# Nondestructive Inspection of Resistance Spot Welds Using **Matrix Phased Array Ultrasonic Technology**

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**Automobile performance and passenger safety both rely on sound welds. A new, high-frequency ultrasonic MPA probe performs nondestructive inspection of these welds, saving time and cost.**

Advanced high-strength steels (AHSS) were introduced to the automotive industry to reduce vehicle weight and are gaining momentum due to initiatives that call for increased body rigidity (driving performance) and improved crash ratings and fuel efficiency. One major challenge these steels present involves the integrity of spot welds. There are roughly 4000-7000 resistance spot welds on every U.S.-made automobile and the reliability of the body structure and passenger safety both rely on sound welds.

The stress state at the weld, fracture toughness of the weldment, and presence of pores, cracks, and embrittled regions in AHSS are driving factors resulting in different failure modes compared to conventional steels—particularly interfacial type failures[1]. Traditional resistance spot weld (RSW) destructive test methods such as pry-bar or chisel check and peel tests are costly and inaccurate when applied to welds made from AHSS. The automotive industry therefore seeks nondestructive tests to ensure safe implementation of AHSS steels.

Some advanced nondestructive inspection (NDI) techniques that may provide solutions are already used in the aerospace and power generation industries. Unfortunately, transferring these techniques to the automotive industry is limited due to fundamental differences[2]. The goal is to reduce the time to validate and increase correlation methodology confidence with less engineering and laboratory time. To reduce the repeatability gap, improved robustness of NDI techniques and little or no dependence on operator skill is needed[2].

### MPA probe meets the challenge

Computational modeling and simulations helped scientists develop a reliable, high-frequency matrix phased array (MPA) probe with an appropriate delay line and an optimal propagation distance for the ultrasonic beam to be focused on a spot weld. A commercially available CIVA modeling package was used to perform this modeling and simulation.

It was necessary to define parameters such as material thickness and spot weld diameter. Research revealed that the majority of spot weld applications are for materials in the thickness range of 0.7-2 mm having a nominal weld diameter of 5-7 mm. Initial beam modeling calculations helped determine general parameters for a probe capable of inspecting spot welds in the targeted range. Consideration was given to current MPA instrumentation capabilities, although many MPA instruments on the market today limit the number of elements to a maximum of 128. Figure 1 shows a schematic of a 100-element 2D MPA probe element with some probe parameters evaluated using the beam modeling tools. The same probe parameters apply to 3D probes with additions of curvature shape and radius.

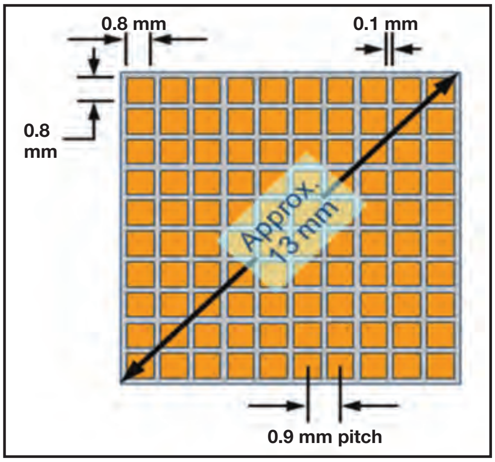


**Fig. 1 —** *Schematic of a 2D matrix phased array (MPA) probe element.*

To achieve good focus at a depth of 0.7-2 mm, the probe needs to have a physical delay distance between the element and part surface. The delay line tip was filled with water because it conforms to surface deformations caused by the welding electrodes. Modeling and simulation results show that a water path length of 18 mm produces a narrow beam with minimum side lobes through the interface of water and metal.

A handheld probe was designed and fabricated with an 18-mm-long water delay line cavity at the end. Subsequent modeling investigation for a 64-element probe with an 8×8 matrix configuration operating at a 12 MHz frequency proves the same water delay line could be used. In this case, the probe element was shaped to have a convex curvature with a 50-mm radius.

### From simulation to reality: Portable NDI

The EWI SpotSight inspection system shown in Fig. 2 harnesses the power of MPA-based ultrasonic imaging technology to accurately evaluate the effectiveness of component joints by showing weld nugget images in real-time with feedback. This new NDI system not only reduces the need for destructive testing of spot welds in manufacturing, but also assesses the structural integrity of products with great cost-savings and efficiency.

In order to generate 2D C-scan weld images, the phased array electronic circuit first activates the MPA probe with commands from the data processing software. Ultrasonic signals detected by the MPA probe are then fed into the imaging algorithm for the fused and non-fused joining areas being inspected. A color-coded ultrasonic C-scan image and additional data such as nugget diameter and fused area are displayed on the screen.

