High Frequency Imaging of Thickness Degradation in Steel Containment Vessels and Liners

Joseph E. Bondaryk
Engineering Technology Center, 200 Boston Ave. Suite 2500, Medford, MA 02155

Abstract: An area of concern in some nuclear power plants is thickness degradation of embedded steel containments just below the interface where the steel enters concrete. This is an area which cannot be examined by traditional UT testing, due to the inaccessibility imposed by the concrete. In this numerical feasibility study, high frequency vibrational sources placed above the interface are used to excite elastic waves in the steel, which propagate into the embedded area. The waves that reflect and scatter from the surface roughness caused by thickness degradation are used to detect and map the degradation of the steel. A range-dependent, stratified layer, wavenumber integration based, numerical model (OASES) is used to calculate the field in the scenario. (Work is supported by the Oak Ridge National Laboratory.)

In the U.S., some nuclear power plants are subject to moisture-induced, thickness degradation of embedded steel containments several inches to a foot below the interface where the steel enters concrete, see Figure 1. (1). This is an area which cannot be inspected by traditional Ultrasonic Thickness testing, due to the inaccessibility imposed by the concrete. The overall objective of this activity is to demonstrate the feasibility of using high frequency bistatic acoustic imaging techniques for the detection, quantification, localization and mapping of thickness reductions in the metallic pressure boundary of nuclear power plant containments.

The Range-Dependent version of the OASES code (RD-OASES) from MIT (2) was used to calculate the acoustic field in this stratified elastic scenario. The problem is broken up into vertical sectors, each characterized by an arbitrary number of fluid or solid elastic horizontal layers. The field within each sector is calculated for a single frequency via an exact, full-elastic wavenumber integration. The field in each sector is propagated to the next by a virtual array of point sources. A single scatter model is used, i.e. the field is calculated once forward through the sectors and then once backward. Thus, the received field due to an arbitrary source array can be calculated at arbitrary depth and range positions.

A 2-D model of the embedded steel containment scenario is shown in Figure 1b. A nominal 1” thick steel layer, which represents the containment, is surrounded by air halfspaces left of the midpoint and by concrete halfspaces right of the midpoint. Degradation of the steel is represented by a 2-sided 10cm long notch. Its thickness, T, and distance from the interface, dx, are parameters of the simulation. A nominal 1” long source array in a “wedge” material, modeled as a fluid, represents the ultrasonic sensor. The array is steered down to couple to a 45 degree shear wave in the steel for frequencies of currently available commercial sensors. The model assumes a plane geometry, i.e. all layers extend homogeneously and infinitely out of plane. Normal stress was computed.

In order to determine the dependence of the field on frequency and depth of the degradation, the model of Figure 1b was run parametrically. Frequencies of 0.1, 0.2, 0.5 and 1MHz were run for a two-sided degradation depths ranging from 0.5mm to 10mm incremented by 0.5mm. Figure 2a shows a plot of Signal Level in dB versus
degradation depth in mm for a family of frequency curves, where Signal Level represents the backscattered level seen by sensor located at 0.3m due to unit normal stress input at that position. The curves all have a distinct rise at 2mm. This indicates that a practical system will be able to distinguish between small “surface irregularities” in the 0.5 to 1mm range and a true degradation in the 2-10mm range. The dependence over the 4-10mm range is small, only about 10dB, which implies that careful calibration will have to be done to determine degradation depth accurately. These results are for the sharp-sided notch. Other research (1) suggests that the pitting and shape of the degradation can have a significant effect on the backscatter level. This simulation indicates a “best case” backscatter scenario.

![Graph of Signal level vs. degradation depth and frequency](image1)

**FIGURE 2.** a) Signal level from a degradation located 5cm from the air/concrete interface vs. degradation depth and frequency. b) Signal level from a 4mm degradation vs. distance from interface and frequency.

The location of the degradation from the interface is a significant parameter in the problem. This determines how much concrete a practical system could penetrate. In order to determine the dependence of the field on this penetration depth, the model of Figure 1b was run parametrically. Frequencies of 0.1, 0.2, 0.5 and 1MHz were run for a two sided, 4mm deep degradation located a 5, 10, 15 and 20cm from the interface. Figure 2b shows a plot of Signal level in dB versus Penetration depth in cm for a family of frequency curves. The curves show a very high attenuation of the received signal with distance. The concrete adds 3-4dB of two-way loss per centimeter of concrete penetrated. This will severely limit the penetration capability of any practical system. Since this dependence is much greater than that seen with degradation thickness, this may limit a system’s ability to effectively map degradation depths versus range. Calibration of such a system will be difficult because of this high loss. For example, the signal return from a 4mm degradation 7cm away is equivalent to the signal return from a 8mm degradation 5cm away. Other studies, not shown here, indicate that backscatter strength is not very sensitive to frequency or angle of transducer (<5dB) for the sharp-edge degradations examined here. This may not be true for tapered degradations, higher losses should be expected.

**Acknowledgements**

The financial and technical support of the Oak Ridge National Laboratory and the Nuclear Regulatory Commission is greatly appreciated.

**References**