DRAFT PAPER

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INSPECTION OF STEEL VESSELS WITH CLADDING OVERLAY, USING MWM-ARRAY TECHNOLOGY

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ABSTRACT. A successful service for inspection for hydrogen blisters in weld overlay clad vessels has been completed at a major facility in Saudi Arabia. JENTEK Sensors, Inc. and Al-Rushaid Technologies performed this inspection in April 2014 during an 8 day period. This included scanning of over 50% of the internal clad surface inside four large vessels. Hydrogen blisters were successfully mapped and digitally registered. Suspect cracks in the steel below the cladding were also identified. The method employed was the next generation MWM-Array eddy current testing (ET) method. This was the first inspection of its kind.

The MWM®-Array sensors and methods use a linear array of inductive sensing elements with a linear drive configuration designed to minimize unmodeled effects, along with a multivariate inverse methods that use precomputed databases of sensor responses to analyze data and provide reliable inspection results. These methods enable rapid scanning of an entire internal vessel surface in less than two shifts compared to the numerous shifts required for Ultrasonic Testing (UT) while also providing the unique capability to image blister volume. The resulting digital record also enables future inspections to be compared to prior inspections to monitor blister volume growth and crack growth, resulting in improved vessel integrity management. The successful inspection in Saudi Arabia lays the foundation for this inspection method to be deployed throughout the world for such high priority inspections through weld cladding overlays.

TECHNICAL APPROACH

For inspection through the internal clad surface inside the four large vessels at a major facility in Saudi Arabia, all measurements were taken using an FA216 MWM®-Array, pictured in Figure 1. Measurements were taken simultaneously at 1.28, 10.24, and 81.92 kHz. For detection and sizing of blisters, the multi-frequency impedance data was processed using four-unknown HyperLattice® databases to produce estimates of sensor lift-off (h), cladding permeability (μ_c), cladding thickness (Δ_c), and cladding-substrate gap thickness (Δ_g). Cladding-substrate gap thickness is representative of blister size and accurate measurement of this gap thickness is used to calculate blister volume. A representative lattice is shown in the Figure 2.

For detection of crack-like indication in the base metal, the substrate permeability (μ_s), was also treated as an unknown, resulting in a five unknown HyperLattice database. Localized changes in the substrate permeability are anomalies and may be indicative of a crack.

