Phased array applied to the examination of the resistance spot weld process

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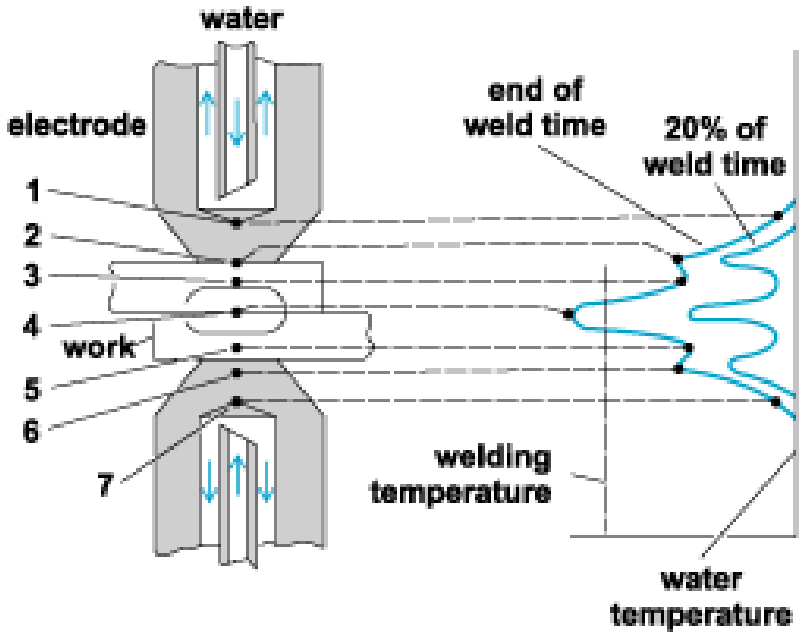
Resistance Spot Welding Process

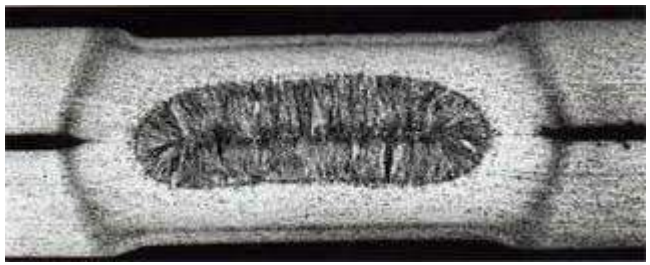
Used extensively in multiple industries

Highly automated process, prone to error

Resistance Welding Process

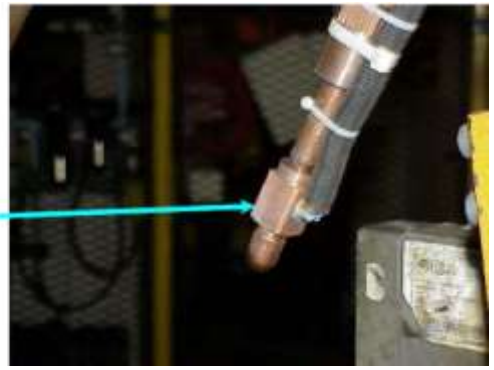
- Makes use of two or more plates clamped between copper electrodes
- Current is applied to heat the plates, with water cooling preventing overheating of electrodes





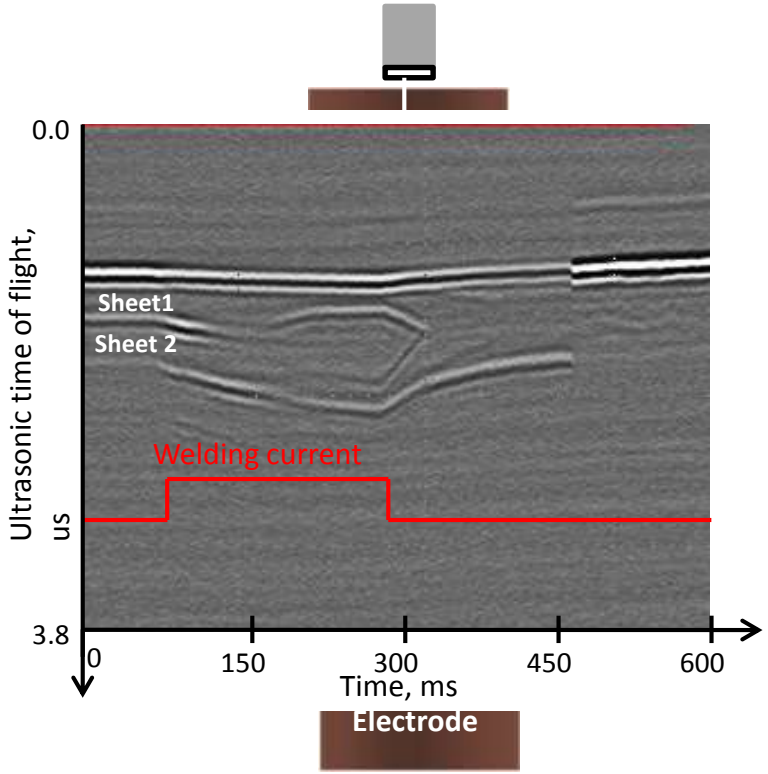
Ultrasonic Monitoring Process

- Transducer is built into the spot weld electrode, allowing for reflection based imaging
- Flexible design allows for adaptation to multiple scenarios



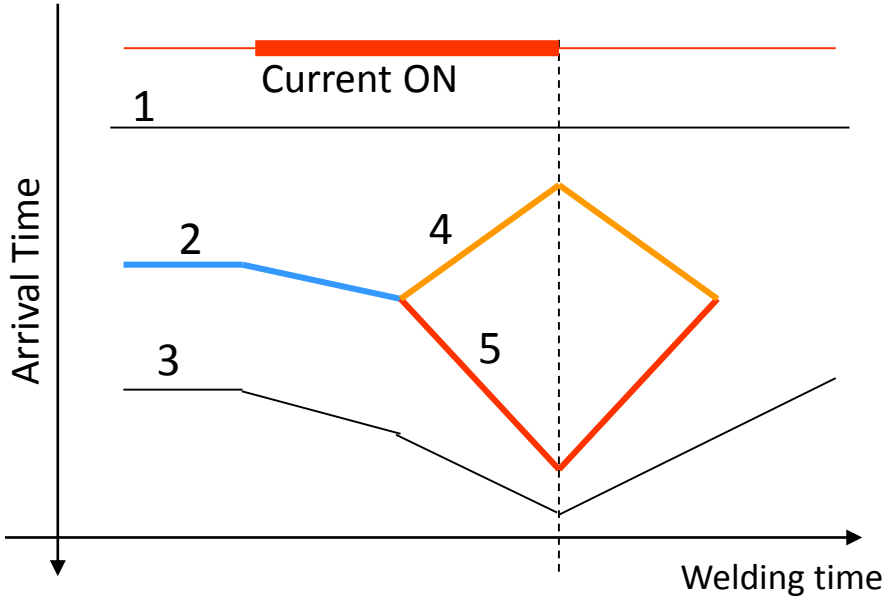
M-scan Formation

- During the acquisition process ultrasound is used to probe the process
- Repeating this at a rapid rate allows for the formation of an M-scan showing the evolution of the weld stack



M-scan Processing

- The best indicator of a good weld is the evolution of the central reflection into two molten pool reflections during the current on (heating) period
- Upon cooling its absence of a boundary between the sheets can be indicative of a bond



Boundary Legend
1 - Copper-steel reflection between cap and workpiece
2 - Reflection from between workpieces
3 - Reflection between workpiece and opposite cap
4 - Top of molten steel pool
5 - Bottom of molten steel pool

Issues with Single Element Design

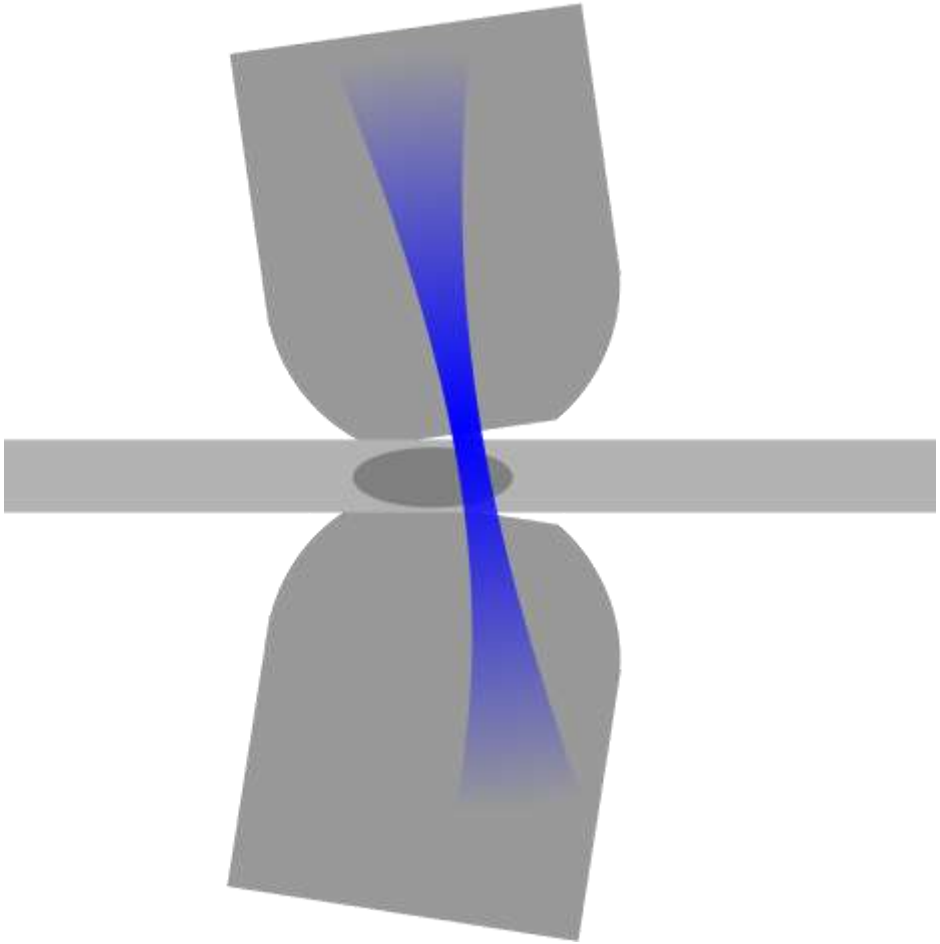
- A single element design requires an axial symmetric system for proper analysis
- Spatial averaging over the spot size of the system can result in overlapping of features of interest
- A high precision system is more prone to misalignment, with a few degrees being enough to affect the monitoring process

