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Title: Linear and Nonlinear Acoustic Resonance Spectroscopy

Author(s): James A. TenCate
T.J. Ulrich
Tarik Saleh
Doug Farr

Intended for: Presentation at JOWOG 39, 22-25 Sept 2008

Los Alamos NATIONAL LABORATORY
EST. 1943

Brief abstract:

This talk will highlight the use of Acoustic Resonance Spectroscopy as a quick sort diagnostic tool for Non-destructive testing applications. Other nonlinear acoustic techniques will be highlighted as well.

(no formal abstract was required for this talk)

Linear and Nonlinear Acoustic Resonance Spectroscopy

JOWOG 39

22 Sept – 25 Sept 2008

AWE Aldermaston, Reading, Berkshire, UK

James TenCate, T.J. Ulrich, Tarik Saleh, Doug Farr

Geophysics (EES-11) and Nuclear Materials Science (MST-16)

Campaign 8 Enhanced Surveillance

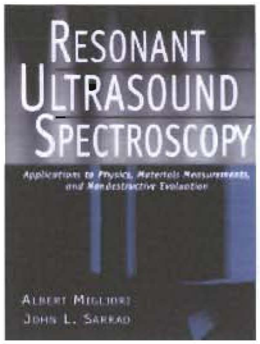
Motivation:

Goals: Develop and deploy two acoustic diagnostics

1. **Nonlinear and linear ARS** - move **A**coustic **R**esonance **S**pectroscopy from "research" to a production setting as a "quick look sorting" diagnostic and determine applicability of *nonlinear* ARS. Deliverable: A "global" good/bad indicator

2. **(TR)END** - develop general **E**lastic **N**onlinearity **D**iagnostic technique for inspection using **T**ime **R**eversal techniques if viable. Deliverable: An image of where disbonds are located

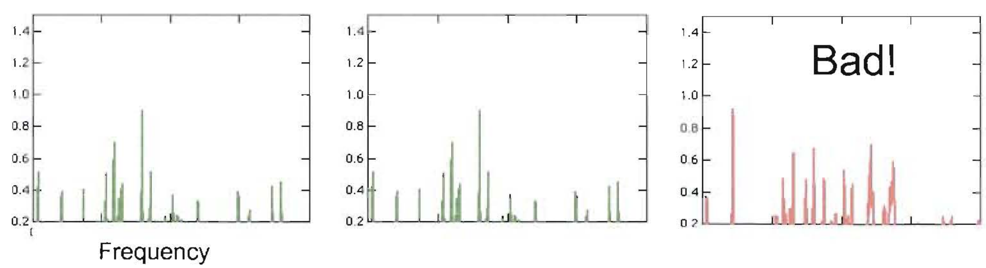
Linear ARS or RUS (*Migliori, Darling, Baiardo*)



Time waveforms

Can't use a hammer(!) so we attach transducers and sweep frequencies instead (see next slide)

Frequency content



Computer

DRS system

Stand with transducers

Note: ARS measurements made at Los Alamos since ~1993!

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Does ARS "work"?

YES. See *D.A. Summa*, "Acoustic Resonance Spectroscopy (ARS): Review of Existing Data/Recommendatios for Future Programmatic Effort"

Los Alamos National Laboratory Final Report.

(LAUR-05-7556)

