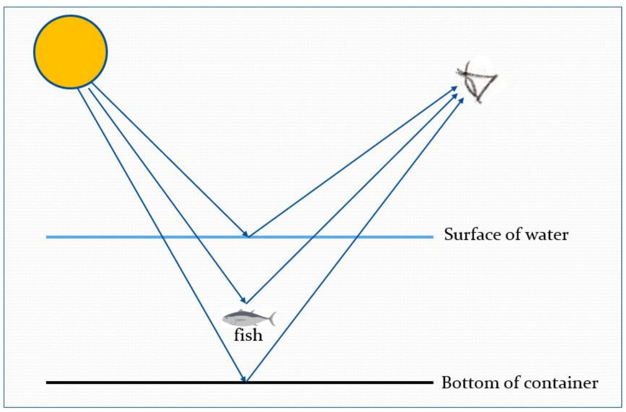
Ultrasonic system with 3-D Matrix Phased Array Probe for testing spot welds

Operational Principles:

Analogy to Light waves:

You can think of the ultrasonic waves (or signals) as being similar to light waves. Light waves emitted from the sun or another source travel through the air until they hit something and then some or all of the light waves are reflected off of the surface of the object, and if someone is observing the object, they see the light that is reflected and that person's brain processes it as an image. When light hits the surface of water, some of the light is reflected off the surface of the water and some of it penetrates the surface and reflects off of objects in the water or off the bottom of the container and the reflected light is received by the eye of the person observing it. Ultrasonic signals travel in a similar manner; some of the signals are reflected at the surface of a spot weld and some travel through the spot weld and are reflected off of either a flaw in the spot weld or off the bottom of the spot weld.



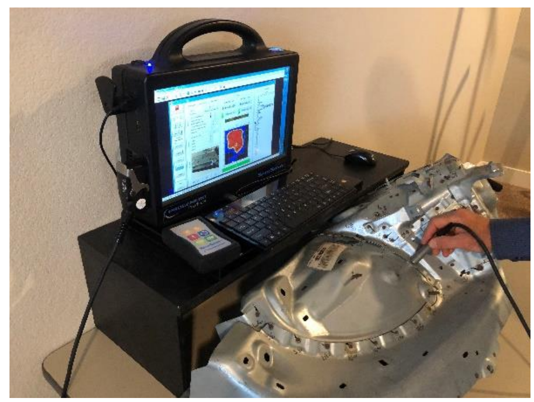


FIGURE 1. Light waves reflecting off different surfaces and being observed by human eye. Similar to ultrasonic sound waves being emitted, reflecting off of bottom surface of spot weld, and being observed by probe.

Three-Dimensional Matrix Phased Array Probe

Three-Dimensional Array Design The spherical geometry of the curved three-dimensional probe elements is illustrated in Figure 2(a); the ultrasonic probe illustrated in Figure 2(b) includes an 8 x 8 array of piezoelectric elements arranged in a spherical geometry and has a flexible membrane to conform to the contoured surface of a spot weld while enabling the sound energy to be transferred directly into the spot weld being tested. The matrix phased array has a radius of 50 mm. The distance of water path from the array to the center of the membrane is 20 mm.

An excitation is sent to a subset group of transducer elements, and are combined to send an ultrasonic beam toward a spot weld. Each transducer element in a subset group may be pulsed at different time intervals (phase delay) and their individual waves summed to produce a focusing effect of the beam as well as a steering effect if needed. Other three-dimensional arrangements are possible for optimizing the performance for specific applications. The total number of elements, overall dimension, and operating frequency determine the overall three-dimensional surface contour shape and its operating characteristics and parameters. SpotSight can accurately inspect an overall spot weld thickness of between 0.5 and 6.0 mm.

