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Title: Identifying cracks in stainless steel using time reversal techniques

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Identifying Cracks in Stainless Steel Using Time Reversal Techniques

A summary of research performed at LANL during Summer 2013.

Student: Brent Reichman

Advisor: Brian Anderson

This research was funded by the U.S. Dept. of Energy, Fuel Cycle R&D, Used Fuel Disposition (Storage) Campaign.

Welcome to the other LA!

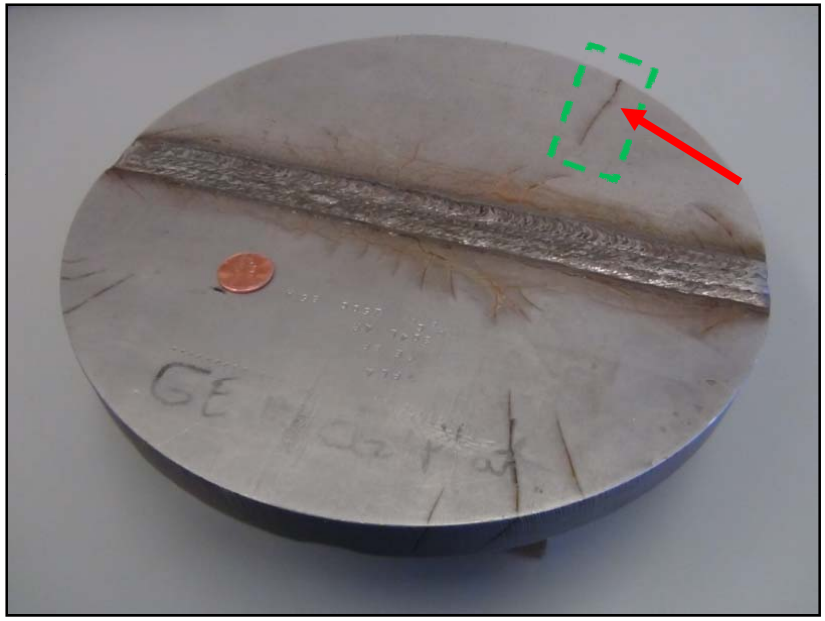
Welcome to the other LA!

Used Nuclear Fuel Containers

- Nuclear power plants produce more used nuclear fuel (UNF) in their lifetime than they have capacity to store
- Dry storage for UNF was made as a storage option in addition to on-site cooling pools.
- These casks of concrete and steel, intended to have a lifetime of a few decades, may need to be used for centuries.

- A method is needed to nondestructively test these casks for stress corrosion cracking (SCC).

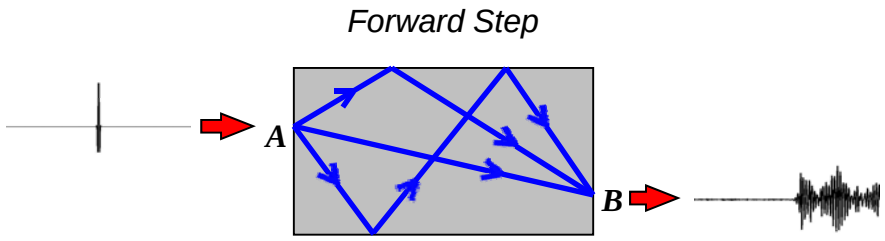
Stainless Steel Plate

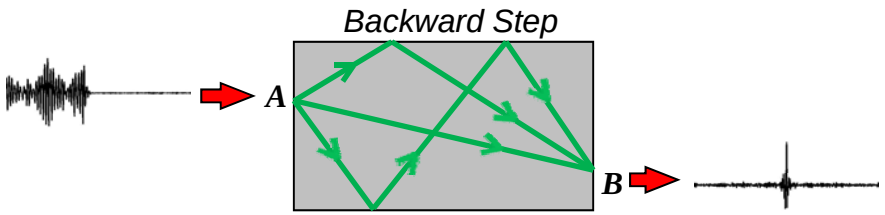


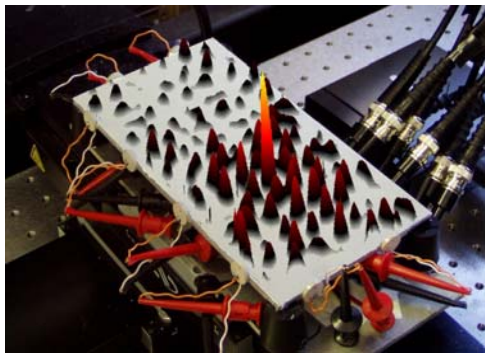
- Circular plate with weld in the middle and bars welded onto the back
- Stress Corrosion Cracking (SCC) was induced by exposure to Magnesium Chloride and stress loading

