Development of a Set-Up for the Detection of Failed Fuels in TAPS BWR Spent Fuels Storage Bay

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Abstract. Detecting failed fuel elements in the leaky fuel assemblies during pool site examination is of great help in monitoring BWR fuel performance and selection of fuel elements for detailed post irradiation examination. Water enters inside the fuel pin through the breach in the Zircaloy clad. Presence of water inside a fuel pin confirms clad/weld failure. Detection of presence of water by non-destructive method helps in identifying the failed fuel pin without dismantling the fuel assembly. Ultrasonic testing technique using wafer probes in transmit and receive mode, has been developed to identify failed fuel pins by detecting presence of water inside the fuel rod.

1. INTRODUCTION

Failed fuel detection methods used in the early stages of the nuclear industry concentrated on the release of the fission products into the coolant. The continuous surveillance of coolant activity levels and effluent release rates were the means of detecting fuel failures. The off-gas system was used for gamma spectrometer monitoring to identify the quantities of Xe and Kr isotopes during reactor operation. Instead of water detection some researchers had tried to use the internal gas pressure in the rod as the measure of its integrity. The gas pressure is calculated from the gamma radiation emitted by Kr^{85}, one of the fission products accumulated inside the fuel rod. For boiling water reactors (BWR), sipping is done at the reactor site to detect assembly having failed fuel rods.

Ultrasonic testing techniques have been used to detect presence of water inside the fuel pin world over from the late 1970s. It is based mainly on attenuation of ultrasonic wave energy due to water coupling available inside the fuel pin. The different working groups worldwide have tried either pulse-echo[1] or transmit/receive method and patented their technique. Both the techniques monitor attenuation suffered by ultrasonic beam due to water coupling on the internal diameter (ID) surface of the clad. Pulse-echo uses single transducer while pitch-catch has separate transmitter and receiver. It is difficult to maintain the same geometry of beam alignment which affects reliability during scanning[2]. In our laboratory we have tried both pulse-echo and pitch-catch techniques on individual pins. Two wafer thin probes in pitch catch mode have been developed to be used to identify the failed rod in the storage pool without dismantling the fuel assembly. This paper discusses the problems associated with the testing geometry, weak signal strength and various approaches to enhance the reliability of failed fuel detection technique.

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2. DESCRIPTION OF FUEL ASSEMBLY

The nuclear power station at Tarapur, consists of two boiling water reactors of 200 MW(e) each. The fuel used in the reactors is enriched cylindrical UO_2 pellets, which is enclosed in Zircaloy–2 cladding tube of 14.3 mm outer diameter and 0.89 mm wall thickness. The ends of the ~4 meter long fuel element is sealed by Zircaloy-2 end plugs welded to the cladding tube by inert gas welding. A fission gas plenum is provided at the upper end of the element, the plenum being maintained with a wire spring. Helium is used as filler gas in the element.

Each TAPS fuel assembly consists of 36 fuel elements arranged in a 6 6 square array. The different fuel elements in the assembly are held together by two stainless steel tie plates, one on either end of the assembly. The fuel elements in the assembly are spaced from each other by seven spacer grids, the distance between two adjacent grids being 48.8 cm along the length of the assembly. The fuel assemblies are held vertically in the reactor core. There are 284 fuel assemblies in the reactor core.

3. CONCEPT OF ULTRASONIC TESTING

In case of a fuel rod failure, water enters inside through the breach in either the weld or clad wall. Water entering inside through the same leak finally settles down near the bottom plug in a vertically standing fuel pin. These fuel assemblies are kept under water inside storage pool where water may again penetrate through the site of clad breach. Presence of water inside a fuel rod confirms clad/weld failure and forms the basis to identifying the failed rod.

The presence of water in the gap between pellet and clad provides coupling for the ultrasonic waves to get transmitted to the pellets. Transmitted part of the ultrasonic energy gets absorbed in the pellets and does not reach the receiver probe. The lost ultrasonic energy is seen as the attenuation of the received beam from the clad ID surface in the ultrasonic signal. An intact fuel pin will have gases inside therefore, ultrasonic waves do not get transmitted to the pellets resulting in total reflection from the ID surface.