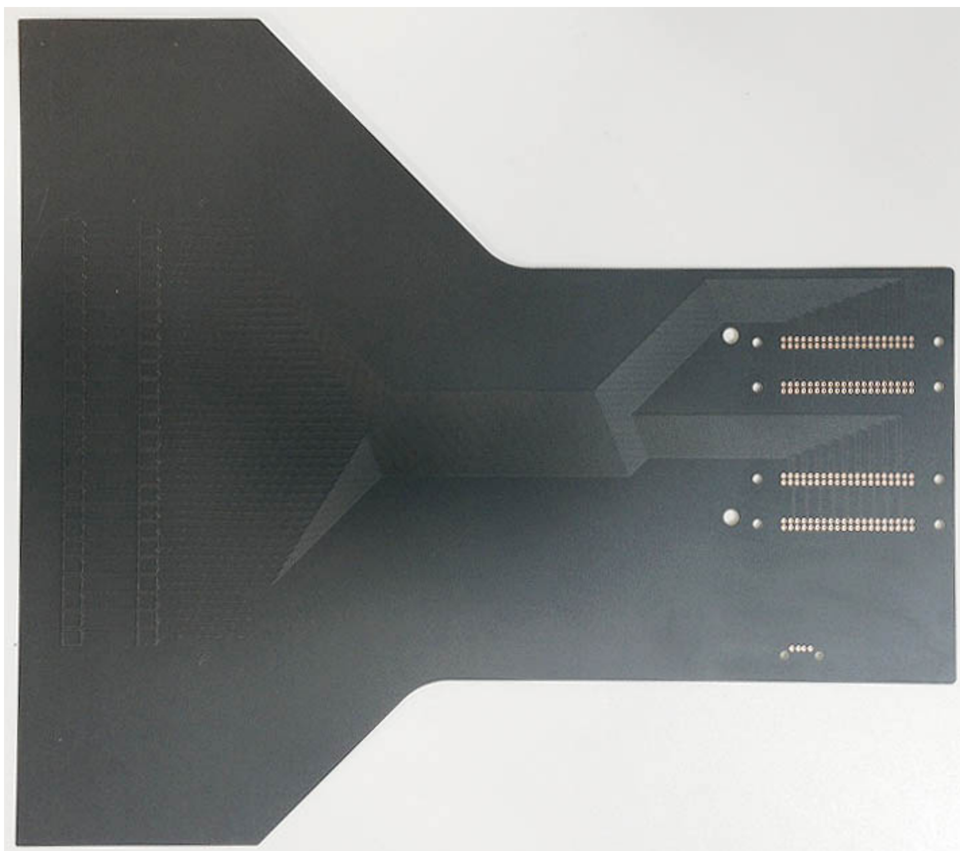

FIGURE 1. FA216 MWM-Array Sensor.

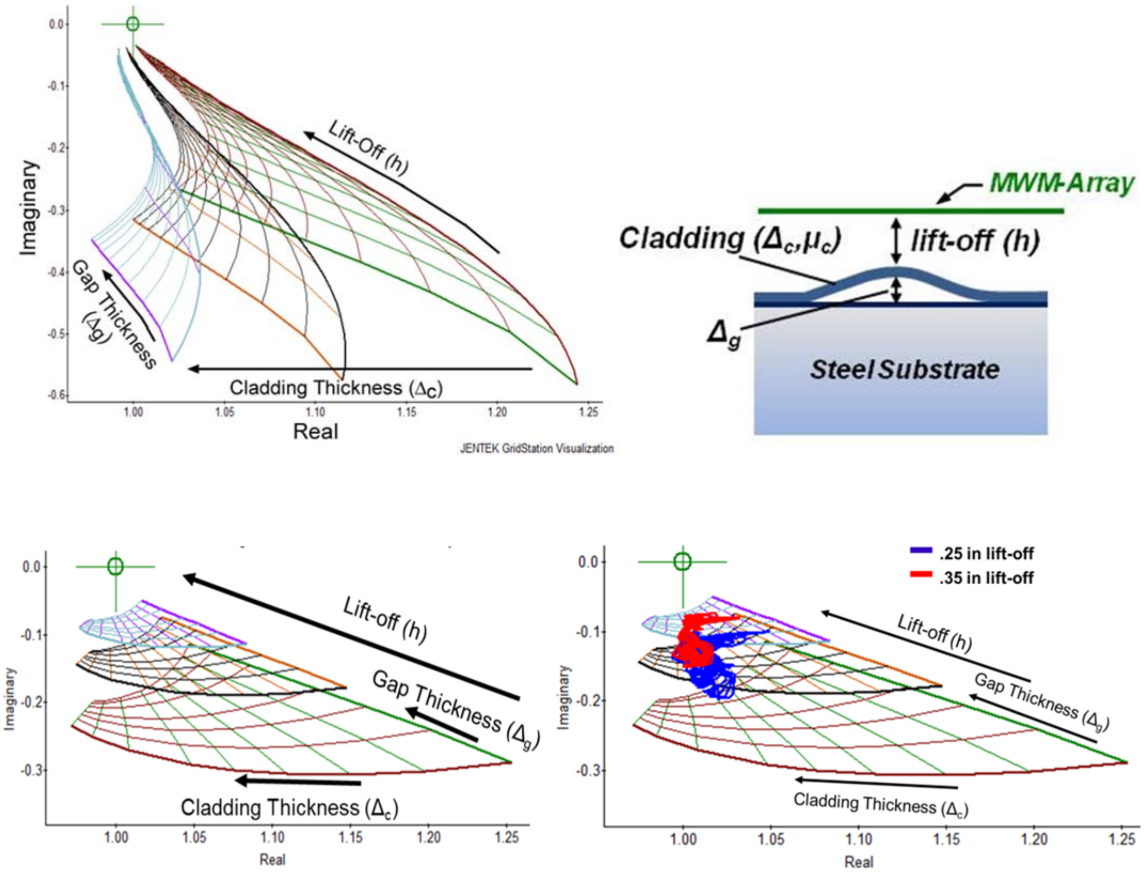

FIGURE 2. Lattices for estimation of gap thickness, lift off, and cladding thickness. This is a simplified visual representation of the HyperLattice database that assumes a substrate relative permeability of 80 and cladding relative permeability of 1.5. In reality, the three frequencies are used to estimate five different unknowns, so assuming a substrate and cladding permeability is not necessary in practice.