An Intro to Time Reversal (TR)

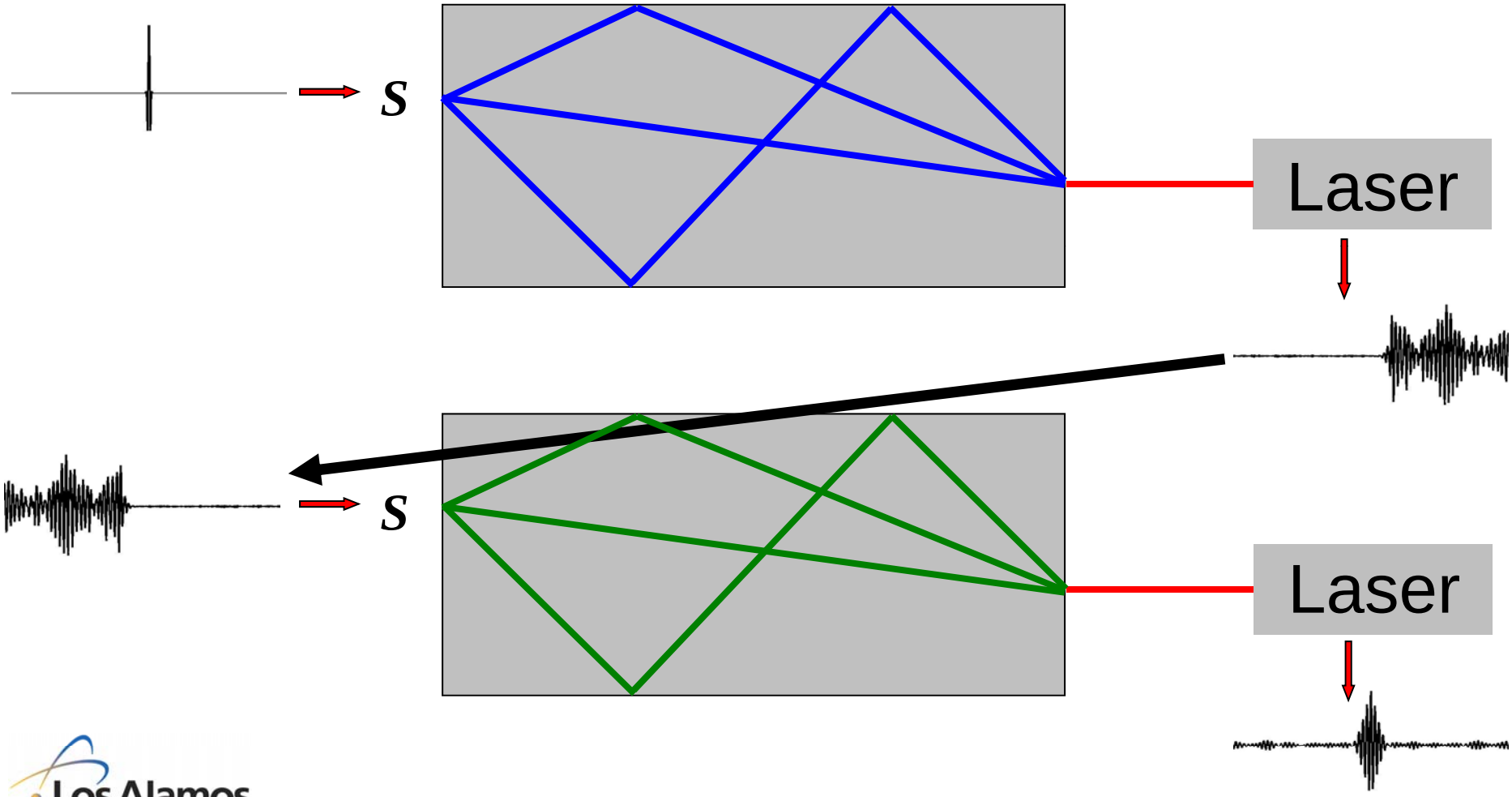
- A pulse input at point A travels along many paths to arrive at point B, producing a complex collection of pulses.
- The signal is then reversed and played back through point A.
- The different parts of the pulse travel back along their respective paths, combining coherently in an attempt to recreate the pulse at point B.