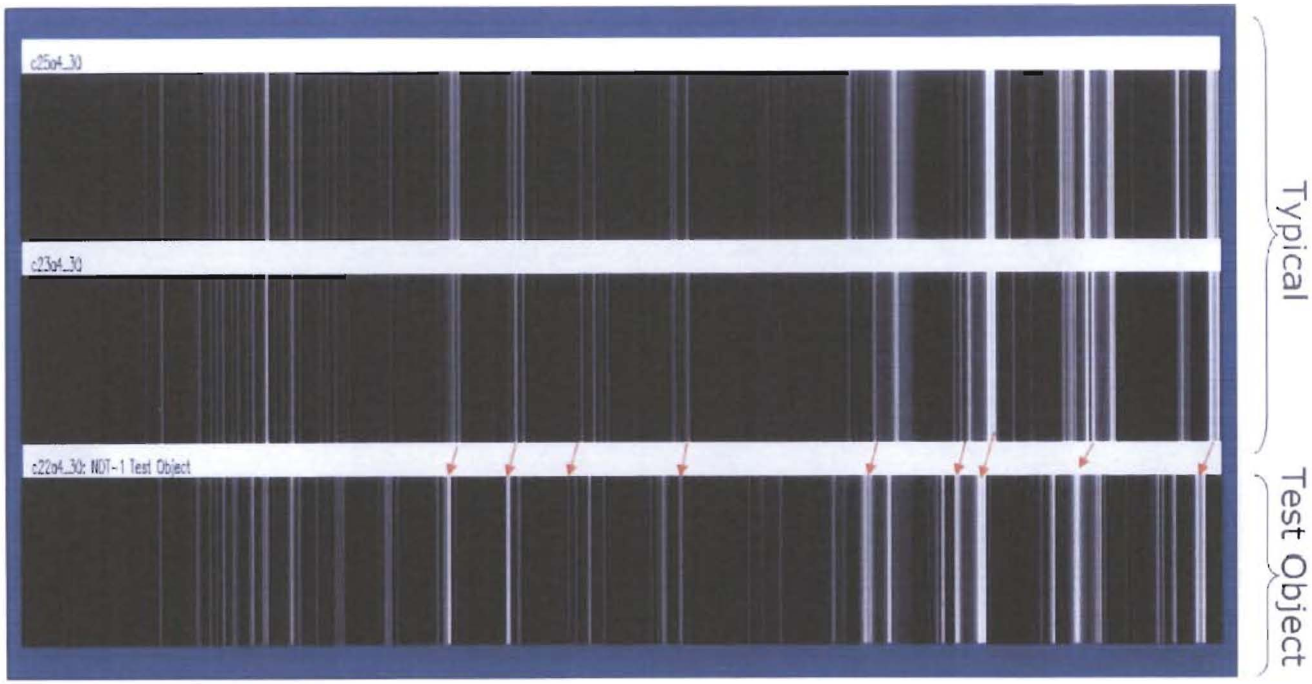


Figure 6: Low frequency ARS spectra of 'good' units compared to that of a test object with embedded (known) defects. Lowest order modes are aligned, but a down-shift of resonant peaks is observed in the latter two-thirds of the spectrum. The general form (i.e., peak width and splitting) remains similar between the units, although some peak broadening is noted in the spectrum of the test object.

Which modes? How much difference?

- Requires a highly trained eye to see differences (Analogy: a radiologist is needed to see a hairline fracture in a rib)
- However, as a quick sort diagnostic, the technique is ready to implement.