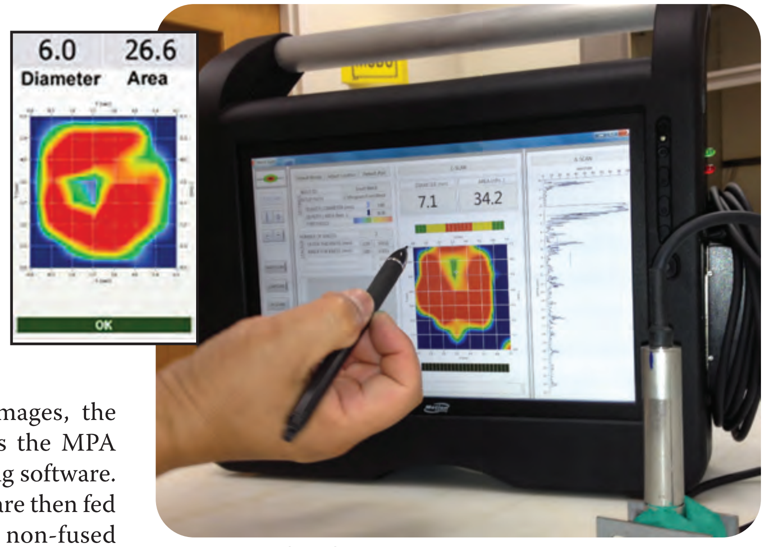


**Fig. 2** — *EWI SpotSight ultrasonic nondestructive inspection system and C-scan image of a resistance spot weld nugget with porosity in the center section (inset).*

The system processes ultrasonic signals as they are detected by individual subgroups of the probe array using two electronic gates, one for the front surface reflection and the other for interface reflection. An ultrasonic image is plotted as raw ultrasonic data is processed in real-time with the dual gate imaging algorithm. Operator feedback occurs in a fraction of a second and probe adjustment is relatively fast and easy compared to other systems that require probe repositioning if results are unsatisfactory.

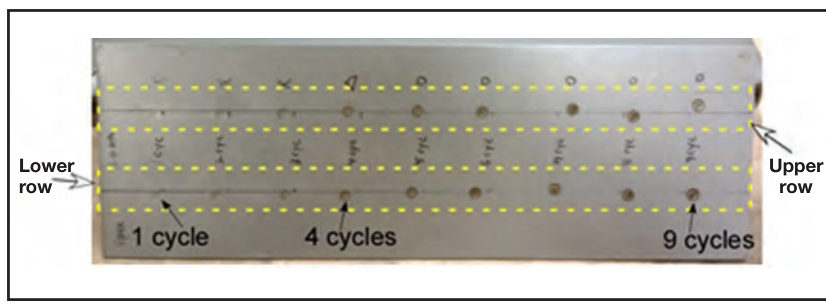


**Fig. 3** — *Test sample with two rows of resistance spot welds.*

## Test results

A set of resistance spot welds with two-sheet stackups and thicknesses at the lower limit of 0.7 mm were prepared. Two rows of nine spot welds each were placed on the test sample shown in Fig. 3. For this sample, a constant current of 6 kA was applied for all welds, while the number of cycles was varied from 1-9 at an increment of one cycle for each weld. Spot welds on the sample stack were tested using the SpotSight inspection system and results are shown in Fig. 3.

The number in the upper left corner of each image in Fig. 4 indicates how many electric current cycles were used to form weld nuggets. For both upper and lower rows, an acceptable spot size weld was measured after five cycles.

