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LIQUID WATER SENSING IN DRY CASK STORAGE SYSTEMS BY GUIDED WAVES

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ABSTRACT

This work focuses on a method for detecting liquid water inside of dry cask storage systems (DCSSs). Ideally, the environment inside of a DCSS confinement is inert and free of water to prevent potential corrosion of used fuel cladding or other internal hardware. However, there is some uncertainty about the amount of residual water potentially left behind in a DCSS after drying processes. Considering the complex spatial and time-dependent temperature profiles in dry storage casks, water may be in liquid or gas phase depending on location inside of the cask and how long the cask has been in storage. This paper describes development of an ultrasonic technique for sensing liquid water inside a Transnuclear TN-32 DCSS. This system is being used in a demonstration of the efficacy of dry storage of high burnup fuel in DCSSs in collaboration between the United States nuclear power industry and the United States Department of Energy.

Keywords: ultrasound, fluid detection, dry cask storage

1. INTROD1UCTION

This work focuses on a method for detecting and measuring water inside of dry cask storage systems (DCSSs) via sensors mounted exterior to the confinement boundary and requiring no physical penetration of the confinement boundary. Ideally, the environment inside of a DCSS confinement is inert and free of water to prevent potential corrosion of used fuel cladding or other internal hardware. However, there is some uncertainty about the amount of residual water potentially left behind in a DCSS after drying processes. Considering the complex spatial and time-dependent temperature profiles in dry storage casks, water may be in liquid or gas phase depending on location in the cask and how long the cask has been in storage. A review of drying specifications by several vendors concludes that if the specifications are followed correctly, the residual moisture left behind in DCSSs should present an insignificant risk to cladding degradation [1]. A more recent analysis has concluded that much larger quantities of residual water could remain in DCSSs, but the amount would still not be expected to lead to significant corrosion of fuel cladding or other internal components [2]. The assumptions made regarding the possible quantities of residual water or their potential significance have not yet been corroborated with field experience for periods of extended storage. The measurement techniques described here can facilitate the direct observation of residual water in the field and help establish operational data that can inform operating and licensing decisions for extended periods of storage.

This paper describes development of an ultrasonic technique for sensing liquid water inside of a Transnuclear TN-32 DCSS. This system is being used in a demonstration of the efficacy of dry storage of high burnup fuel in DCSSs in collaboration between the United States nuclear power industry and the United States Department of Energy.

2. BACKGROUND

The transfer of spent fuel into DCSS systems occurs in the spent fuel pool facility of nuclear power plants (NPPs). The process involves submerging the opened DCSS system into the pool and loading the spent fuel under water to minimize worker exposure to radiation. Once loaded, a lid is placed on the DCSS system and it is lifted out of the spent fuel pool. After removal from the spent fuel pool, the DCSS is drained and undergoes a drying procedure to remove water that is not discharged by draining. Eventually, the system is sealed and backfilled with an inert buffer gas (such as He) to protect the fuel cladding from corrosion.

The Transnuclear TN-32 DCSS can be referred to as a bare fuel loaded system [3]. Used fuel is loaded into a fuel basket inside of a metal confinement boundary, which is integrated with additional layers of materials for biological shielding and physical protection. An illustration of the TN-32 DCSS is provided in Figure 1. The figure shows the layered design of the system, and the interfaces between these layers prevent the efficient transmission of ultrasonic signals to the interior. One potential path for transmitted ultrasound from the exterior of the

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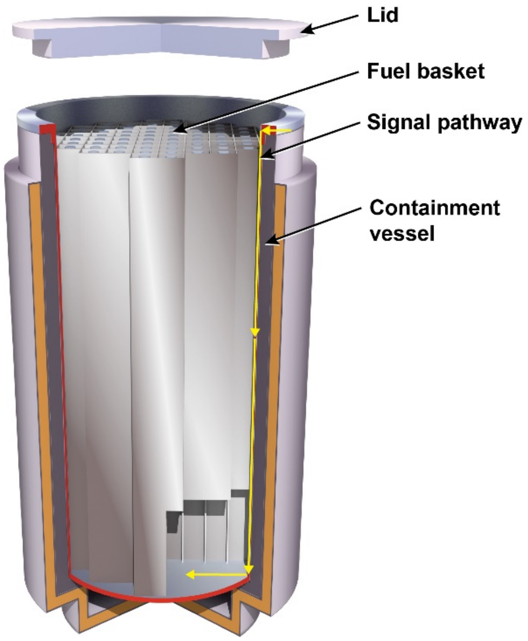

FIGURE 1: REPRESENTATION OF TN-32 DSS SYSTEM ILLUSTRATING PATH FOR ULTRASONIC SIGNAL TO INTERIOR.