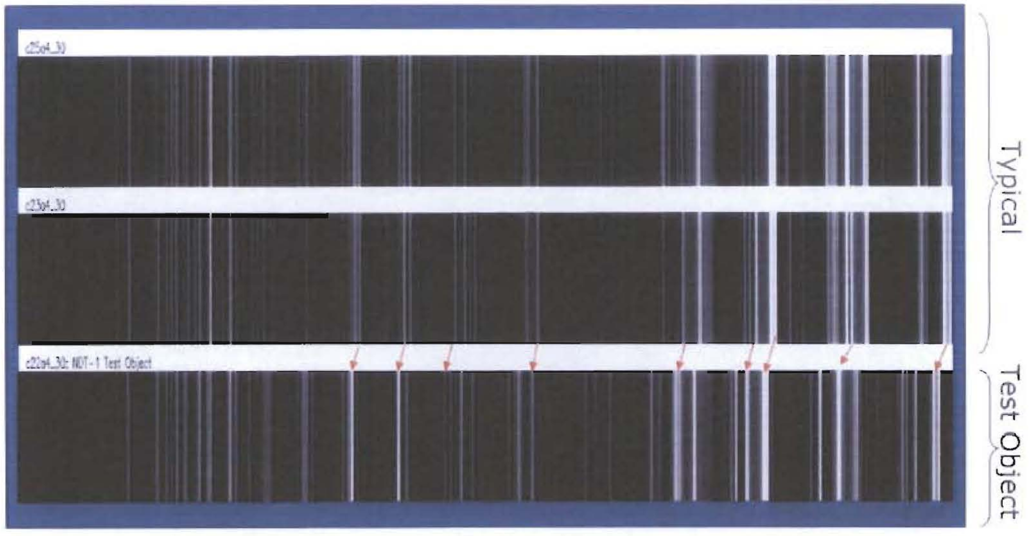


Figure 6: Low frequency ARS spectra of 'good' units compared to that of a test object with embedded (known) defects. Lowest order modes are aligned, but a down-shift of resonant peaks is observed in the latter two-thirds of the spectrum. The general form (i.e., peak width and splitting) remains similar between the units, although some peak broadening is noted in the spectrum of the test object.