X-gun Arrangement

- X-gun arrangements make use of a scissor like motion to secure the workpiece during welding.
- During welding, resurfacing of the caps and variations between parts results in a misalignment occurring with respect to the workpiece

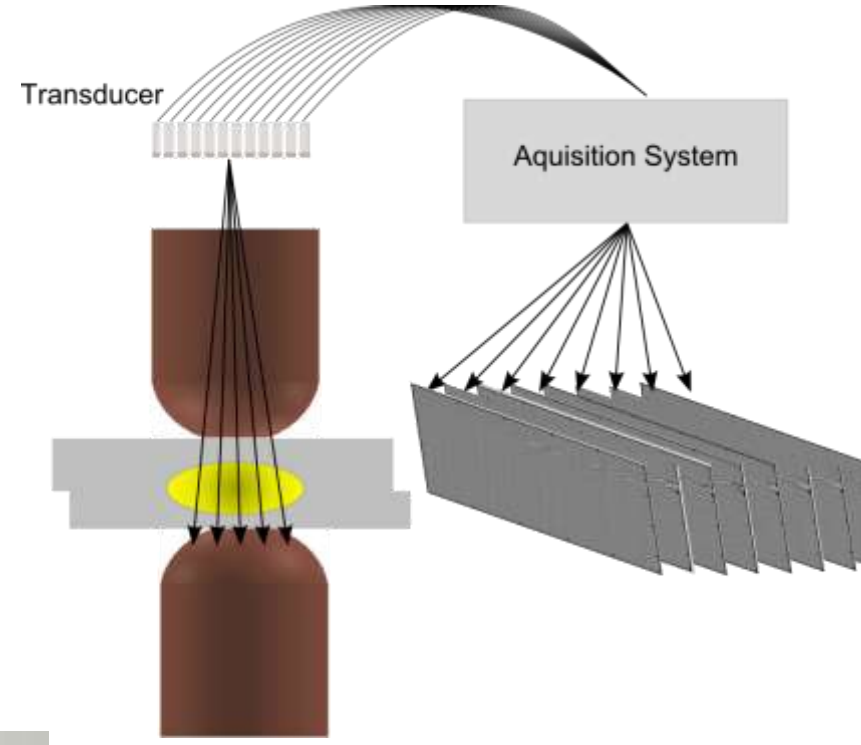
X-gun Arrangement

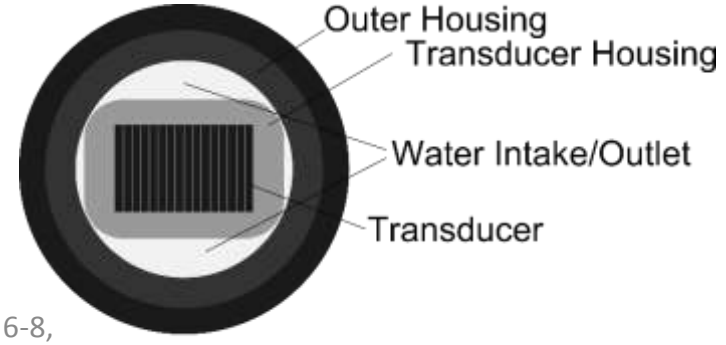
- This misalignment does not severely degrade weld quality, but can make monitoring difficult when it becomes greater than a few degrees



Phased Array Monitoring

- With this and other issues resulting from misalignment, a phased array implementation of the monitoring system was investigated
- This system allows for scanning along a single dimension, eliminating one degree of misalignment



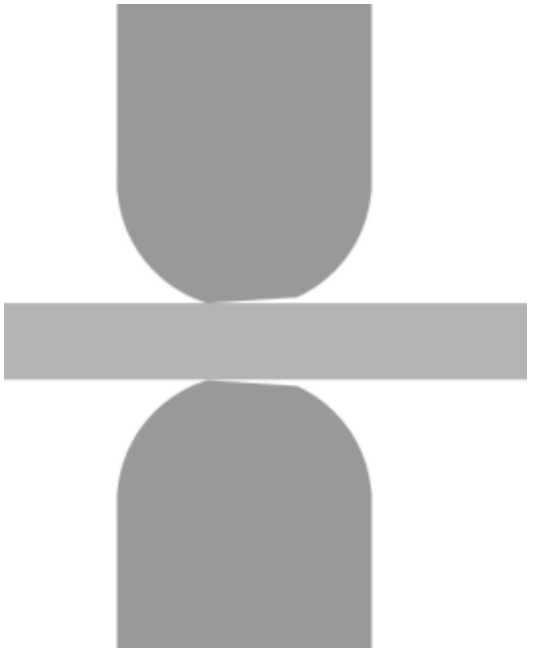


C-gun Arrangement

- These experiments were conducted using a C-gun arrangement

C-gun Arrangement

- Misalignment was simulated by polishing weld caps at small angle, introducing



Generating misalignment

- This results in a weld offset from the center of the cap
- Imaging direction was adjusted to be along misalignment of system

Parameters of Imaging System

- Probe Parameters

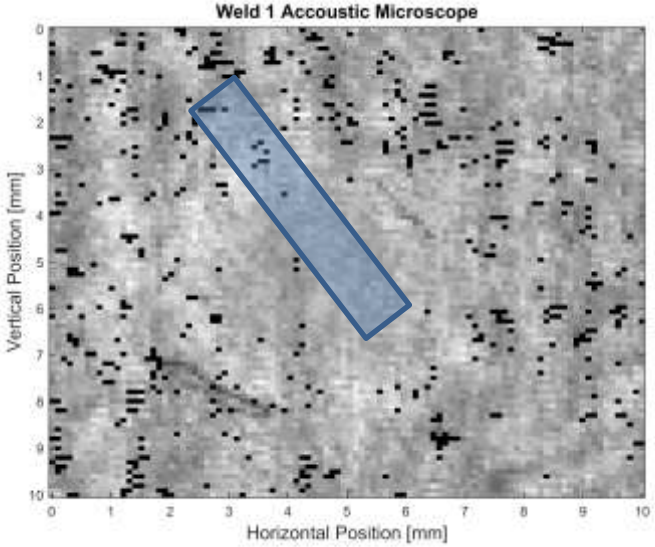
Probe	
Frequency	15 MHz
Number of Elements	24
Elementary Pitch	0.34 mm
Elevation	5 mm
Bandwidth	~65%

- System Parameters

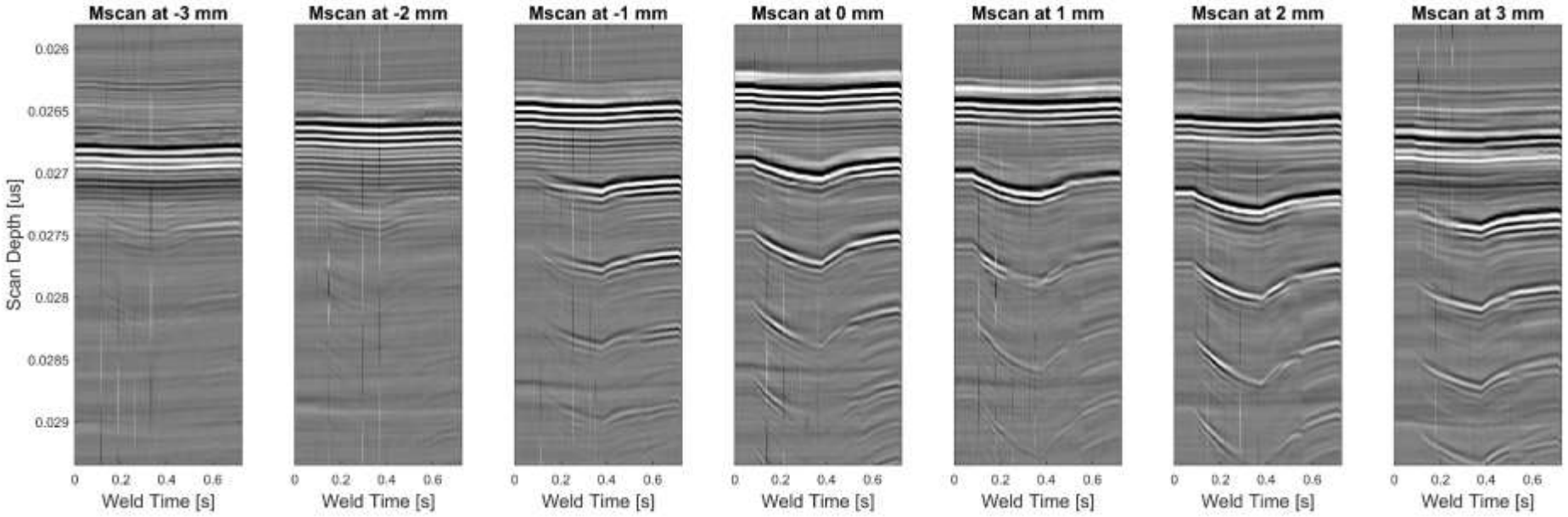
Acquisition System	
Sampling Frequency	100 MHz
ADC Bit Range	12 Bit
Transfer	Ethernet