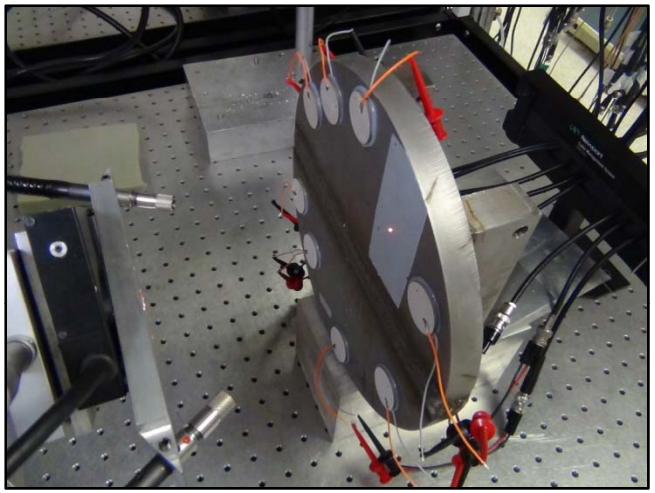


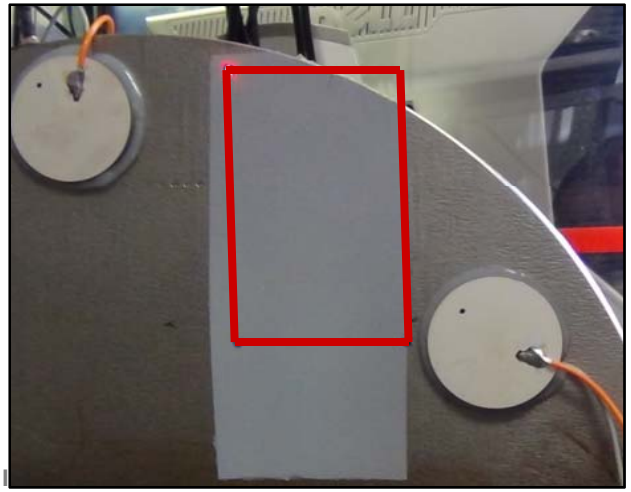
Reciprocal Time Reversal (High Amplitude Focusing)



Experimental Setup

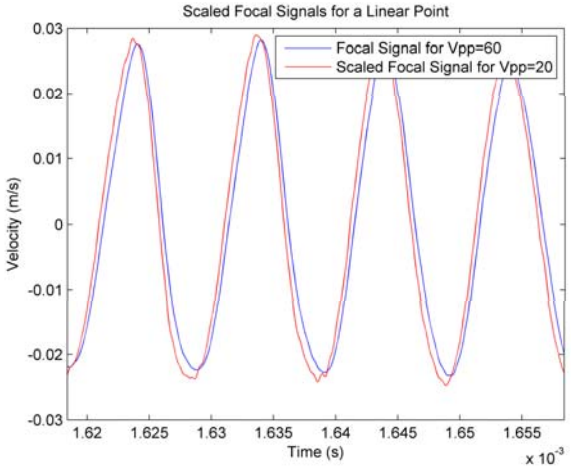
- Eight piezoelectric transducers were bonded to the surface of the plate.
- Two laser vibrometers (Out-of-plane and in-plane) were used to take measurements.
- Reflective tape was placed over the sample area to improve signal for the vibrometers.