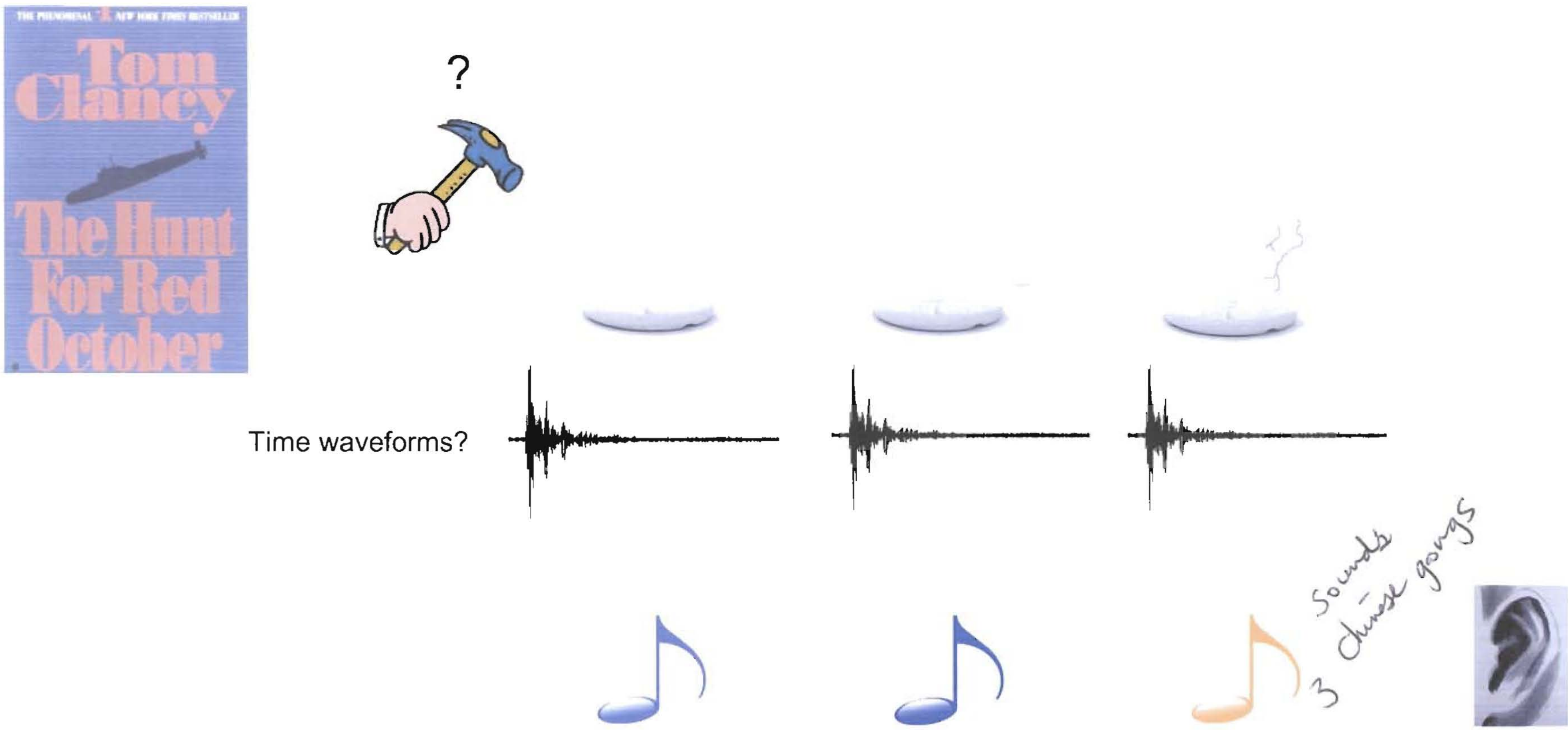
Current issues in ARS

Claims:
- Given an ARS spectrum, you can invert for the shape of the part, e.g., this mode ⇒ this feature and…
- … by watching changes in the spectra you can locate and ID problem areas.

Problems:
- Not really. Parts *have* been modeled but they are simplistic and only match the most important modes.
- Current technique uses *one* single mounting orientation and the result is a forest of modes. Q: *Which* are the most important? Q: Is it possible to miss important modes? (Yes.)

Solution: *Remount part several times, sum and average; locate most important modes to watch; make a quick-look template to sort for inspection (i.e., find the most important trees in the forest)*

Is there another approach? YES.

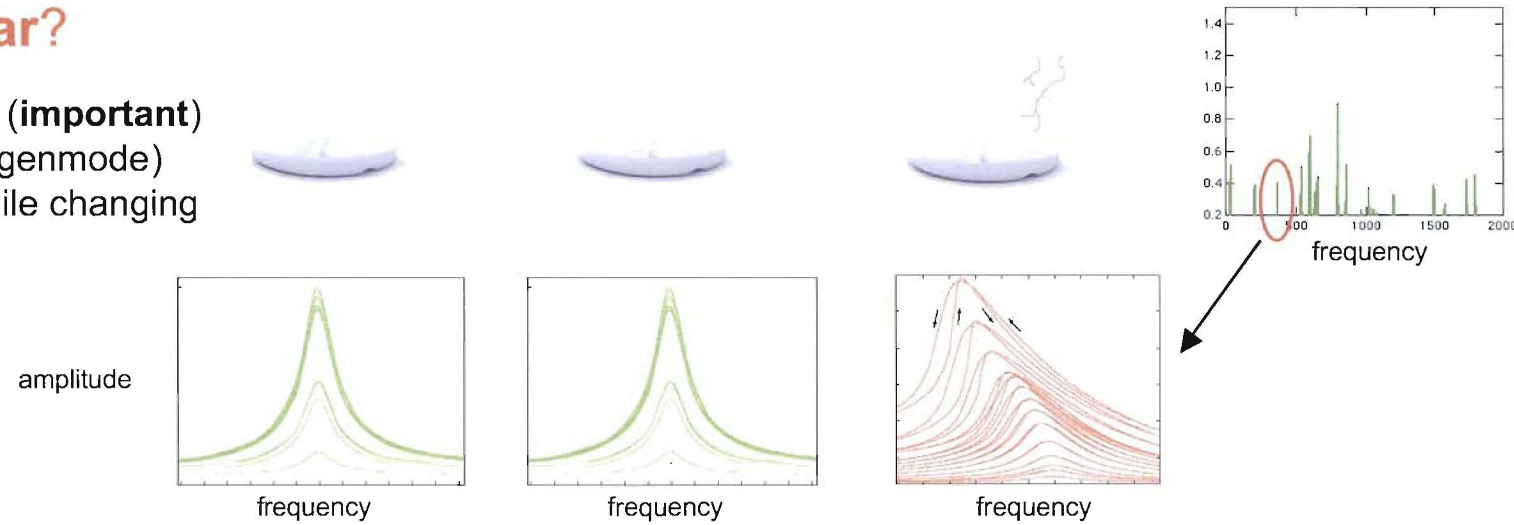


Maybe we don't need a highly trained expert?

Nonlinear ARS (NRUS)

Nonlinear?