DCSS to the interior is through the path identified in Figure 1. The figure illustrates the inner confinement barrier with a cup-like configuration that expands into a flange at the top end. The outer layers for biological shielding and physical protection wrap around the confinement barrier but only extend up to the underside of the shoulder formed by the flange of the confinement barrier. Thus, the outer face of the confinement barrier flange is directly accessible from the DCSS exterior and enables the transmission of ultrasonic signals to the cask interior.

3. APPROACH

The approach for sensing water at the bottom of the confinement barrier is based on transmission of ultrasonic energy from sensors mounted on the exterior-facing surface of the confinement barrier flange. To do this, it is proposed to generate guided ultrasonic plate waves in the confinement barrier wall. More specifically, the approach is based on the generation of the fundamental anti-symmetric plate wave mode, A0. Background information on plate waves and specific excitation modes can be found in ultrasonic textbooks [4]. Dispersion curves for the group velocity in this geometry are displayed in Figure 2. The shaded area to the left of the figure represents the desired region of operation as the minimum number of modes will exist in this regime. For this application, operating at frequencies less than 100 kHz is required. Even when operating in this regime, it is possible for S0 modes to exist and complicate signal interpretation.

3.1 Mockup

A mockup for developing the ultrasonic sensing method for detecting liquid water at the bottom of the DCSS was designed and fabricated. The mockup was designed to capture relevant dimensions and geometric features and to simulate the access path for ultrasonic signals from the exterior surface to the interior, as shown in Figure 1. A drawing of the mock-up is provided in Figure 3, which shows that the curvature of the confinement barrier sidewall is neglected. This approximation is justified as the radius of curvature for the wall is much greater than the wall thickness. The mockup is fabricated from carbon steel material.

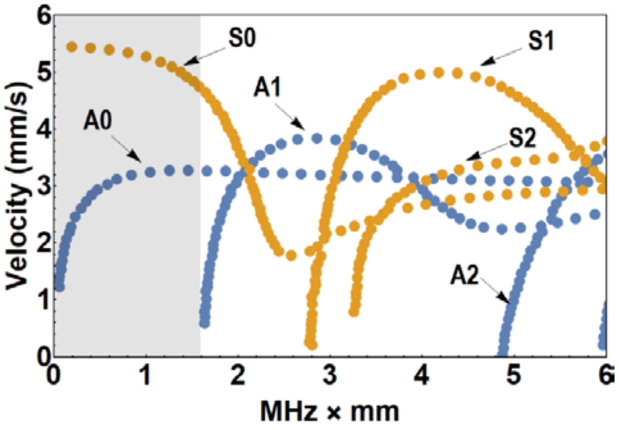

FIGURE 2: DISPERSION CURVES FOR GROUP VELOCITIES OF ANTISYMMETRIC AND SYMETRIC PLATE MODES.

3.2 Scoping Tests and Equipment

Scoping tests are currently being performed to optimize sensor design. The flange at the top of the confinement barrier represents a geometric complexity which is expected to make the transmission of A0 modes though the confinement barrier sidewall more challenging. The angle of incidence for

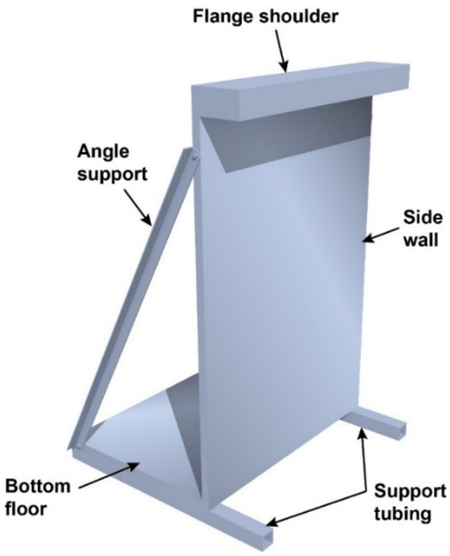

FIGURE 3: ILLUSTRATION OF MOCKUP TO SIMULATE SIGNAL PATH ON TN-32 DSS.

transducers mounted on the exterior face of the flange will impact the efficiency with which ultrasonic energy that enters through the flange will convert to A0 mode and propagate through the side wall.