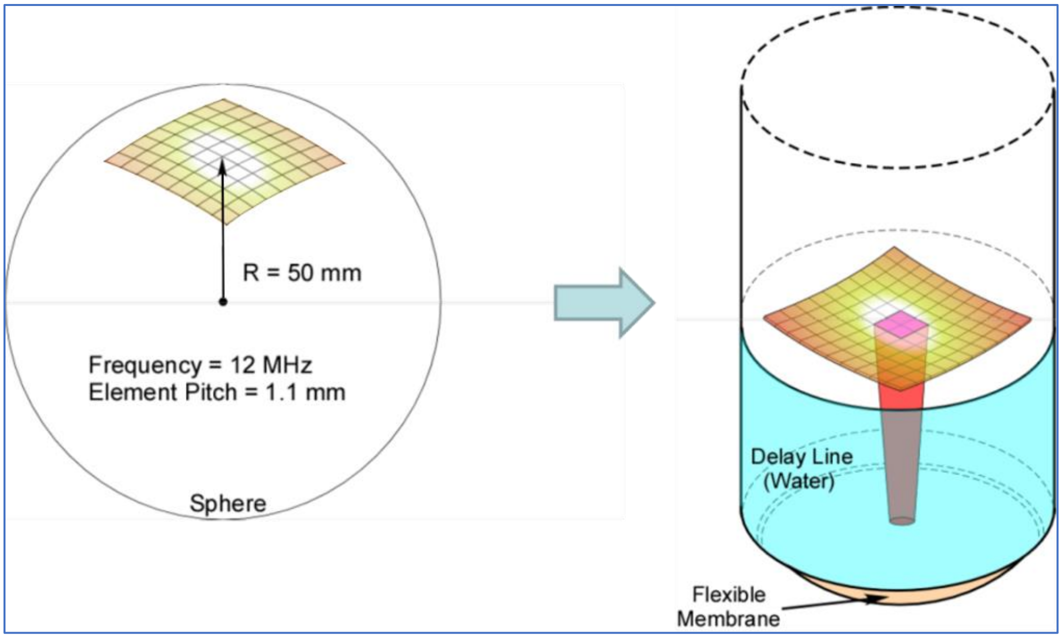


FIGURE 2. (a) 3-D MPA elements (b) 3-D array element in probe and sub-element group

When inspecting a spot weld, the end of the probe is dipped in water to make good connection to the spot weld (this water is in place of the gel couplant that most systems require). The flexible membrane allows the tip of the probe to conform to the contour of the welded area. The fluid filled chamber acts as a pathway for focusing and steering ultrasonic beams. A curved array of ultrasonic elements transmits ultrasonic beams into the welded area to capture the associated reflections of those ultrasonic beams. The Matrix Phased Array (MPA) electronics unit communicates with the ultrasonic elements through signal pathways and the computer processes the incoming ultrasonic data and generates a readout of the spot weld thickness and average diameter as well as a visual representation of the fused area.

Ultrasonic Signal Processing Methodology

SpotSight™ uses a combination of A-Scans and C-Scans to generate the signals and resulting reflections that provide the necessary information to determine thickness and diameter of the spot weld. A-Scans use a single signal and reflection that is valuable in determining thickness. C-Scans use an array of signals and reflections to give a more complete picture of the area of the spot weld. SpotSight uses both A-Scans and C-Scans along with complex algorithms to process all of the data to provide a complete representation of the spot weld.

Ultrasonic Image Processing

The SpotSight system directs ultrasonic energy into a spot weld where some of the Ultrasonic signals are reflected from the surface of the Top Sheet of the welded part and some travel through the weld and are reflected off of the bottom of the Lower Sheet. SpotSight receives the reflected signals and process the data to produce an A-Scan image, a C-Scan image, and the resulting average Diameter and Thickness of the spot weld. The system then compares this information to the minimum acceptable Diameter and Thickness settings that are provide to it by the user in order to determine if the spot weld is OK or No Good (NG).