Pick *one single* (**important**) spectral line (eigenmode) and watch it while changing drive level



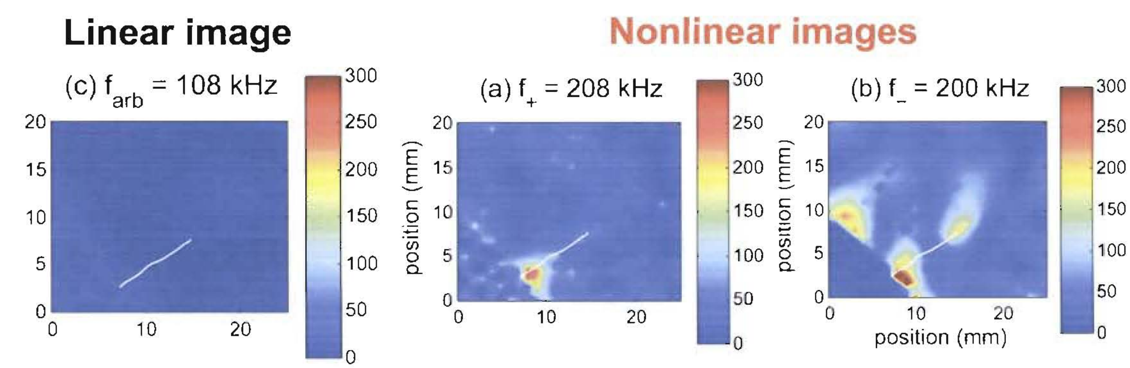
(1) Does frequency change with drive amplitude?
*(2) Is there harmonic distortion? Part is **bad**!*

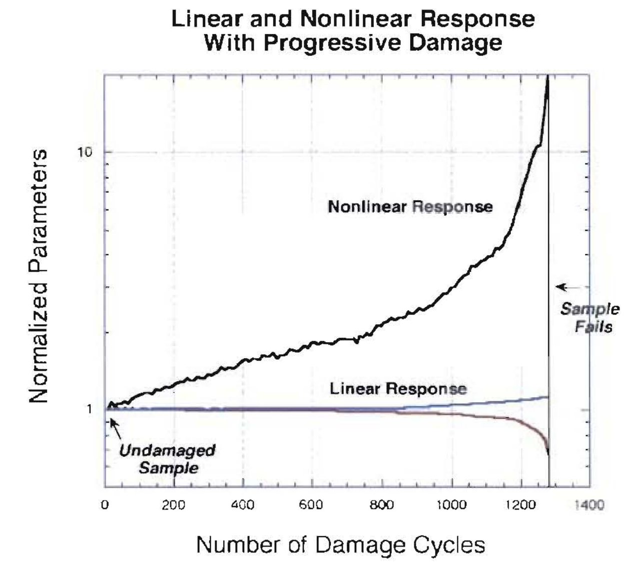
We have a patent on this technique (NRUS). Three units have already been measured this way. Results pending.

Other NONLINEAR techniques…

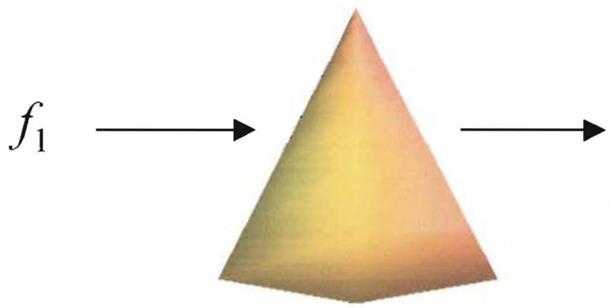
- Nonlinear measurements see different kinds of defects (e.g., "cracks" rather than voids or an impedance contrast)

- Potentially much greater sensitivity to tracking damage than linear measurements





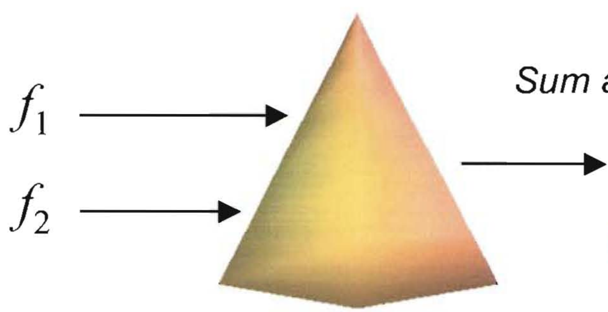
What do you measure?