SCANNING RESULTS ON MILD STEEL SAMPLES, 1.9 MM THICK

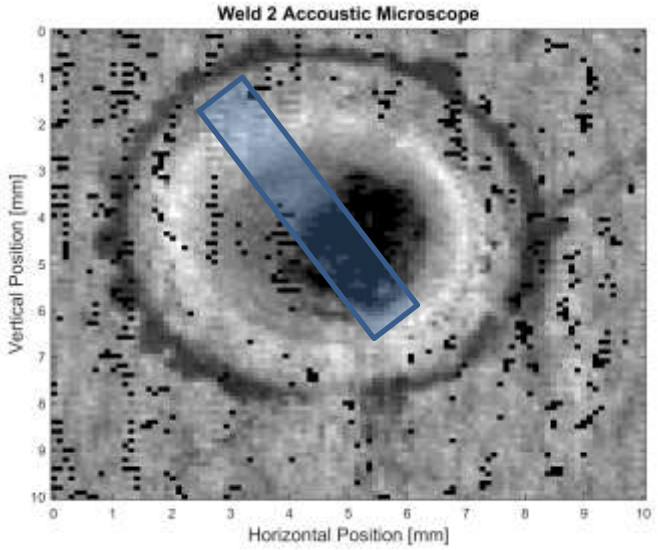
6000 A, 18 Cycles (0.3 s)



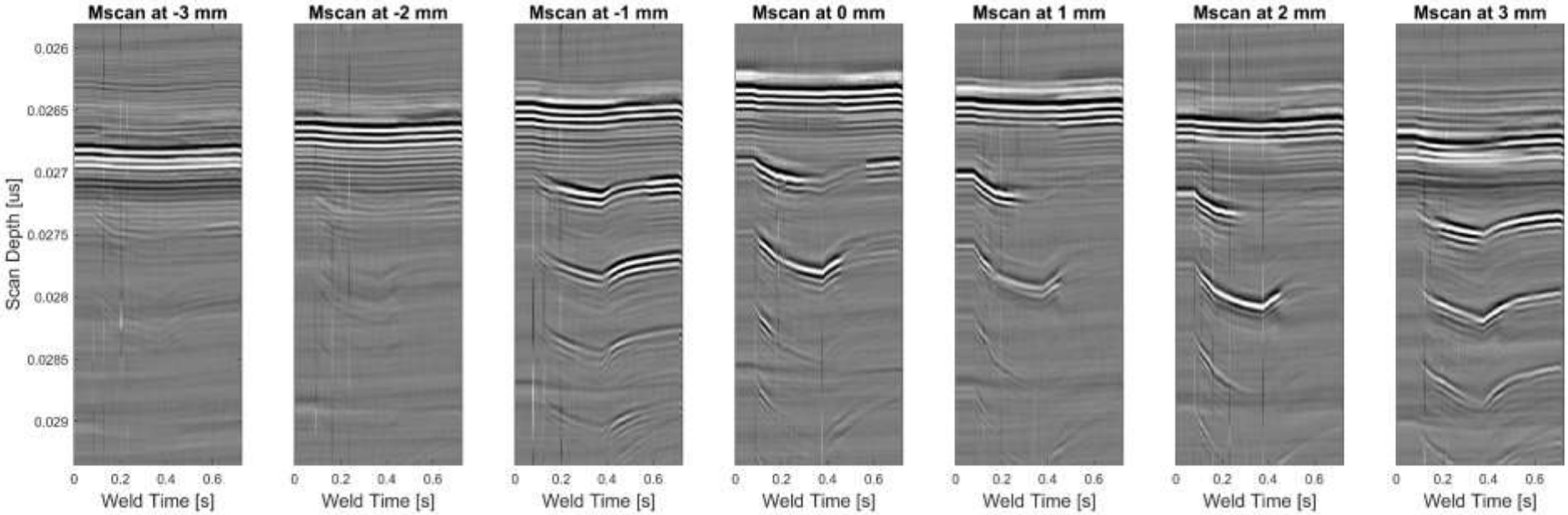
Clear reflections show no adhesion of any kind during the weld process



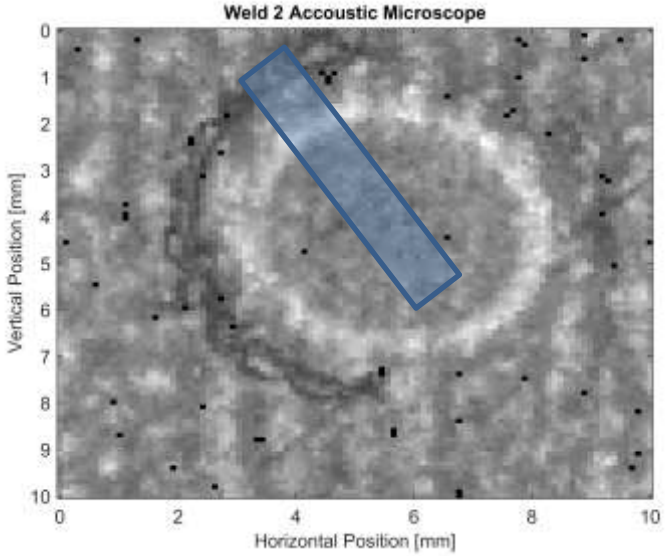
7000 A, 18 Cycles (0.3 s)



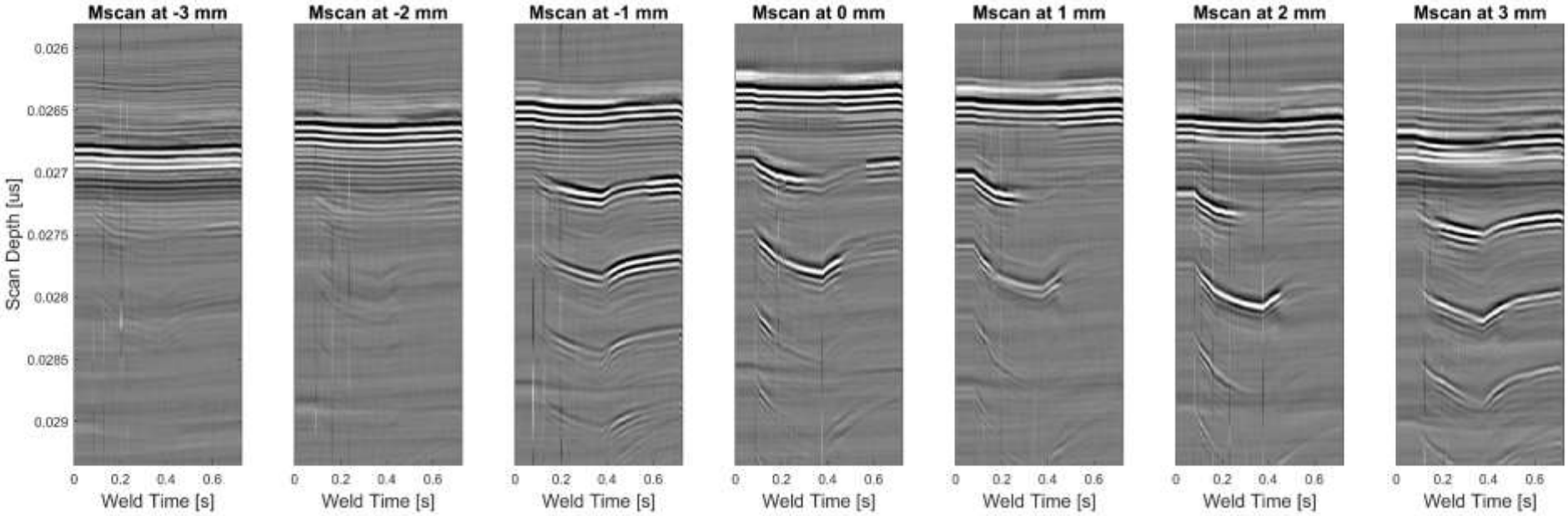
No Melting observed, boundary disappears



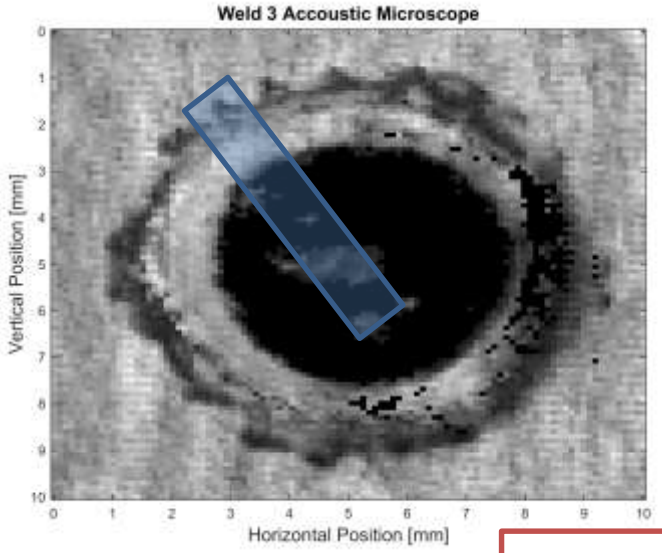
7000 A, 18 Cycles (0.3 s)
*same weld as previous



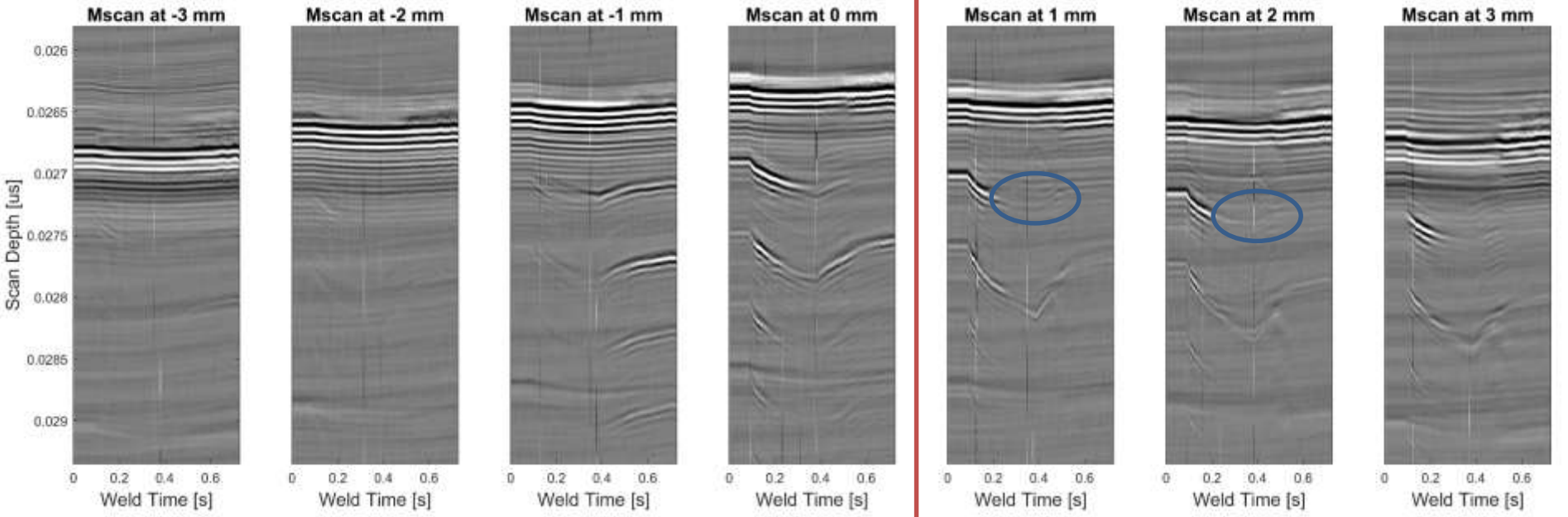
Impact and subsequent scanning shows that bond formed by zinc layer, no weld present