SCANNING OVERVIEW

Four vessels were scanned during the inspection. The first vessel was scanned using an automated vessel wall scanner, seen in Figures 3 and 4. Each scan performed covered approximately 0.3 m circumferentially with the 11.5 cm long vertical array of sense elements on the FA216. A total of twelve vertical locations could be scanned at a single position of the track that the scanner rides along for a total of 129.5 cm vertically of coverage, after which the track itself was repositioned. The circumferential direction of the weld overlay cladding lines makes circumferential scanning preferable to vertical scanning because scanning in this manner eliminates a source of periodic property variation over the course of a scan.

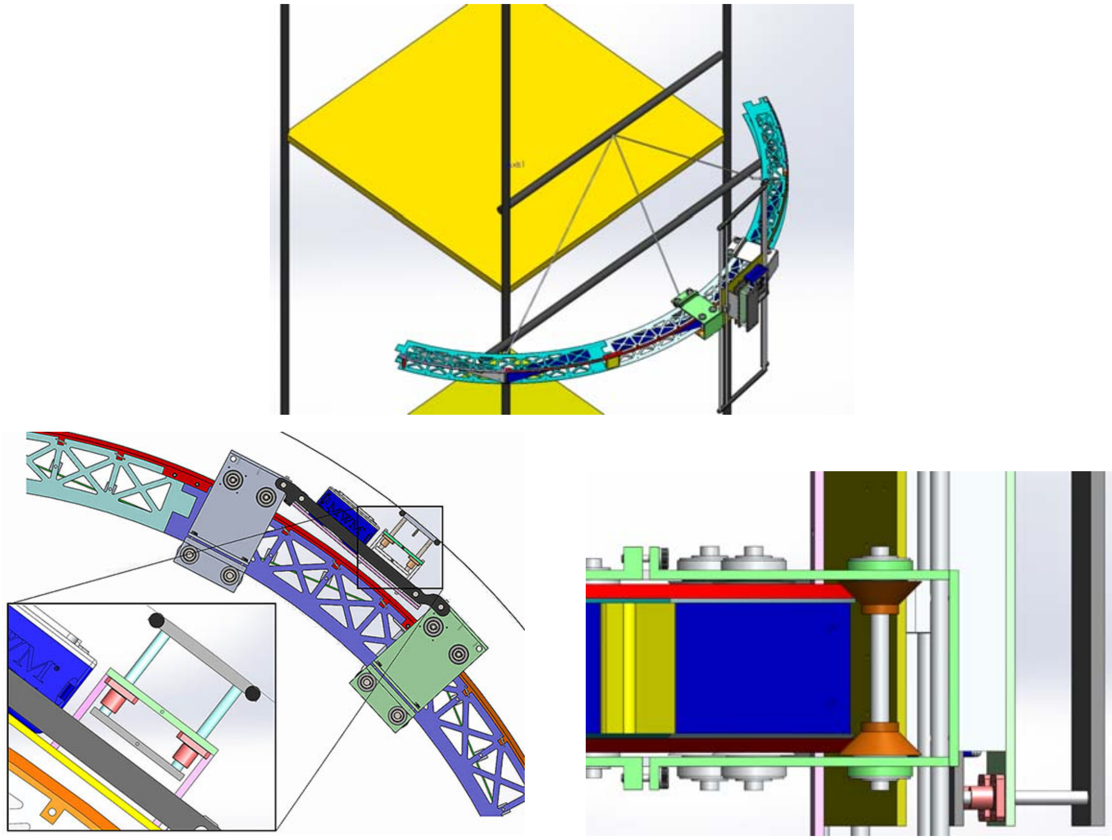

FIGURE 3. Renderings of automated vessel scanner for reactor wall inspection.