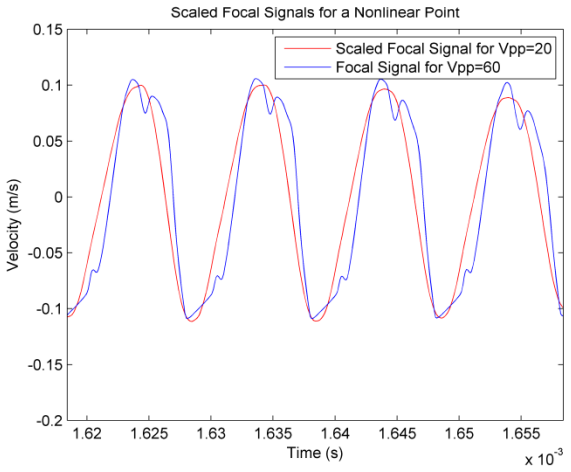




Linear vs. Nonlinear

- TR signals are sent through the transducers at high and low amplitudes for each location.
- If the point under inspection is linear, the signals will be scaled versions of each other.
- If the point is nonlinear harmonics can be generated.
- Cracks are nonlinear features!



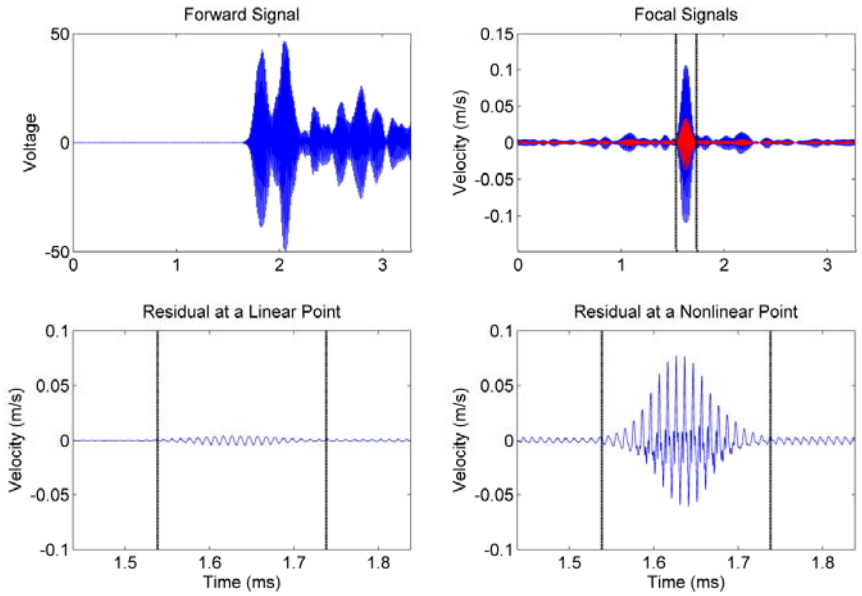


Ulrich *et al*., J. Acoust. Soc. Am. **119**(3), 1514-1518 (2006).

Scalerandi *et al*., Appl. Phys. Lett. **92**(10), 101912 (2008).

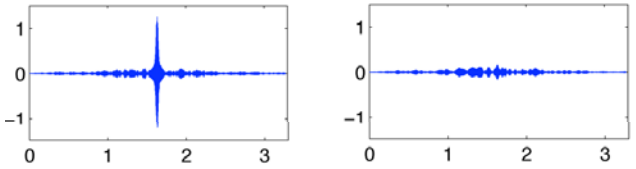
TREND and SSM

- In the time reversed elastic nonlinearity diagnostic (TREND) multiple amplitude steps are used to inspect each point for nonlinearity.
- The lower amplitude signals are scaled up and subtracted from the higher amplitude signals.
- The residual is smaller for linear points than nonlinear points.



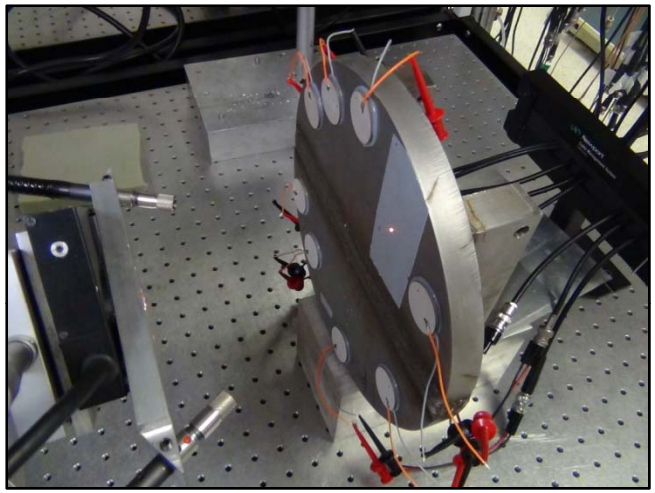
- The sum of the absolute value of the residual signal within the original pulse width is used to quantify the nonlinearity.