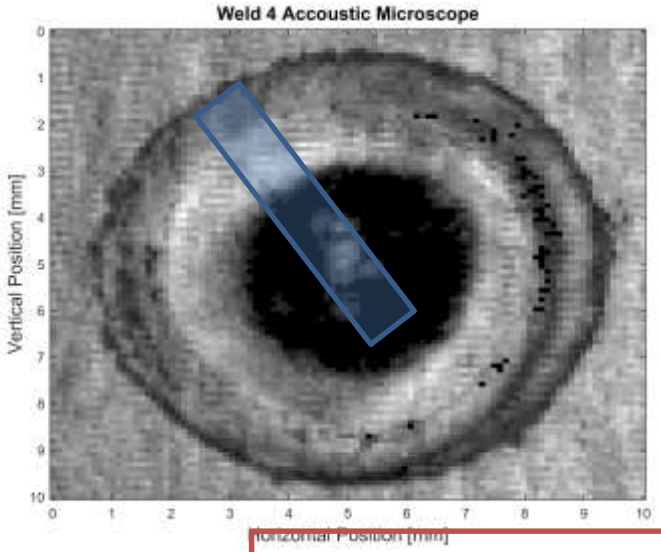
8000 A, 18 Cycles (0.3 s)



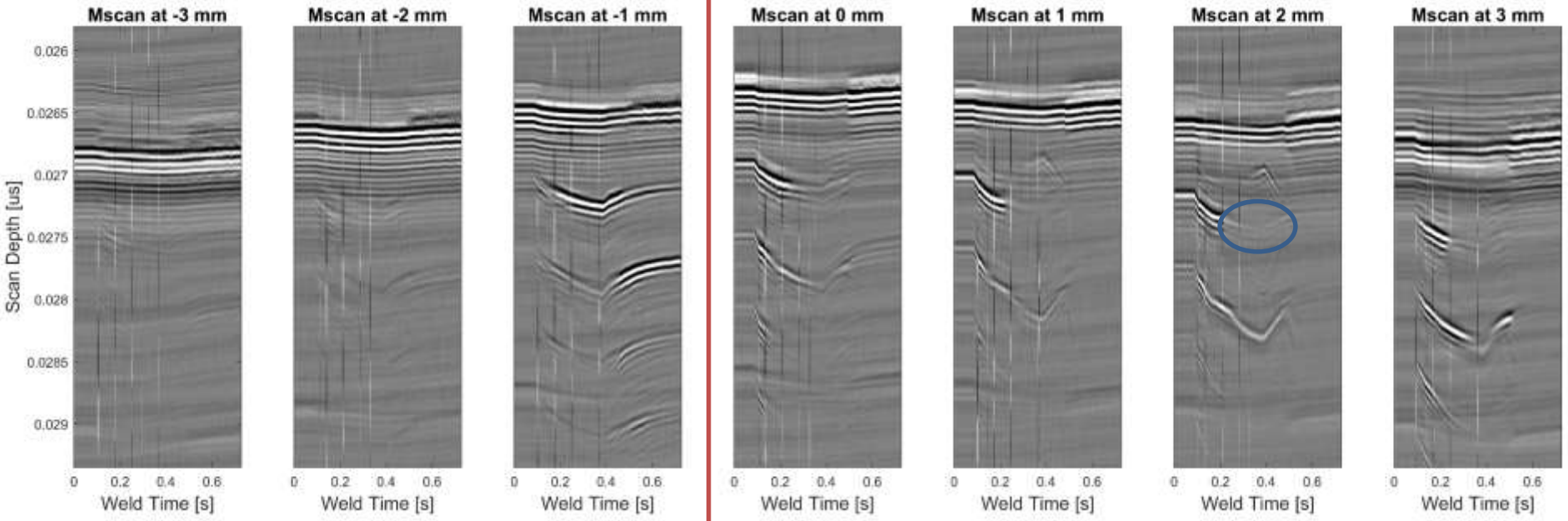
Melting observed, but interface is present during molten phase



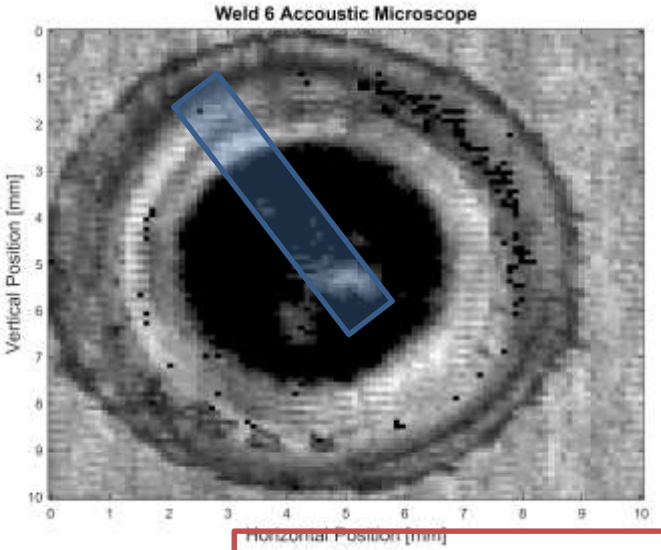
8000 A, 18 Cycles (0.3 s)

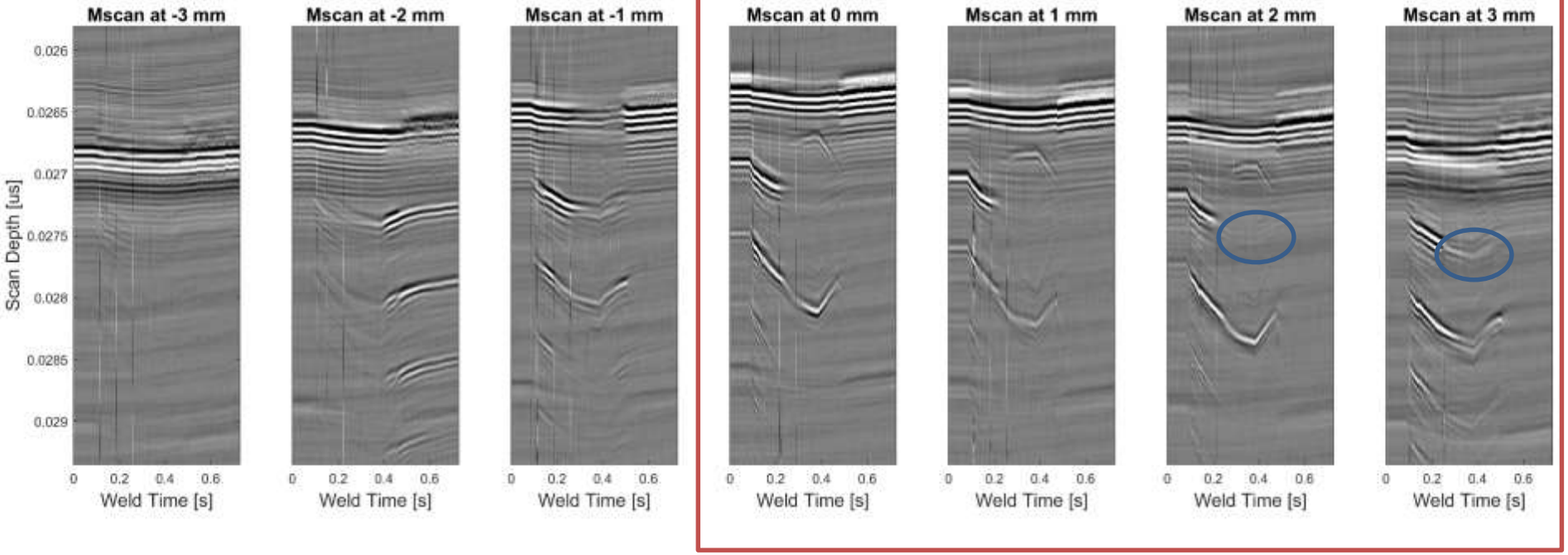


No Melting observed, boundary disappears. Possible void detection outlines in blue