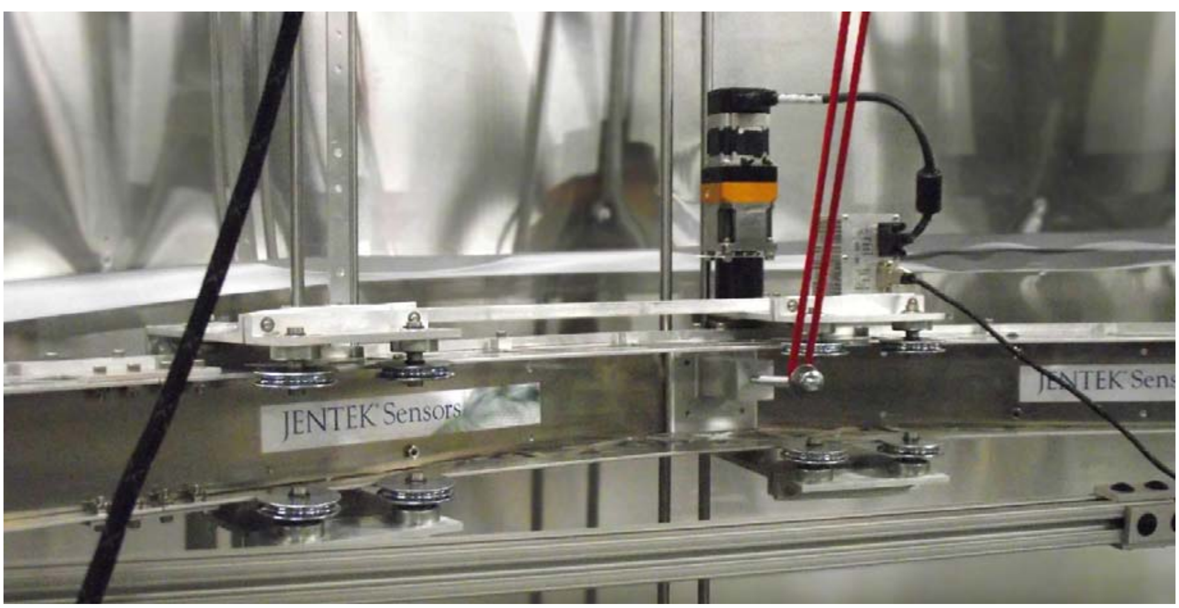

FIGURE 4. Automated vessel scanner assembled in JENTEK's Waltham office being tested on a mockup of a large reactor vessel.

Because the scaffolding in the second vessel scanned during the service was constructed significantly off center, it was incompatible with the automated scanner so scanning on this vessel was performed using the hand held manual scanner in Figure 5. Also, because wall coverage rate was considerably higher while using the manual scanner, it was used for the last two vessels inspected. The ideal scanner for future inspections would be a semi-automated solution that provides the higher inspection speed of the manual scanner with the improved position control of the automated scanner. For example, for the automated scanner the vertical position of the scans can be controlled in fixed intervals of 10 cm, while intervals between manual scans were measured by hand with substantially more positioning error. Because of this, the spatial registration of the data taken with the automated scanner is significantly more accurate than the spatial registration of the data taken with the manual scanner. Additionally, automated scans are much straighter circumferentially than scans performed by hand with the manual scanner. This type of manual scanning made processing of the manual scanning data more time consuming to avoid false indications. If the scanner shifts vertically during a scan, especially when the sense elements cross a weld line in the cladding, it appears as a localized property change in the scan line that could potentially corrupt the processed data. A semi-automated solution would involve a mechanically guided manual scan that could be performed as quickly as manual scans, but with the spatial registration of automated scans.

FIGURE 5. Manual scanning cart.

EXAMPLE DATA

Figure 6 shows a mapped overview of blister locations and relative sizes as well as substrate anomaly locations for one of the four vessels scanned during the service. 56% of this vessel wall was scanned over two shifts consisting of four man teams. Figure 7 shows a gap thickness C-Scan of one of the zones with the largest total blister volume scanned during the service. Figure 8 demonstrates the 3D gap thickness plots that can be generated using the data presented in the gap thickness C-scan images.