4. PULSE-ECHO METHOD OF TESTING

In pulse-echo mode an ultrasonic pulse is sent from outer diameter (OD) side to the cladding wall using a single transducer and a number of back wall echoes are obtained on the CRT. A single focused normal probe sends ultrasonic beam to the fuel pin OD surface to produce multiple back echo pattern from a sound fuel pin shown in Figs 4.1–4.2. An attenuated reflection pattern of back wall echoes is seen in case of a failed pin because of partial transmission of ultrasonic energy at ID surface. Transmission takes place through the water coupling in the gap between clad and pellet. A small fraction of ultrasonic energy (~1dB) is transmitted to the pellets which does not come back to the probe. The attenuation ~1dB per trip in the clad wall is too less compared to the attenuation arising due to misalignment of the probe.

5. PITCH-CATCH METHOD OF TESTING

Two wafer thin probes are placed opposite each other in pitch-catch method of testing. The wafer probes pair which can go inside the BWR fuel assembly to detect the failed rod is shown in Fig. 5.1. Three pairs of wafer probes fixed at the end of two stainless steel blades and three more pairs in staggered position are used for the testing of all the fuel pins in the assembly. The six pairs of probes are inserted inside the fuel assembly at a height nearly 25 mm from the bottom plug weld.

Water available in the pool couples the ultrasonic transducers from OD side of the fuel rod. The encoder based movement controller inserts the probe to the pre-calculated off set position on the first row of the fuel elements. The signal is shown in Fig. 5.2. for sound fuel rod. The amplitude of the signal in the gate goes down below the threshold in case of failed rod. The pitch-catch technique provides higher reliability of detection of failed fuel rod as there is 8–10 dB difference in signal strength. A similar situation is obtained on the other side off set of the same fuel rod.

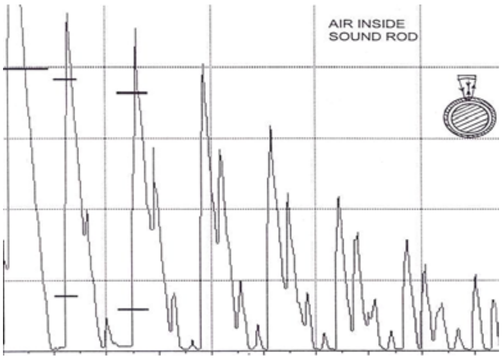

FIG. 4.1. Multiple pulse-echo back wall pattern.

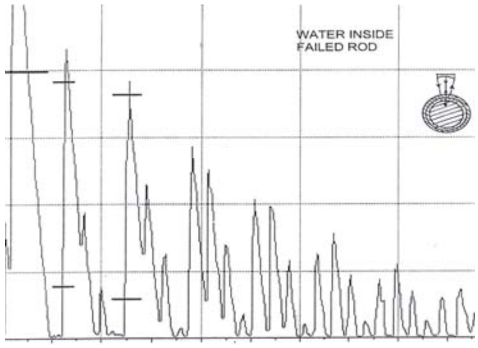

FIG. 4.2. Attenuated back wall decay pattern.

FIG. 5.1. 100% signal for sound fuel rod.

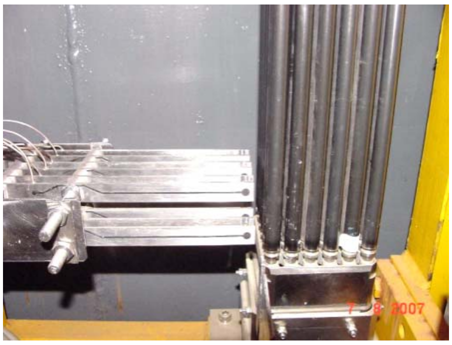

FIG. 5.2. Signal reduced for failed fuel rod.

All the fuel elements are examined in a fuel assembly till the defective rod is identified. The signal is re-checked while reversing the probe out of the fuel assembly.

6. CONCLUSION

Both pulse-echo and pitch-catch techniques were tried in our laboratory and the results were compared. The single probe pulse-echo technique was prone to misalignment problem.

It was found that the pitch-catch technique has higher signal to noise ratio. Trials have been taken to demonstrate the technical feasibility and reliability of pitch-catch mode of testing to detect failed fuel elements without dismantling the fuel assembly.

Remotely operable gadgets for reconstitution have been tried on a dummy fuel assembly.

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