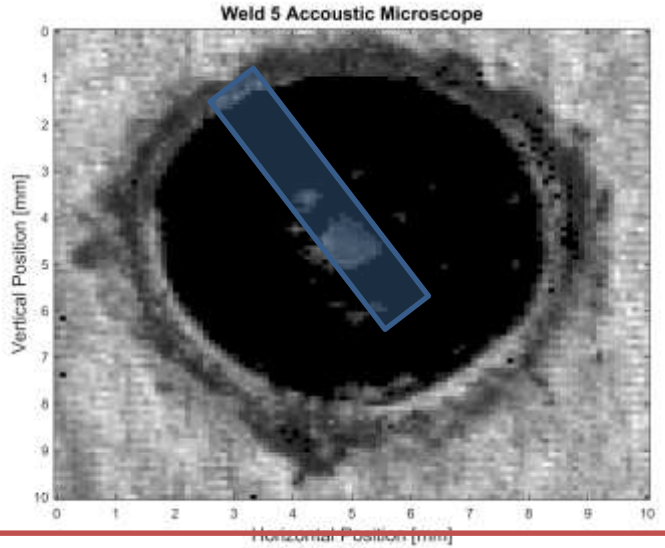


9000 A, 18 Cycles (0.3 s)

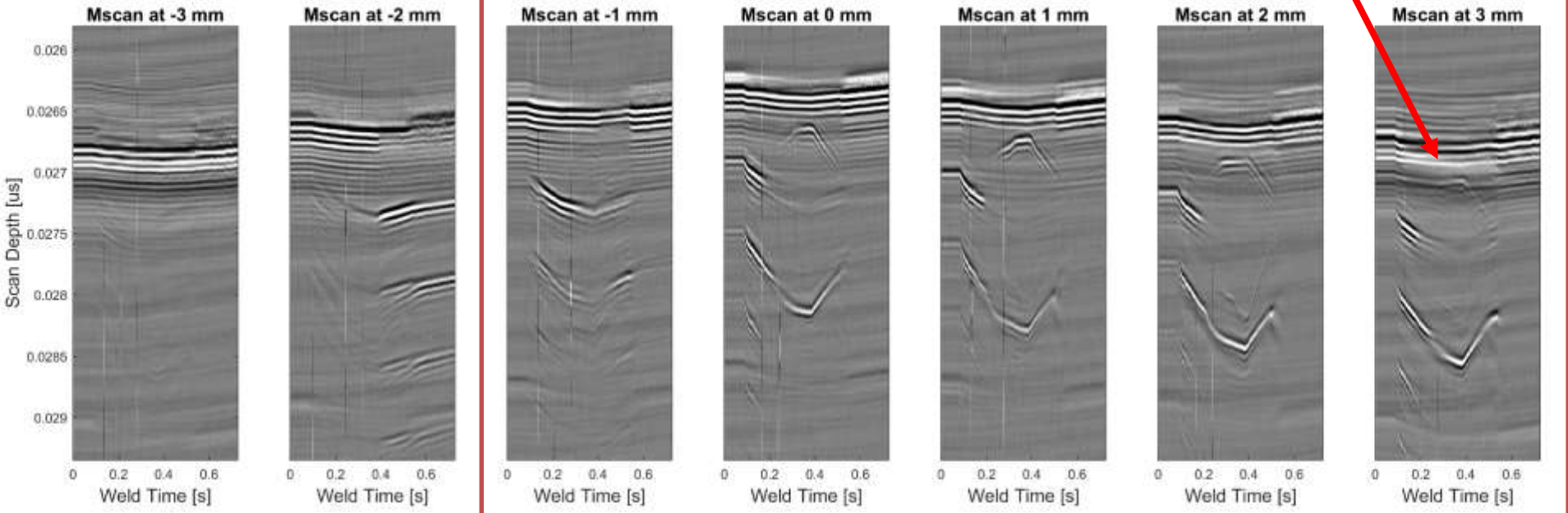




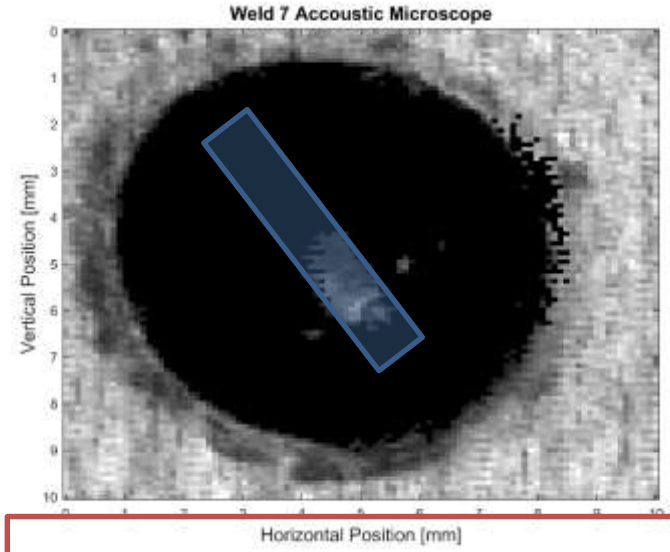
9000 A, 18 Cycles (0.3 s)

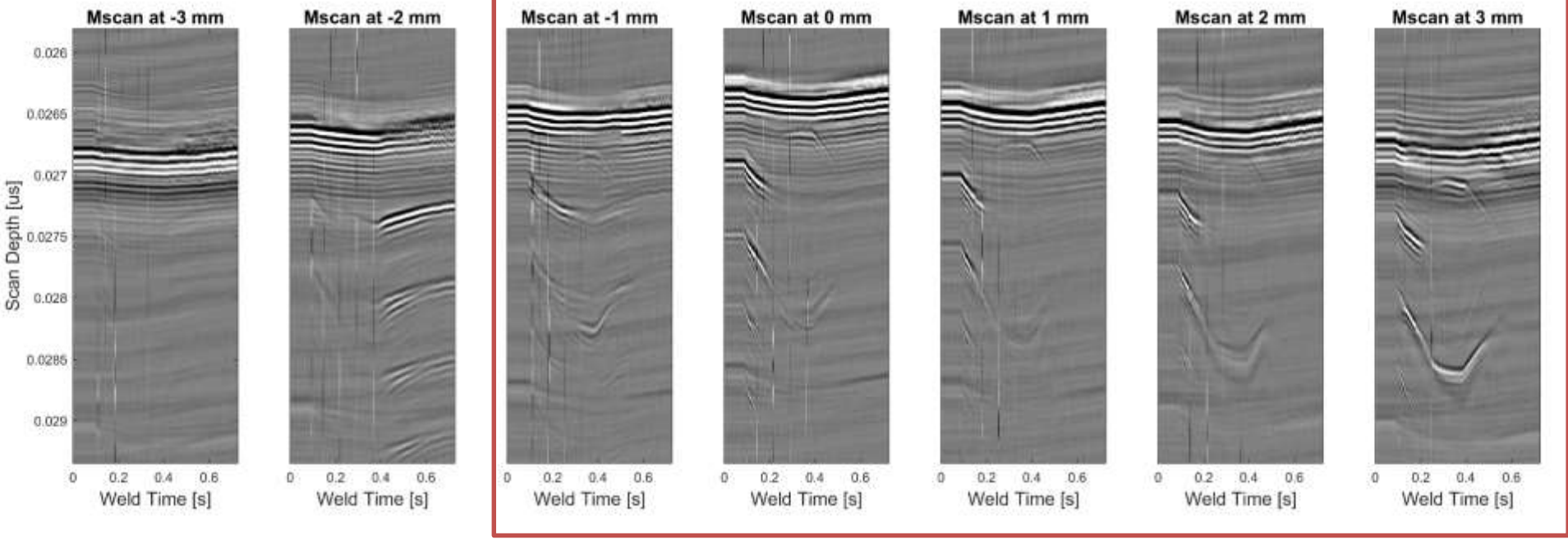


Large Weld nugget visible, Should extend further than view range

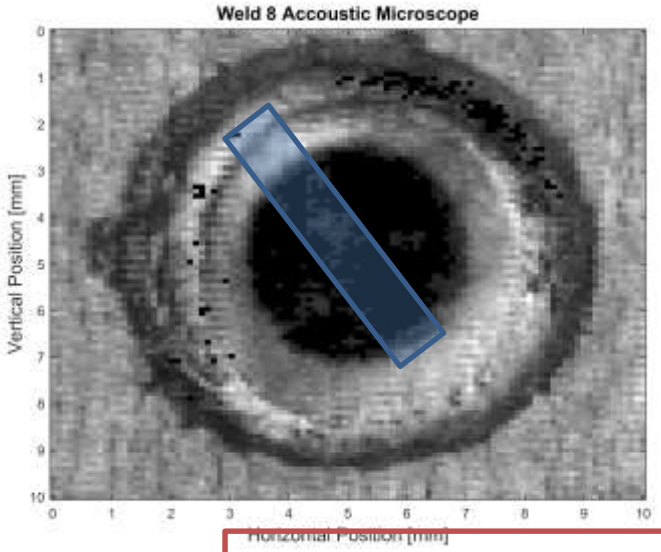


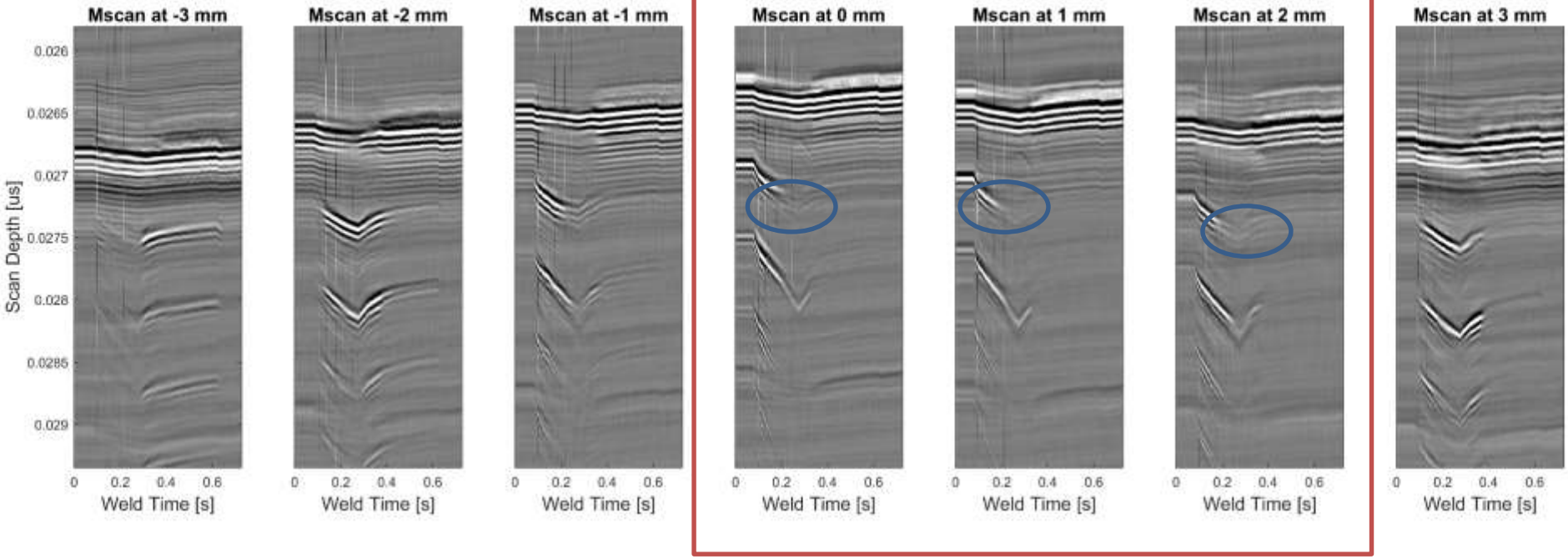
10000 A, 18 Cycles (0.3 s)