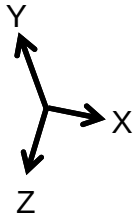
Ulrich *et al*., J. Appl. Phys. **106**(11), 113504 (2009).



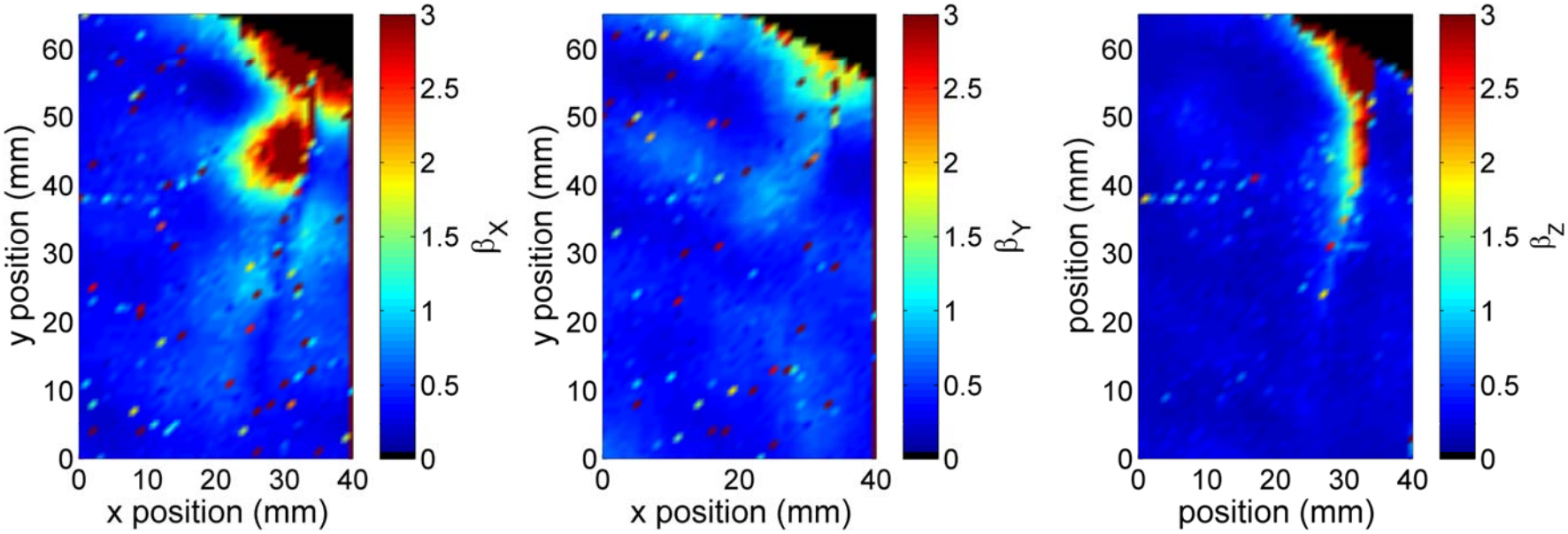
3D TREND

- A TR focus can be created in any orientation, and the energy will primarily be focused in that orientation.
- An out-of-plane and an in-plane laser vibrometer are used to create a focus in 3 directions: One out-of-plane and two orthogonal in-plane.
- A full TREND experiment is performed in each orientation to reveal more information about the orientation of the crack.