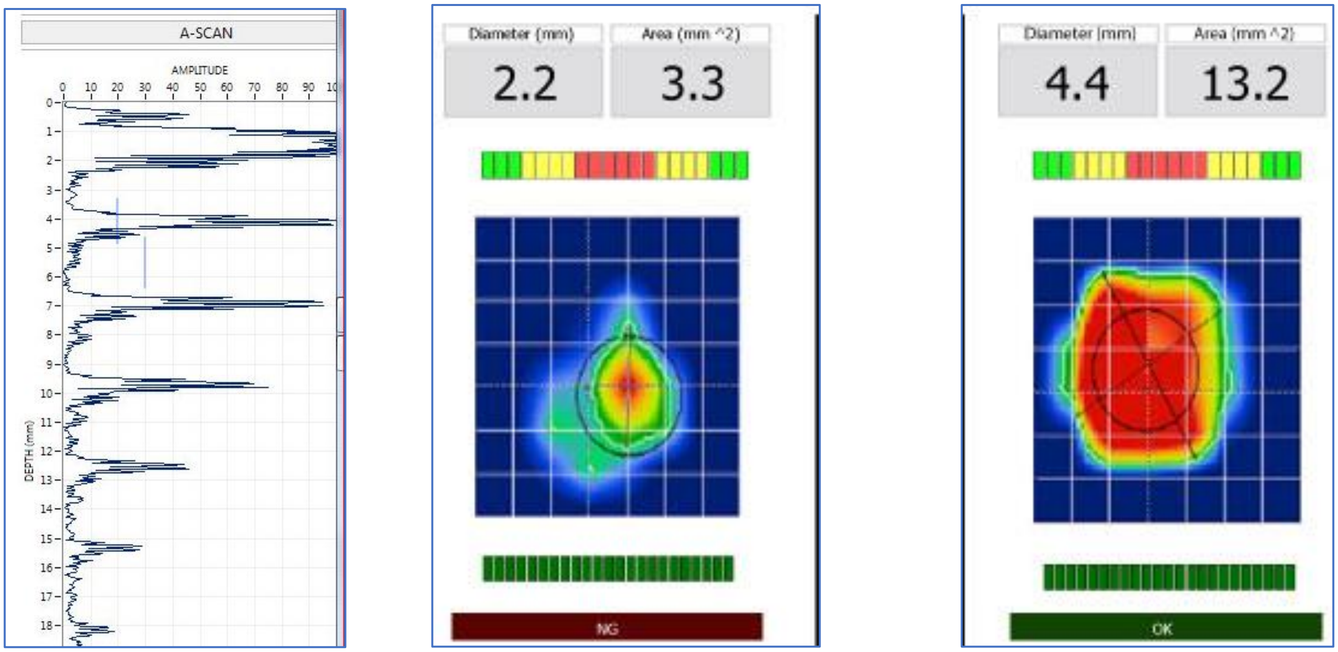


FIGURE 3. (a) A-Scan Image (b) C-scan image of a bad weld (c) C-scan image of good weld

SpotSight uses "Gates" to determine which ultrasonic signals the system will look at when determining if a spot weld is good or not. This differs from other systems, which utilize an attenuation coefficient compensation method. In recent use at an automobile manufacturer, a round of inspection was performed on a part from spot weld #1 through #22 without stopping while the total inspection time was timed with a stopwatch. The average inspection time was estimated to be 13 seconds per spot weld.

Good Weld

Figures 4 & 5 below show the ultrasonic signal traveling from the probe, through the spot weld and reflecting back to the probe where the signal is transmitted to the Matrix Phased Array (MPA) Electronics for processing and imaging.

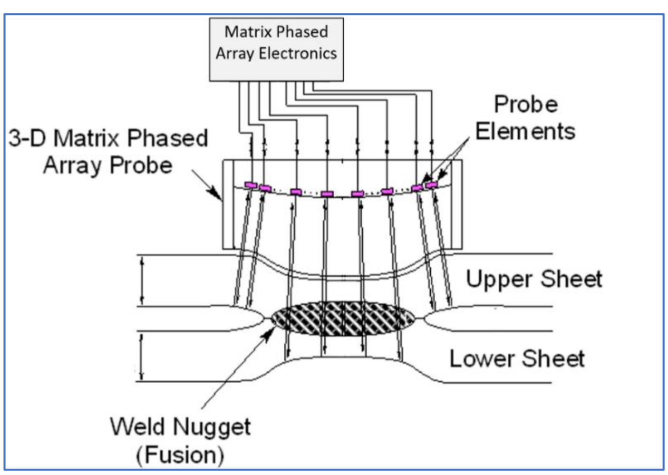


FIGURE 4. the primary components of a three-dimensional Matrix Phased Array (MPA) probe.