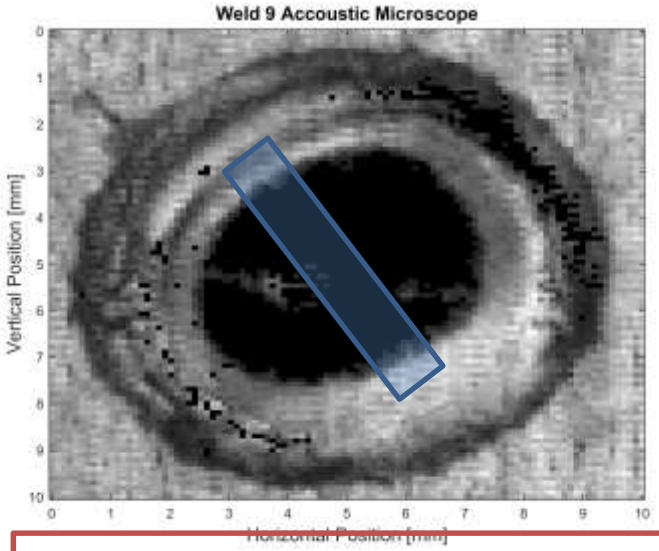


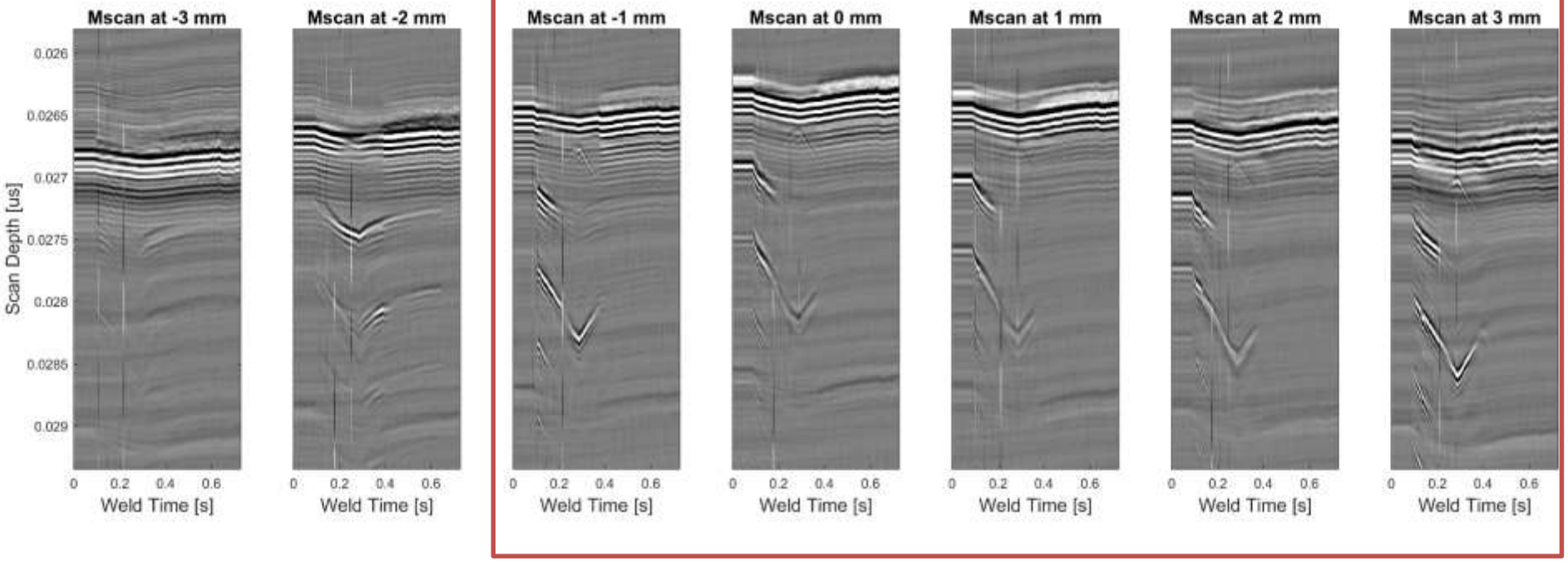
10000 A, 18 Cycles (0.2 s)



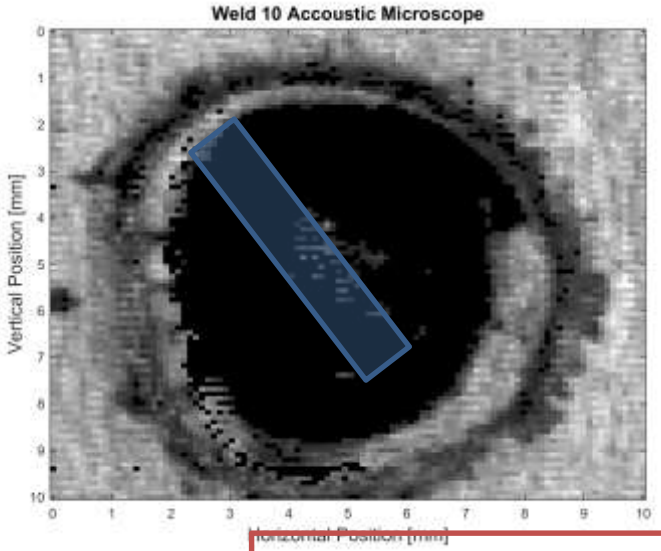


11000 A, 12 Cycles (0.2 s)

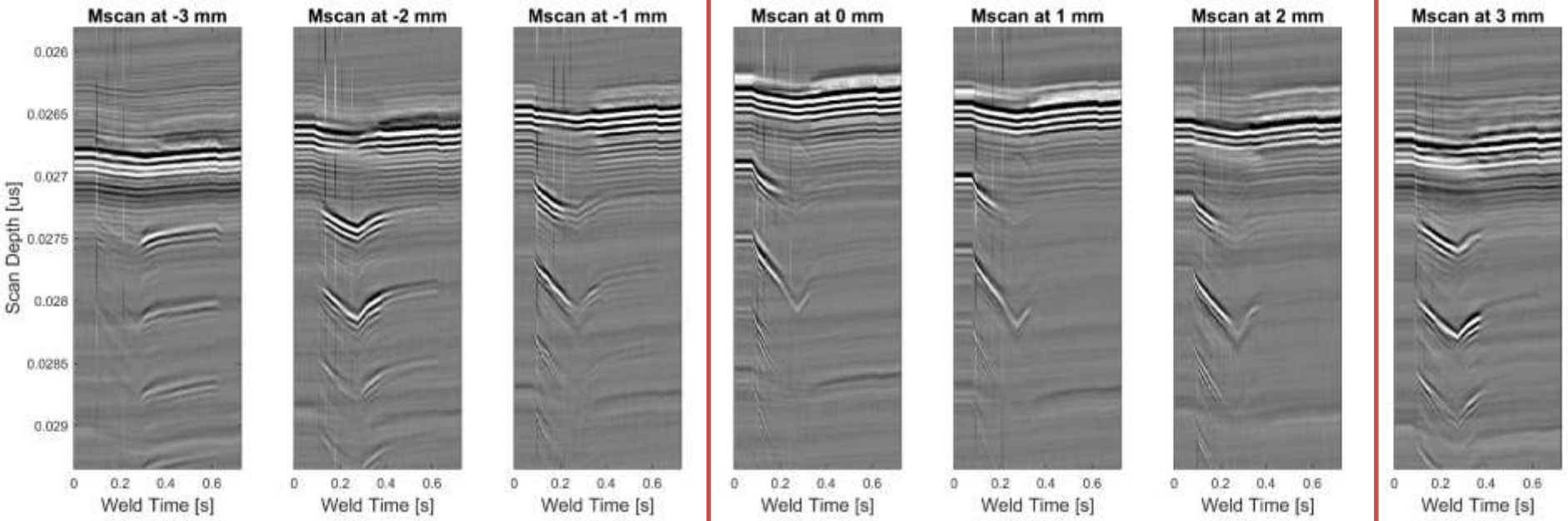




12000 A, 12 Cycles (0.2 s)



Weld appears much larger than predicted. Further investigation needed as to cause.