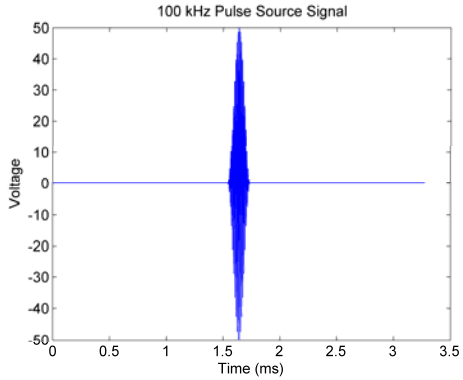


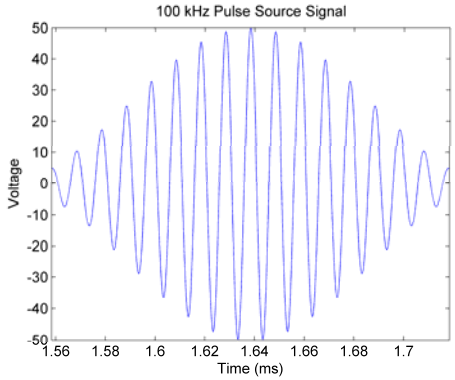
3D TREND at 90 kHz

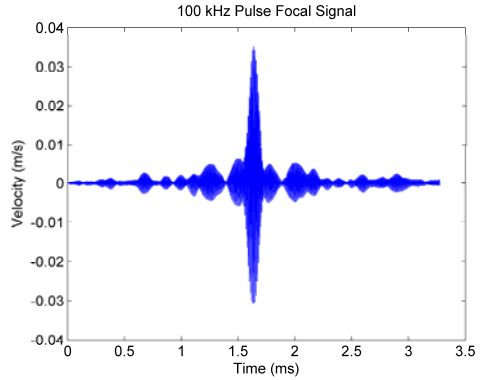


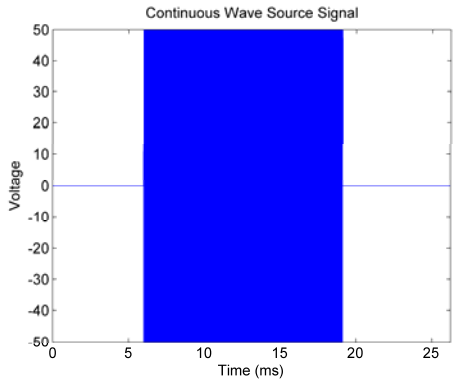
Continuous Wave TREND

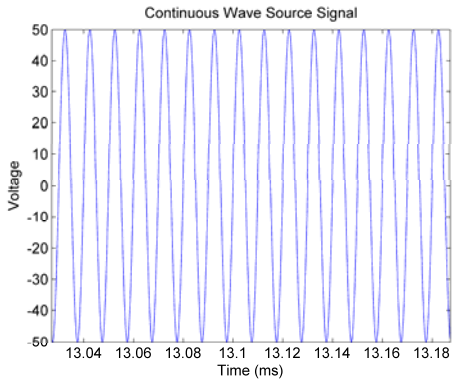
- Uses a continuous wave instead of a wave packet with a bandwidth centered on a frequency.