$$f_1 + 2f_1 + 3f_1 + \ldots$$

1. Harmonic distortion

(samples with nonlinearity)



Sum and difference frequencies (sidebands)

$$f_1 + f_2,\ f_1 - f_2,\ \text{etc.}$$

2. Intermodulation distortion

Examples on next slide…

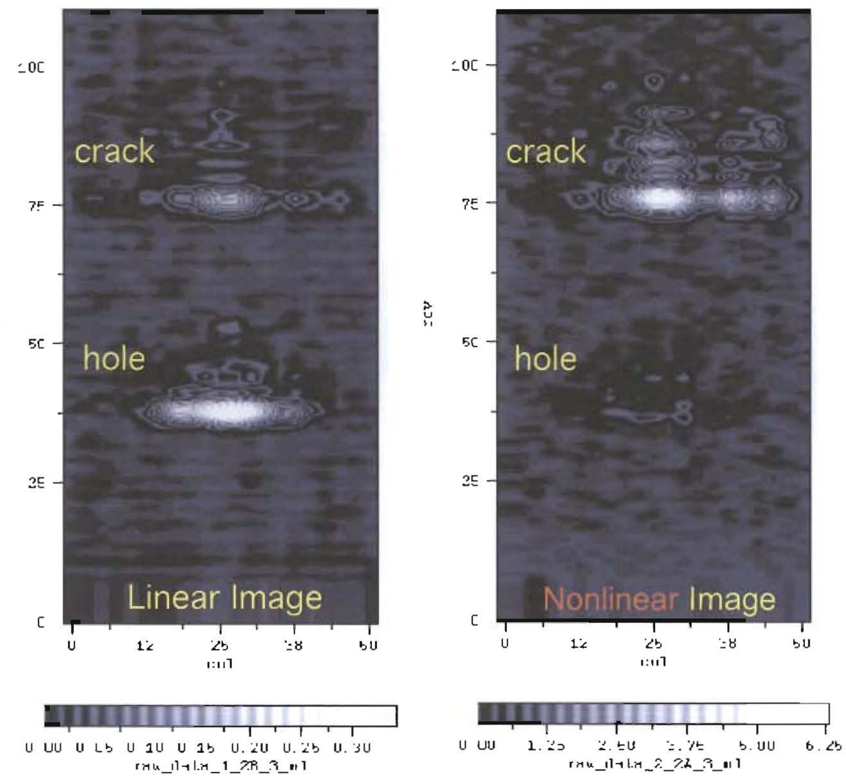
Examples of Nonlinear imaging:

Second harmonic imaging now commonly used in medical ultrasound

Pulse Inversion Harmonic image with high sensitivity and clear visualization of contest agent

Nonlinear "intermodulation imaging" (NEWS) of a (1) *crack* and a (2) *hole* in a plate

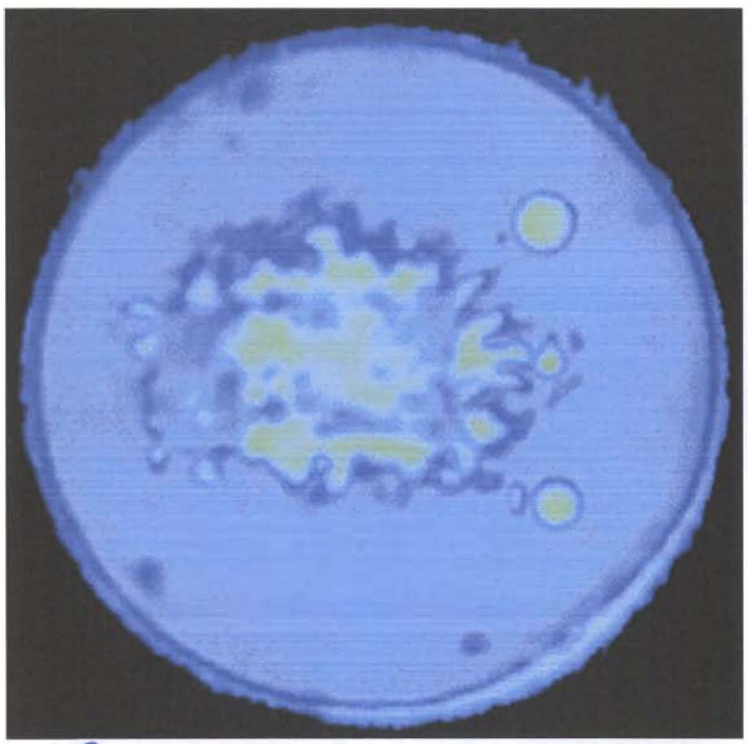
V. V. Kazakov and P. A. Johnson. Nonlinear Wave Modulation Imaging. *Nonlinear Acoustics at the Beginning of the 21st Century*, **2**, 763-766. (2002).