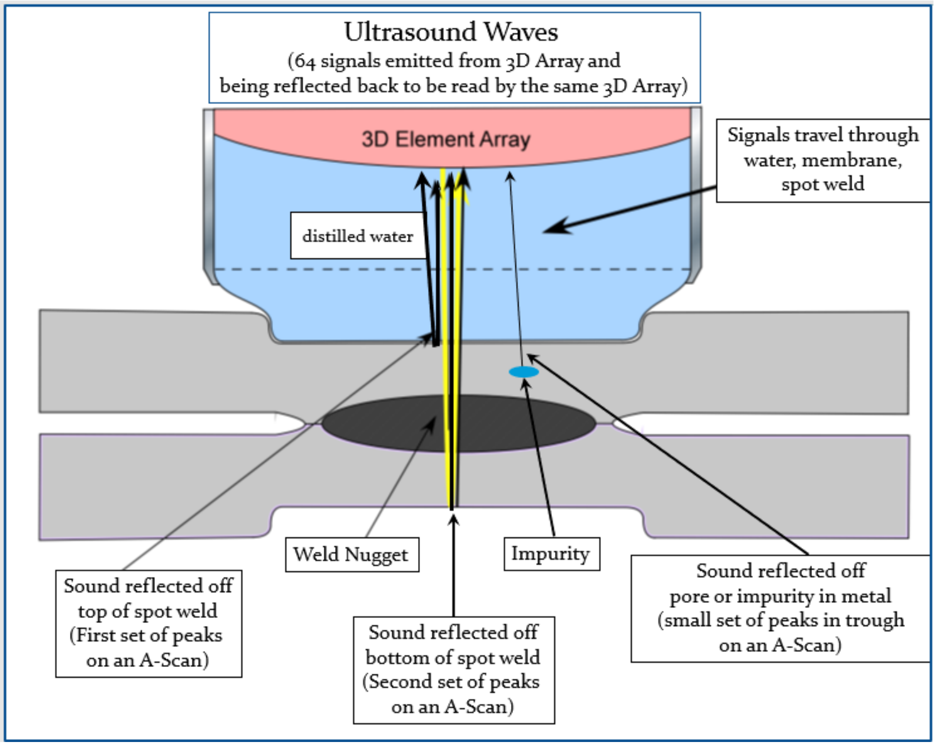


FIGURE 5. Ultrasound signals travel through probe & spot weld to create A-Scan and C-Scan readings

Figure 6 below illustrates the A-Scan image on the SpotSight screen, showing

The amplitude of the peaks diminishes with each successive reflection of the ultrasound signal as it echoes back and forth from the bottom and top surfaces within the spot weld.

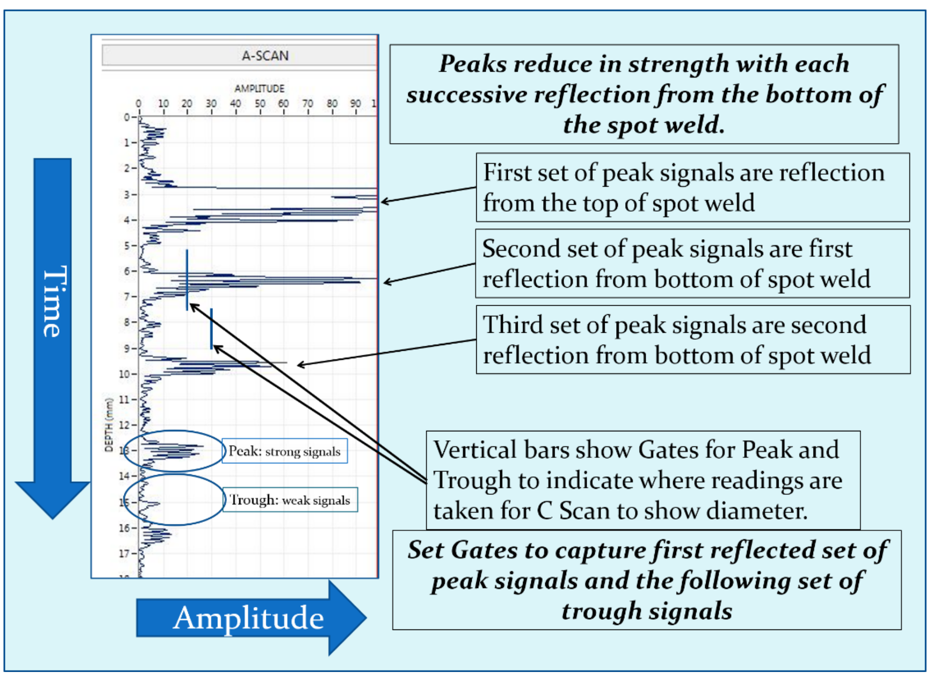


FIGURE 6. A Scan resulting from signals in Figure 5

Figure 7 below shows what the SpotSight screen looks like when a spot weld passes inspection.