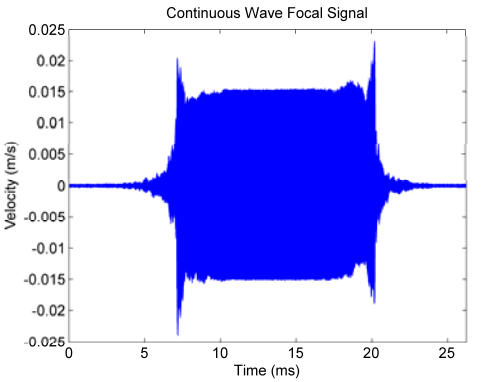












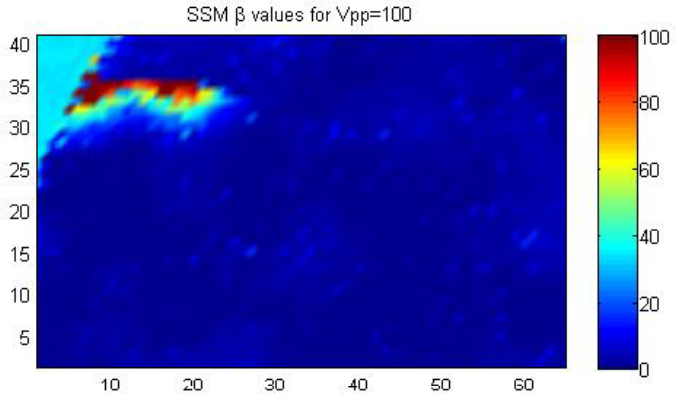
Continuous Wave TREND

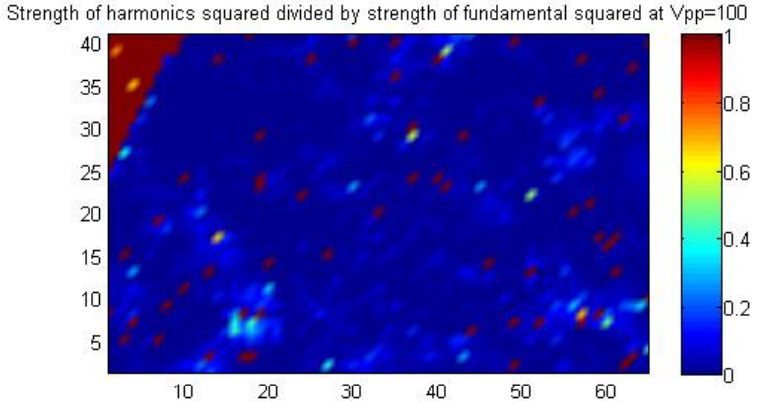
Pros

- Higher signal-to-noise ratio in harmonics
- Don’t have to worry about resonance of transducer

Cons

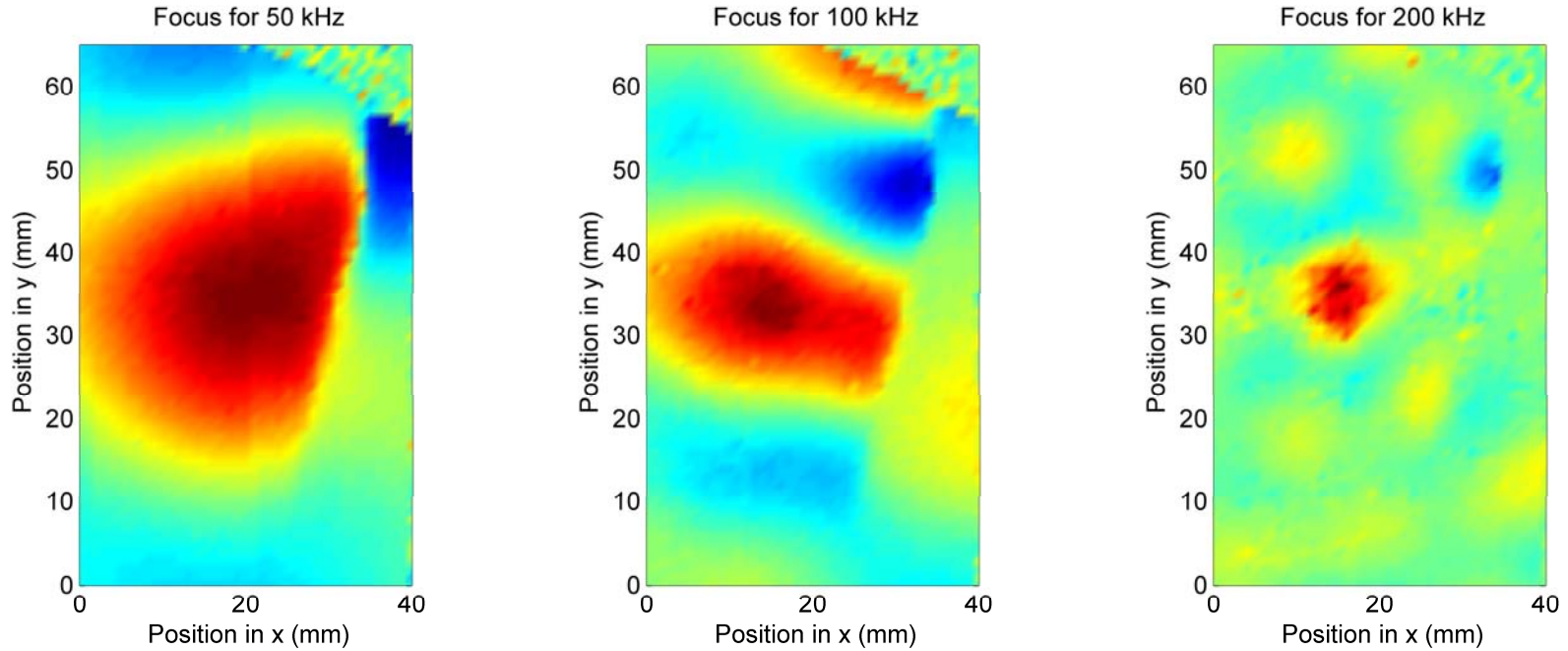
- Takes a very long time
- Harmonic strengths still not as expected