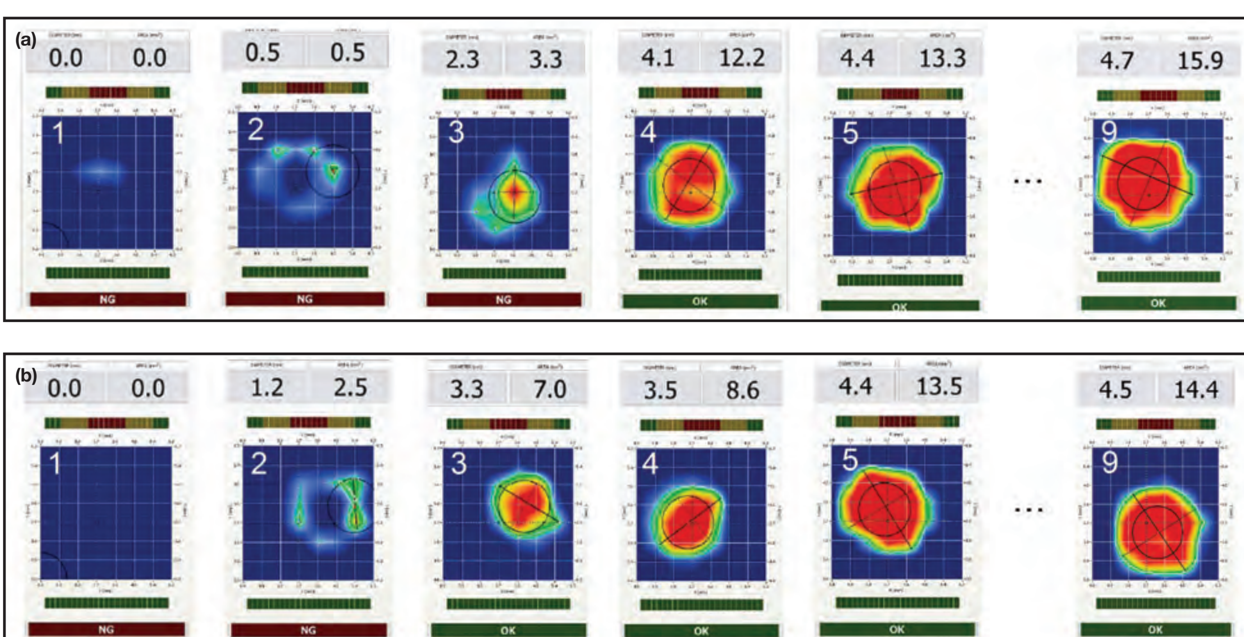


**Fig. 4** — *Ultrasonic images of spot weld nuggets for the test sample plate shown in Fig. 3. Welds in the upper row (a), welds in the lower row (b).*

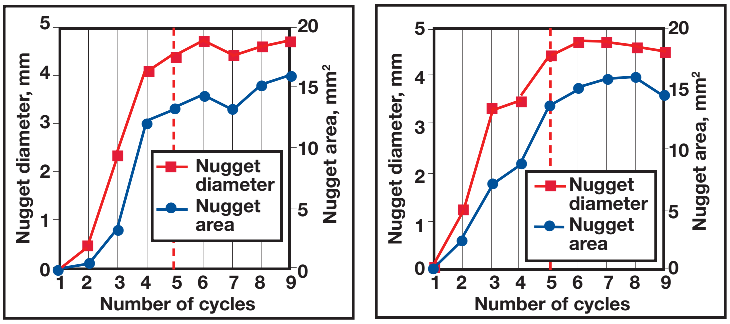


**Fig. 5 —** *Increase in nugget diameter and fused area as a function of number of cycles for each row. Data is based on ultrasonic image data shown in Fig. 4.*

The left and right numbers shown in the upper portion of each ultrasonic image indicate nondestructively estimated nugget diameter and area, respectively. Nugget size did not improve much after five cycles. For both rows, the overall increase in nugget size was less than 10% after five cycles.

Graphs in Fig. 5 were generated using the ultrasonic images in Fig. 4, showing improvements made to nugget diameter and fused area as the number of weld cycles increased. Diameter and area improvement start saturating once the number of cycles is higher than five at 6 KA of constant current.

## Conclusions

A high-frequency ultrasonic MPA probe designed to perform nondestructive inspection of resistance spot welds on automotive chassis was developed and tested. Based on modeling and simulation results, a water delay line with a length of 18 mm produced the best penetration of ultrasonic signals at the water and metal interface, as well as throughout the metal interface where resistance spot weld nuggets form. An innovative electronic dual-gate imaging process discriminates fused and unfused sections of the weld and displays results in a color-coded C-scan format for easy interpretation. Average nugget diameter and fused area data are also displayed in real-time to provide realistic operator feedback.

NDI results of spot welds made on two 0.7-mm metal sheets with different cycle numbers at a constant electrical current level show that a good weld nugget with an acceptable diameter and fused area could be formed after four or five cycles. The number of cycles currently used on automotive chassis may be reduced to save time and cost without over-welding with additional cycles. ❍

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**References**

1. J. Gould and W. Peterson, Advanced Materials Require Advanced Knowledge - Understanding Resistance Spot Weld Performance on AHSS. *The Fabricator,* Vol 35, No. 8, 2005.
2. D. Hopkins and the USAMP NDE Steering Committee, Reliability in High Volume Manufacturing: An Automotive Perspective. *Materials Evaluation,* 2007.