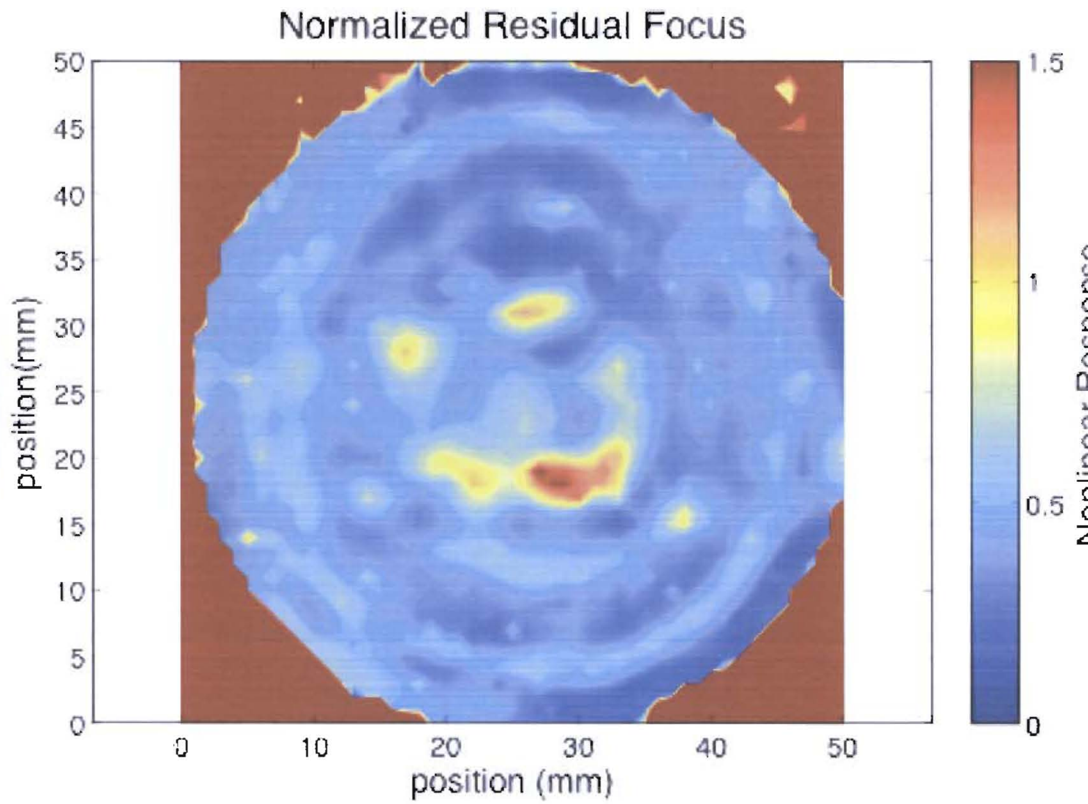
Linear vs. Nonlinear TREND images

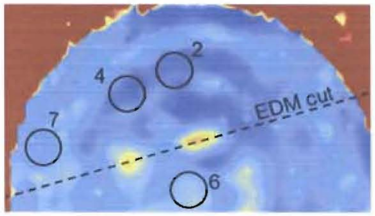
Testing of a dual-layer diffusion bonded disk

C-scan (linear)