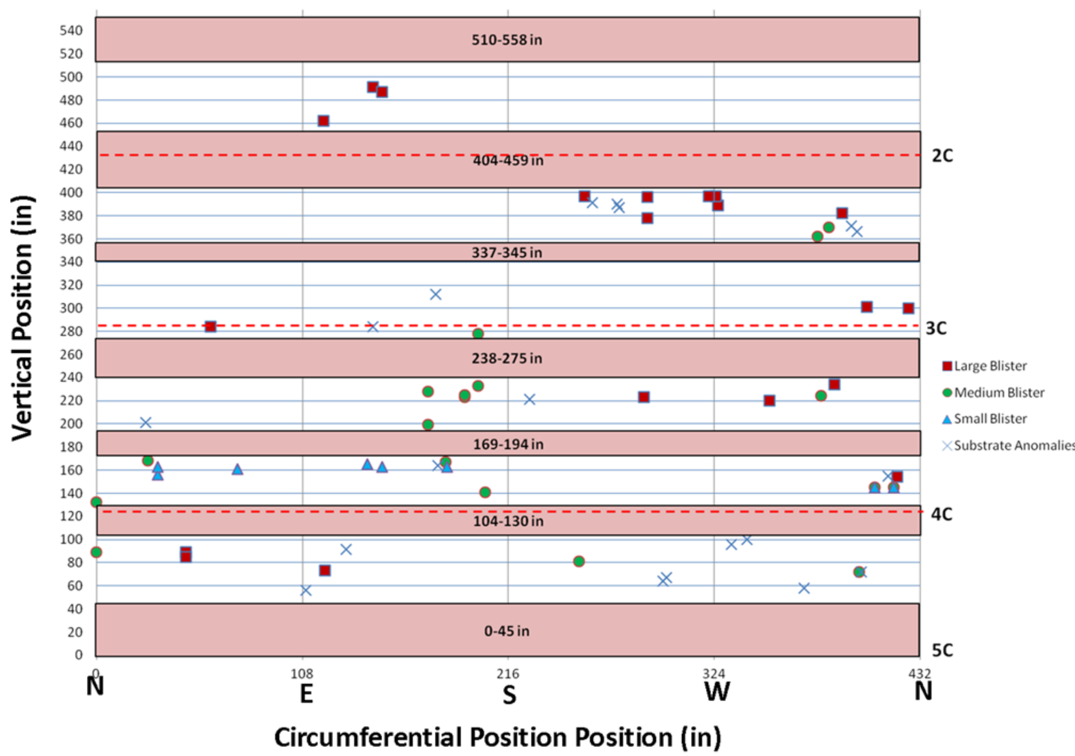

FIGURE 6. Reported blister locations and relative sizes on a scanned vessel.