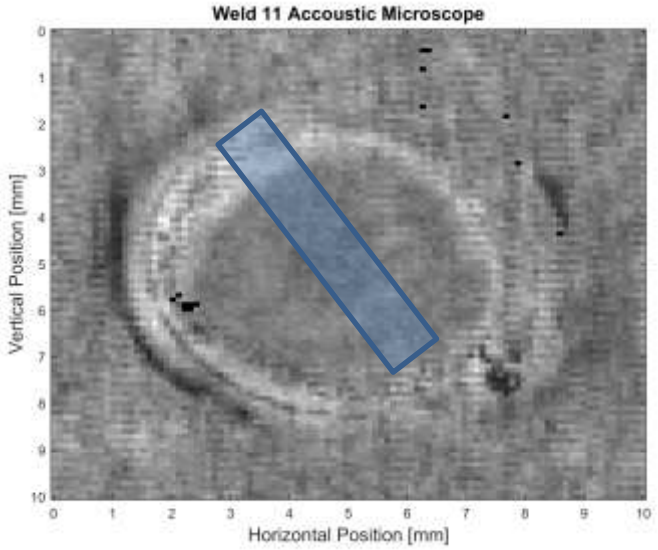
Expulsion from Weld Pool

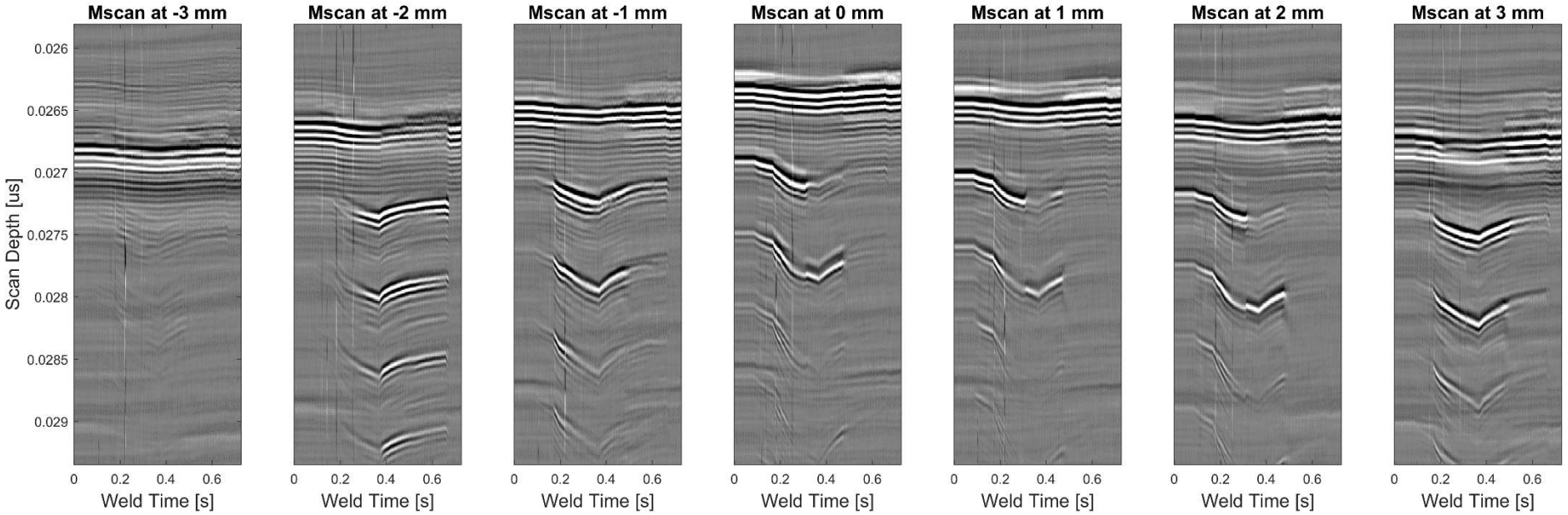
During welding, if the cohesive force of the pool is disrupted or overcome molten metal is ejected from the weld

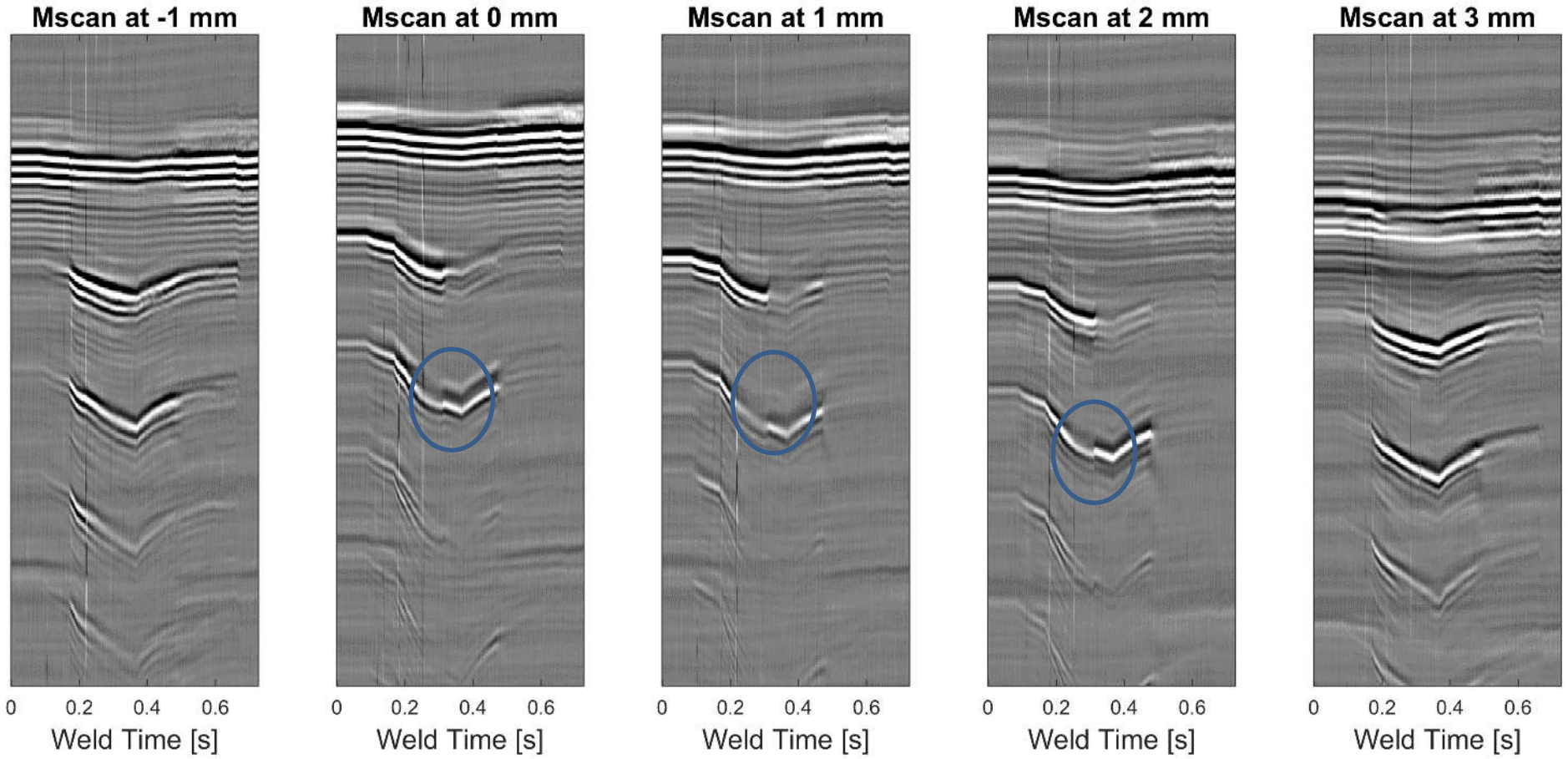
Depending on the amount or severity of expulsions the weld can be considered defective

Expulsion can occur from any of the interfaces during welding

5000 A, 5 Cycles (0.08 s)
9000 A, 12 Cycles (0.2 s)







Expulsions identified by partial wave shifts between frames. Localization to the middle of weld

Results

- Issues such as misalignment were found to have little effect on the imaging system, in contrast to the single element
- Defects such as expulsion were visible and could be localized within the image
- Pores were detectable in most cases by the observation or continuation of boundaries with the presence of a molten pool
- Weld sizes could be estimated to within the accuracy of the scanning system (1mm) in most cases.

Issues

- Scanning arrangement currently under samples the weld to a large degree, resulting in missed defects and unprecise sizing comparison
- Current system has some design issues to overcome before out of lab testing (sealing, electrode cap production)
- A few samples were inconsistent in size when compared to acoustic image, cause has not been determined

Further Work

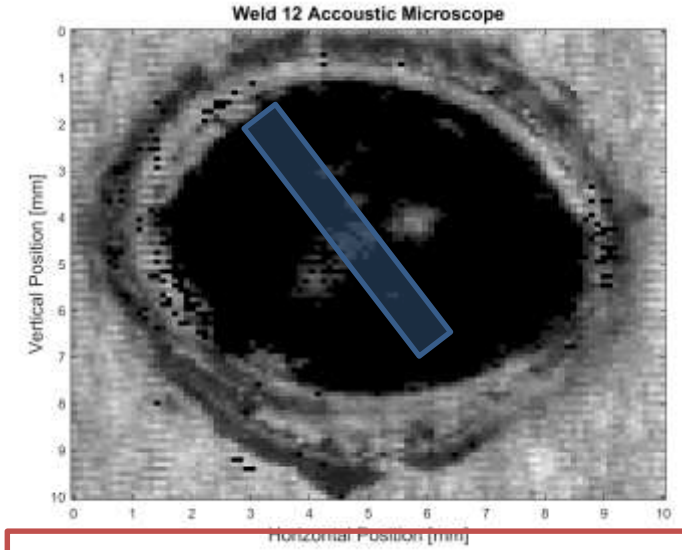
- Develop and adapt processing algorithms for detection of boundaries across all frames
- Larger sample sizes needed to determine viability across material types and setup arrangements
- Transducer life within system is not yet determined
- Industrial deployment will be needed to test noise in more realistic environment.