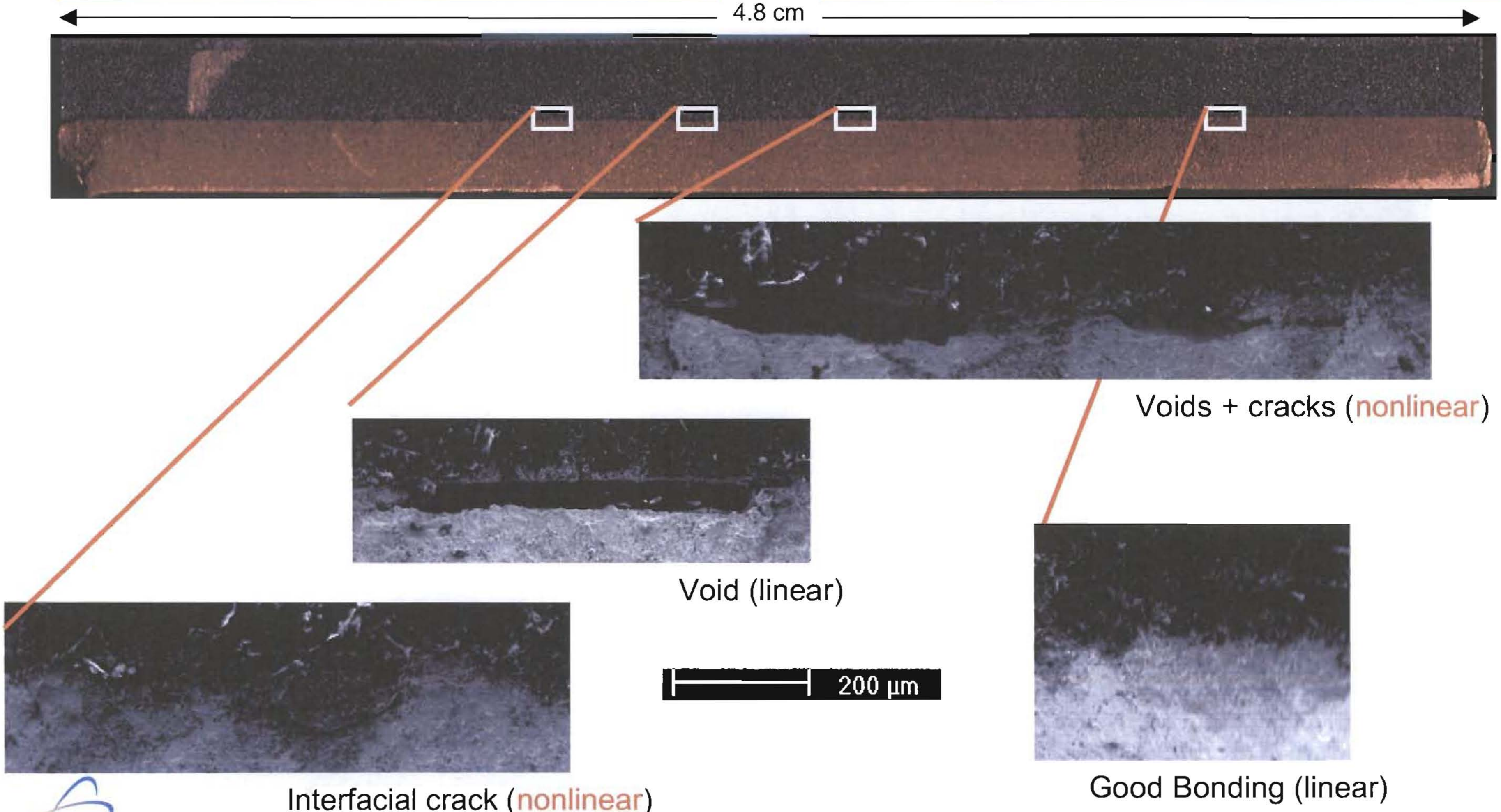


TREND Scan (nonlinear, IM image)





EDM Cut: SEM images



Work in Progress

- Deploy linear RUS/ARS diagnostic for quick sorting
- Decide if nonlinear RUS/ARS is worth pursuing
- Further develop TREND imaging for various applications