In this effort, the optimum angle of incidence will be evaluated empirically using commercial off-the-shelf piezoelectric transducers and a variable angle wedge. The angle of incidence will be systematically varied while the strength of the A0 signal that propagates through the mockup sidewall is recorded.

Transducer array configurations will also be explored to improve control of sound field focusing and directionality in the confinement barrier wall. To observe the sound field in the mockup, a laser interferometer is set up and scanned over a grid of points. The spatial distribution of the sound field intensity of signals leaving the transmitter can be mapped for visual presentation. A photograph of the mockup and measurement equipment is provided in Figure 4.

4. RESULTS

Testing has been performed to confirm that the A0 mode can be generated with enough isolation (i.e., with little interference from the S0 mode) in the vertical plate portion of the mockup. Additional testing was performed so that the A0 mode could be propagated through the 90° joint connecting the vertical plate to the horizontal plate at the bottom of the mockup. In this case, testing was performed to assess the impact of the 90° joint on the A0 signal considering 1 pass and 2 passes through the joint. These tests are referred to as Cases 1, 2, and 3:

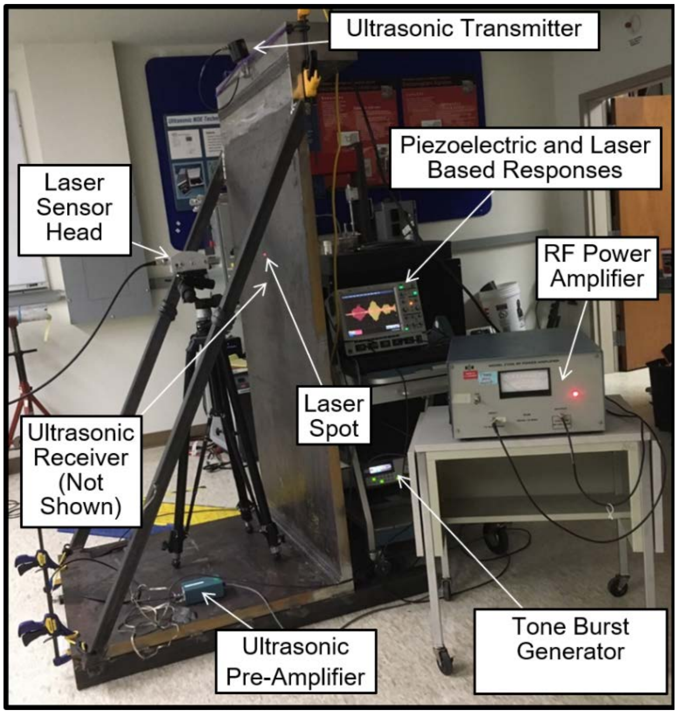

FIGURE 4: PHOTOGRAPH OF MOCKUP AND MEASUREMENT AND TEST EQUIPMENT.

- Case 1 – Generation of A0 mode in vertical plate of mockup (transmitter and receiver on vertical plate)
- Case 2 – Propagation of A0 mode through 1 pass through 90° joint (transmitter on vertical plate; receiver on bottom plate)
- Case 3 – Propagation of A0 mode through 2 passes through 90° joint (transmitter and receiver co-located near top of vertical plate

A-scan responses for Cases 1 and 2 are displayed in Figure 5 while the A-scan response for Case 3 is provided in Figure 6. Figure 5 confirms that an A0 mode signal can be generated and propagated through the 90° joint without significant interference from the S0 mode. Figure 6 depicts a more complicated signal. In this case, it appears that the receiver is picking up several reflections from the mockup boundaries. Damping material was placed on the end edge of the bottom mockup plate, and the resulting signal was subtracted from the signal obtained without application of the damping material. The “Difference” response in Figure 6 is obtained from this subtraction. The response shows that only the A0 mode is propagating to the end of the bottom plate and back to the receiver.

Finally, a map of the sound field intensity in the mockup measured with the laser interferometer is shown in Figure 7. The right side of the figure displays the intensity on the discrete grid points (3 in. × 3 in.) where measurements were collected. A Hilbert transform is applied to generate a continuous map of the intensity on the left. Significant divergence of the sound field can be observed for the single transducer transmitter.

5. FUTURE WORK

Further scoping work will be performed to determine suitable parameters for a prototype sensor. Current testing has focused on verifying the generation of the A0 mode in the plate components of the mockup and verify that passes through 90° joints are feasible with minimal degradation of the A0 signal.