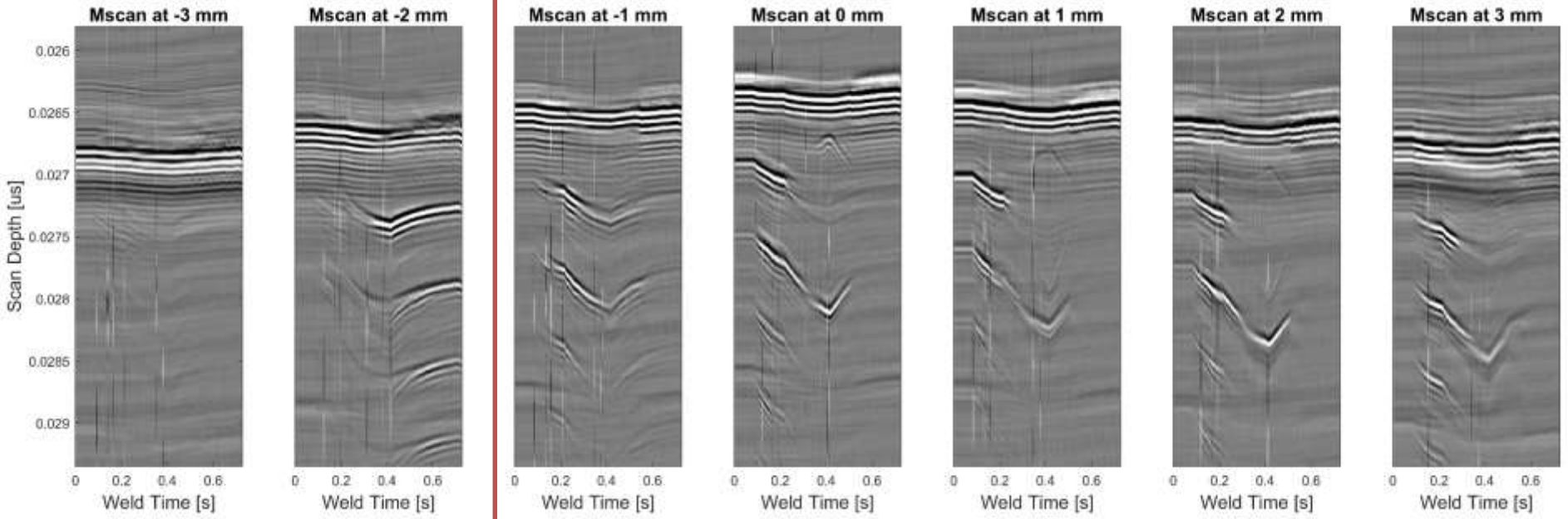
Acknowledgments

- This work has been supported in part by the Institute for Diagnostic Imaging Research and the University of Windsor

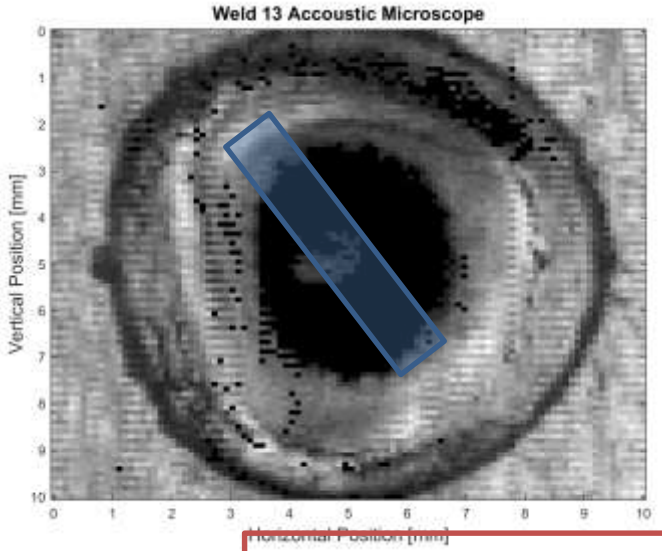
Questions?

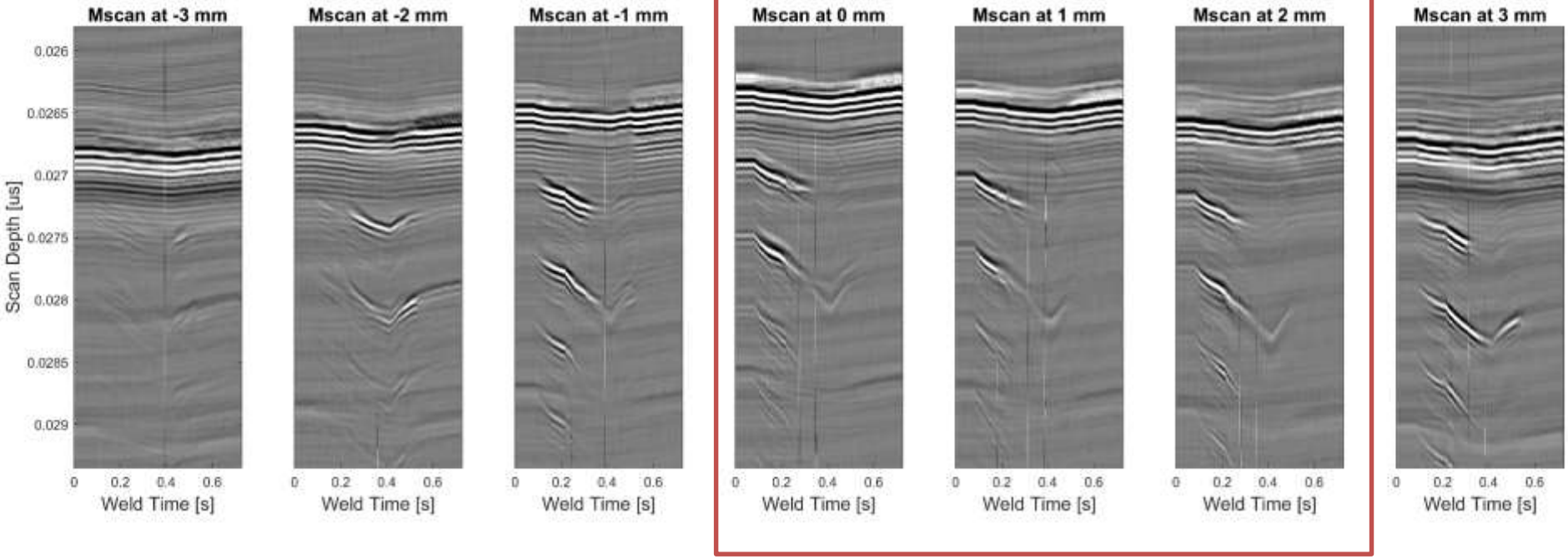
6000 A, 5 Cycles (0.08 s)
10000 A, 12 Cycles (0.2 s)



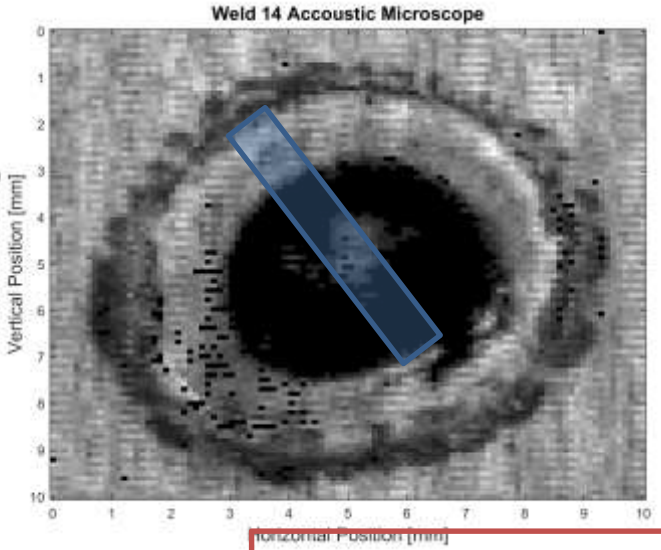


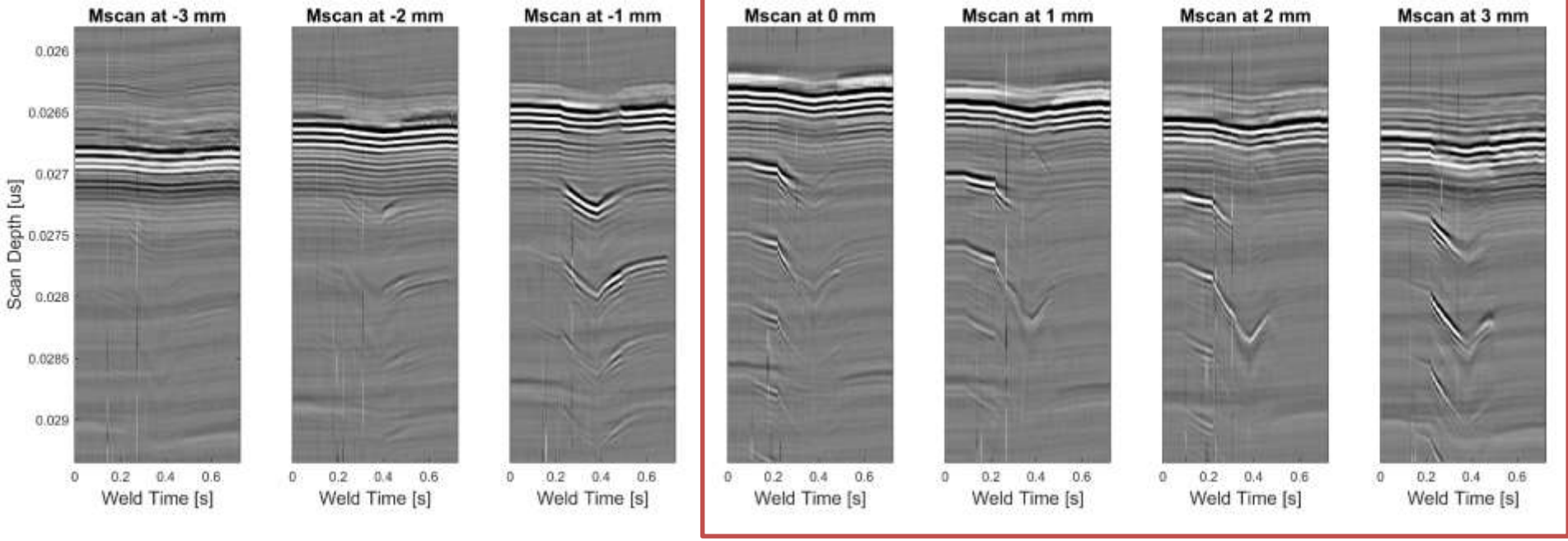
6000 A, 5 Cycles (0.08 s)
10000 A, 8 Cycles (0.13 s)





6000 A, 5 Cycles (0.08 s)
10000 A, 12 Cycles (0.17 s)





6000 A, 5 Cycles (0.08 s)
12000 A, 12 Cycles (0.17 s)