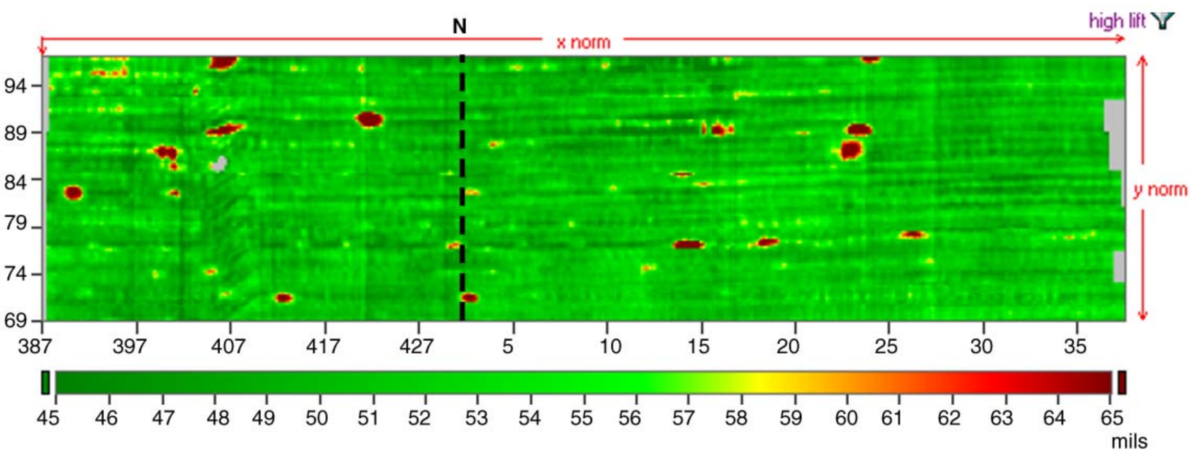

FIGURE 7. Gap thickness C-scan of a blister zone the first vessel scanned using the automated vessel scanner. The origin of the C-Scan shown is at vertical height 69 inches above the nearest weld seam and circumferential position 387 inches (where 0 inches is facing north) Total area and volume of the blisters shown in this image are 62.2 in^2 and 0.60 in^3 respectively.

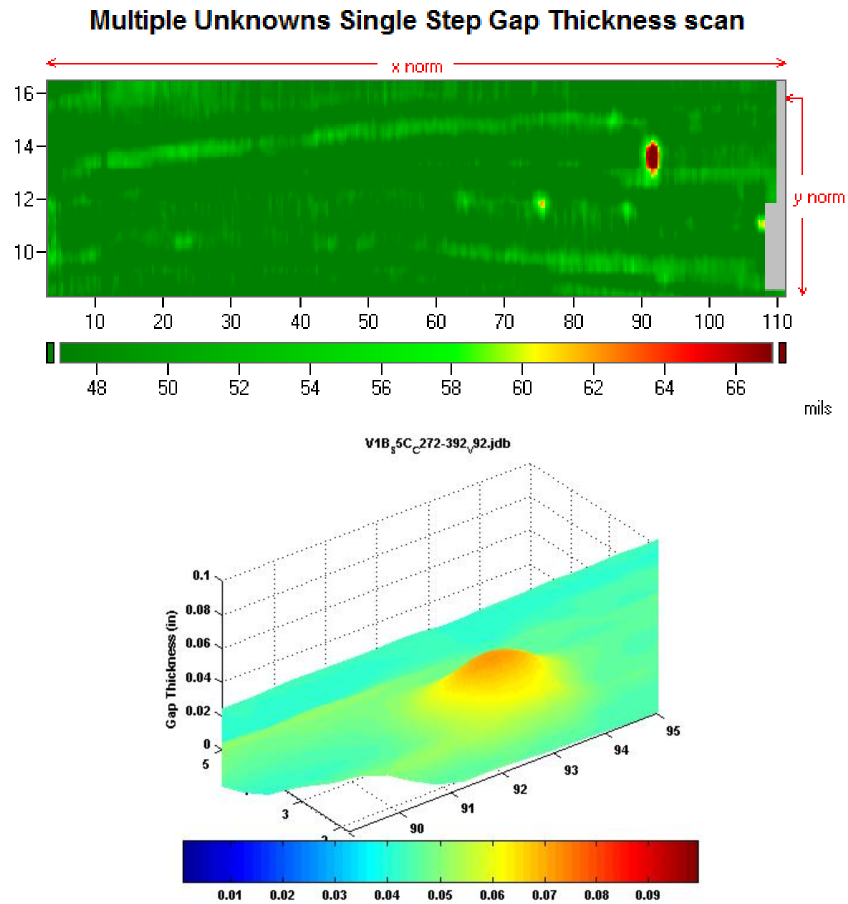

FIGURE 8. Example gap thickness C-scan and the corresponding 3D plot localized around the location of the blister. This particular blister had a maximum gap size of 0.7 mm, and area dimensions of 63.5×43.2 mm.

CONCLUSION

The purpose of this program was to demonstrate imaging and characterization of blister volume using MWM-Array sensor technology. A successful first service for inspection for hydrogen blisters in weld overlay clad vessels was completed at a major facility in Saudi Arabia during an 8 day period. This included successful scanning of over 50% of the internal clad surface inside four large vessels. Hydrogen blisters were successfully mapped and digitally registered. Suspect cracks in the steel substrate below the cladding were also identified.