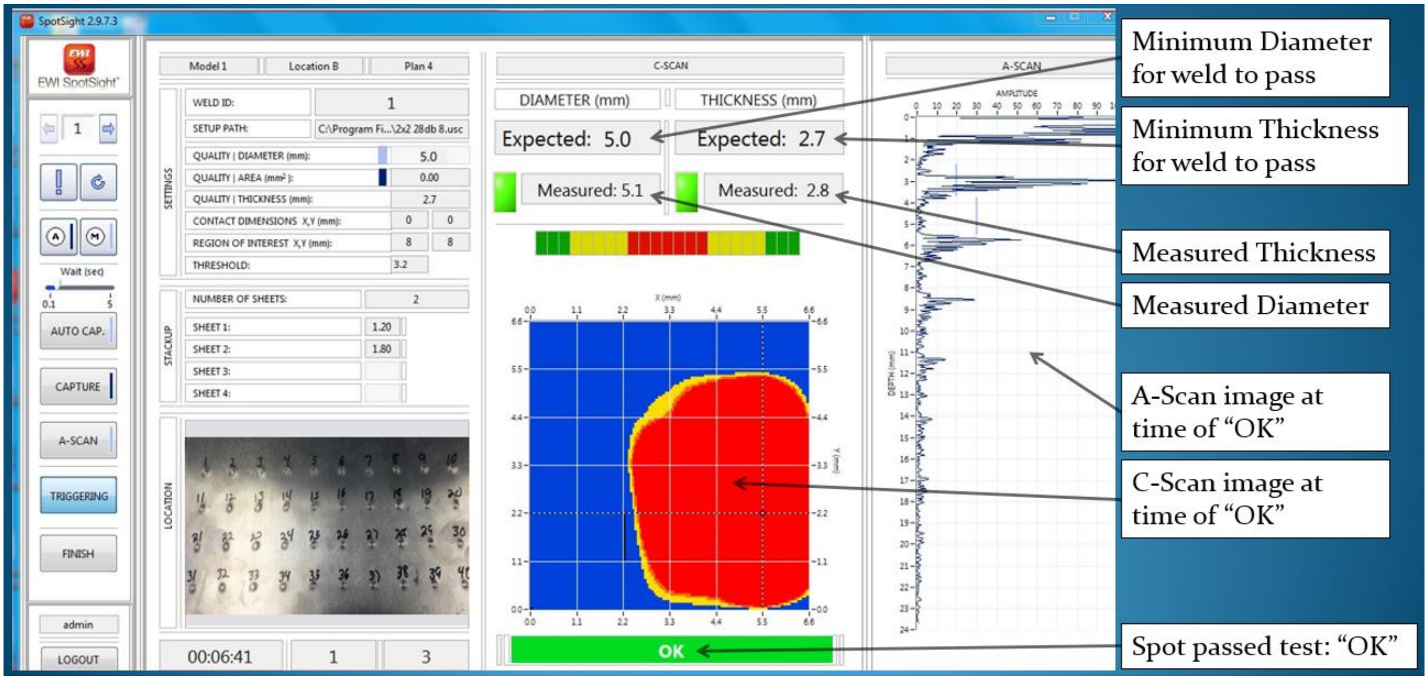


FIGURE 7. Screenshot of spot weld test that tested OK.

Poor Weld

Figure 8 below shows that with a bad spot weld, the ultrasonic signals reflect back to the probe from the bottom side of the Upper Sheet where little or no weld nugget is formed. The results from a SpotSight inspection of this spot weld will show that it does not meet the minimum requirements for diameter and/or thickness and is considered no good.

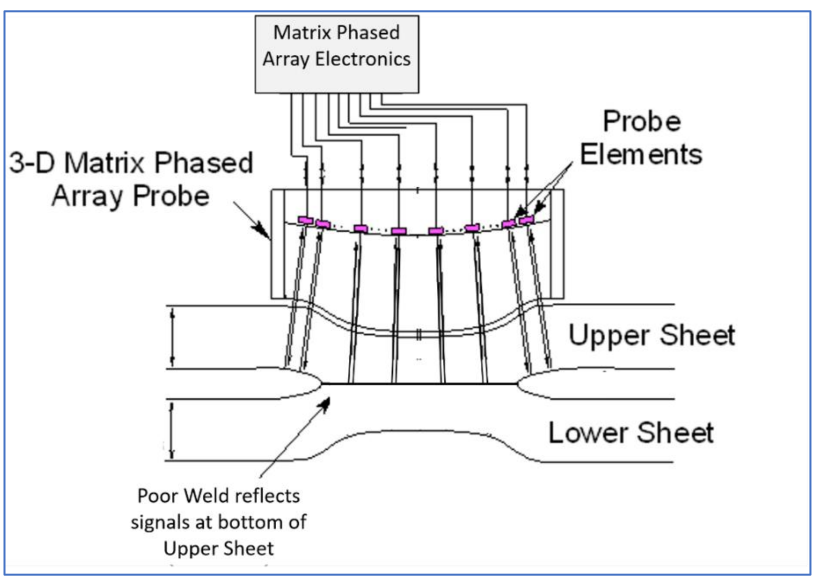


FIGURE 8. Ultrasonic beam reflecting off the bottom of the Upper Sheet because of poor weld.