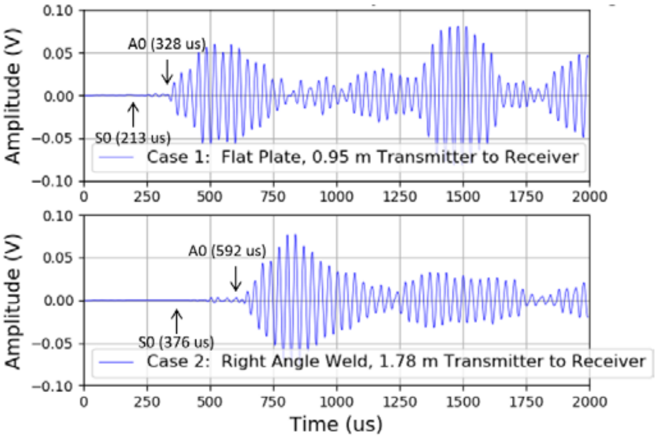

FIGURE 5: A-SCAN RESPONSES FOR (TOP) CASE 1– GENERATION OF A0 MODE IN VERTICAL PLATE OF MOCKUP AND (BOTTOM) CASE 2 – PROPAGATION OF A0 MODE THROUGH 1 PASS THROUGH 90° JOINT (TRANSMITTER ON VERTICAL PLATE; RECEIVER ON BOTTOM PLATE)

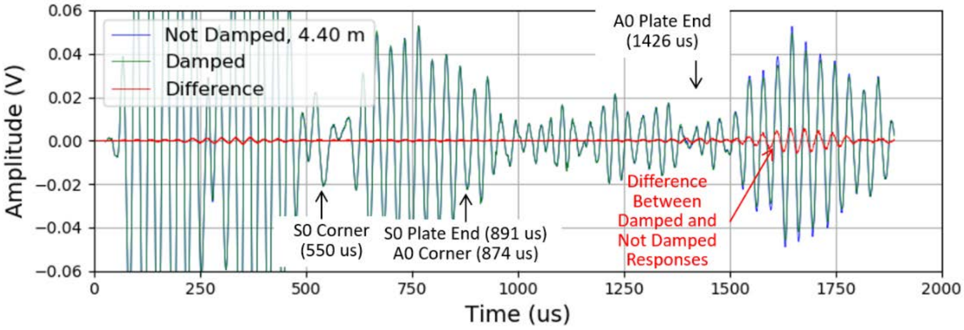

FIGURE 6: A-SCAN RESPONSES FOR CASE 3– - PROPAGATION OF A0 MODE THROUGH 2 PASSES THROUGH 90° JOINT

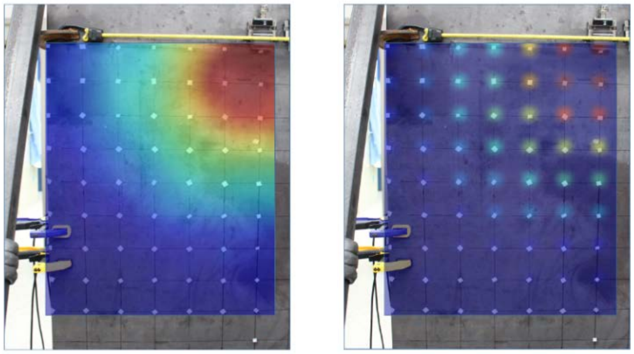

FIGURE 7: INTENSITY MAPS OBTAINED WITH THE LASER VIBROMETER: (RIGHT) REPRESENTATION OF INTENSITY AT DISCRETE GRID MEASUREMENT POINTS, (LEFT) CONTINUOUS REPRESENTATION AFTER PROCESSING ORIGINAL DATA.

The flange shoulder at the top of the mockup introduces a complexity with respect to generating desired modes and ensuring minimal excitation of unwanted modes. A systematic evaluation of angle of incidence for transducers mounted on the exterior face of the flange shoulder will be performed. In addition, multiple transducer array configurations will be investigated to improve focusing of the energy.

Although the current mockup simulates many relevant features for this application, it introduces edge effects that will not be present in actual systems. Further, a true pitch-catch configuration with a transmitter and receiver mounted on the exterior face of the flange but located on opposite sides of the DSS (positioned 180° relative to each other) can not be tested with this mockup. Once suitable design parameters for a prototype sensor are determined, testing on a full-scale system will be useful.

ACKNOWLEDGEMENTS

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