODELLING TO INSPECTION QUALIFICATION

The Sizewell B experience has shown that, for complex geometries, achievement of 100% coverage of an examination volume by techniques assuring high detection reliability (ie. techniques with low misorientation angle) can be costly in terms of the number of different scans required. Since modelling allows the contribution of each additional technique to be assessed, it is possible to use modelling to establish a suitable balance between the degree of coverage and its cost. Any resulting limitations in coverage can then be identified and declared in advance of performance demonstration.

Where a high degree of coverage is essential, modelling methods have been developed for establishment of optimum examination techniques by projection of beams back from the defects to be detected to the available scanning surfaces. These have been described elsewhere [3].

The modelling approach can also be applied to the design of the performance demonstration itself. If 100% coverage really is required in a given application, then a modelling assessment of the examination geometry will allow the performance demonstration administrator to identify those areas or those defect orientations which inspection contractors are likely to find most difficult and to design test specimens accordingly. Conversely if 100% coverage is not essential and it is accepted that the examination geometry imposes limitations then modelling can be used to ensure that test specimens present a fair test to inspection contractors.

A particularly valuable application of coverage modelling is to the extrapolation of performance demonstration results obtained on a generic test specimen to a specific plant examination. In the nuclear industry for example, there are a large number of reactor vessels each of which has different design details from the others. These design details may affect details of examination techniques.

Thus, for example, a nozzle having a tapered bore would require different probe angles for the nozzle-bore scan of the weld than a nozzle having a straight bore. Rigid adherence to the rules of Appendix VIII would seem to require separate test specimens for these two cases. Many similar examples could be cited implying that numerous different full scale mock-ups of reactor vessel vessel nozzles, each costing hundreds of thousand of dollars, could be required. Inspection contractors would then have to go through numerous expensive and time consuming performance demonstration exercises. In the authors view [4] modelling can be applied to avoid this. An inspection contractor could demonstrate performance experimentally on a generic test specimen and could then use modelling to extrapolate the established performance to specific plant geometries. The generic exercise would prove the capabilities of the contractors equipment and personnel and would prove his capability to design an examination technique for a sample geometry. Modelling would be used to assess the contractors design for the plant nozzle examination and to show that its performance would be comparable to that of the generic nozzle examination.

6. CONCLUSION

Computer modelling therefore can play a key role in inspection qualification/performance demonstration programmes. This role lies both in helping to enhance the effectiveness of examination techniques and also in reducing the cost of performance demonstration by minimising the extent to which experimental trials on expensive mock-ups are required. Techniques for putting the modelling approach into practice are now well established and they are likely to be applied increasingly in future.

7. REFERENCES

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