Figure 9 below shows what the SpotSight screen looks like when a spot weld doesn't pass inspection.

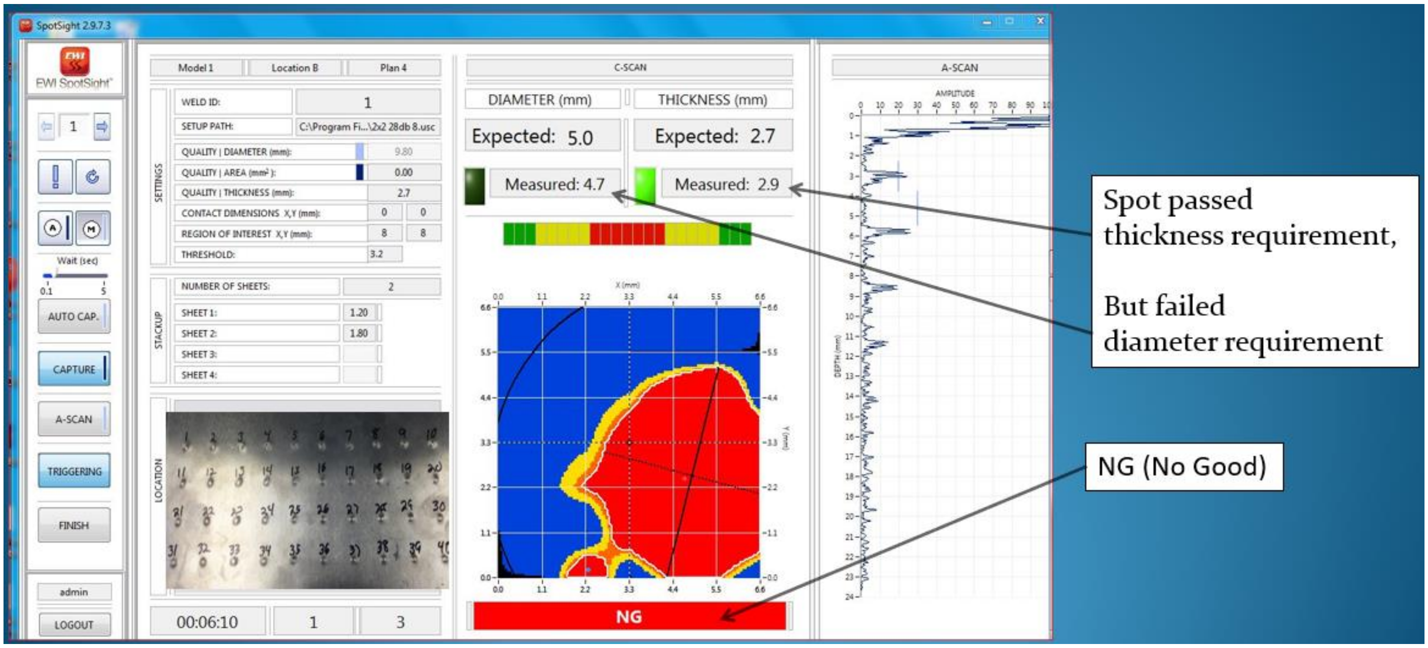


FIGURE 9. Screenshot of spot weld test that tested NG (No Good).

References

J. Gould and W. Peterson, “Advanced Materials Require Advanced Knowledge-Understanding Resistance Spot Weld Performance on AHSS”, *The Fabricator*, Vol. 35, No. 8 (2005).

D. Hopkins and the USAMP NDE Steering Committee, “Reliability in High Volume Manufacturing: An Automotive Perspective”, *Materials Evaluation* (2007).

J. Na and R. Spencer, “Design and Development of High Frequency Matrix Phased Array Ultrasonic Probes”, Review of Progress in Quantitative Nondestructive *Evaluation, Vol. 31A (2011).*