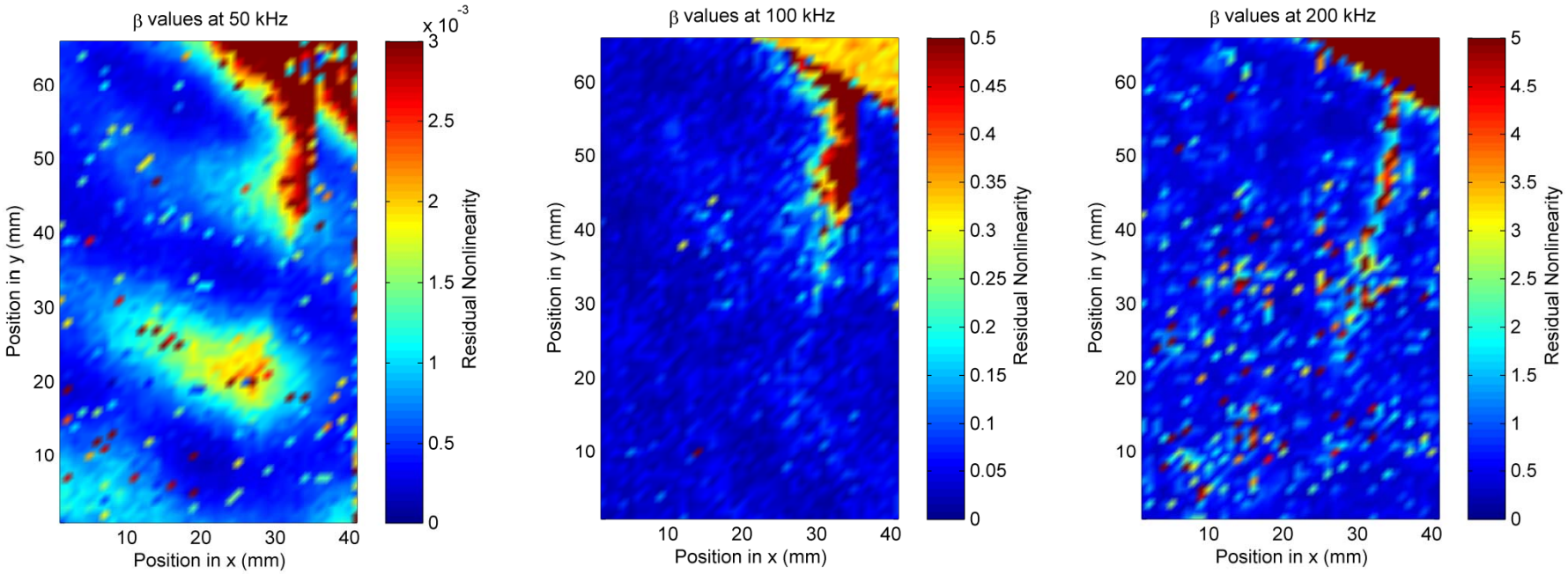
Using Different Frequencies

- Using TR with different frequencies produces foci of different sizes



- Lower frequencies form larger foci that penetrate deeper into the material

Using different frequencies



Possible explanations for feature visible in 50 kHz Scan:

- Different behavior at crack tip
- Nonlinearity below surface
- Imaging the opposite surface of plate

Further Areas of Study

- 3D TREND at varying frequencies

  (in progress)

- Relationship between frequency and depth of focus

- Shape of focus with different orientations

What I Learned This Summer

- TR is a useful branch of acoustics with many real-world applications.
- Nonlinearities can be identified using TREND, and more information can be obtained about the orientation through 3D TREND.
- Different frequencies could be used to reveal more about the depth of nonlinear features.
- Go on internships early on!