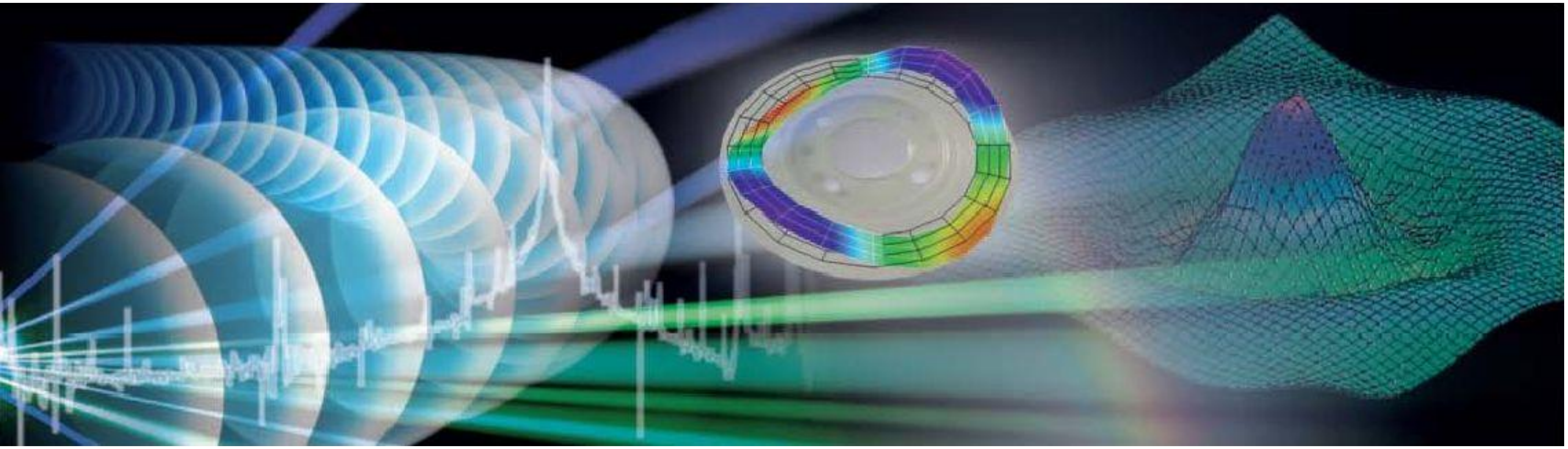
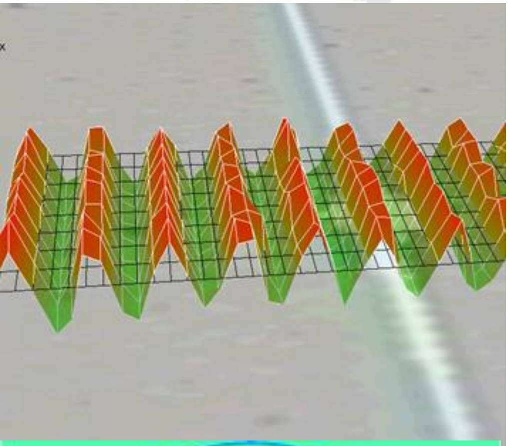
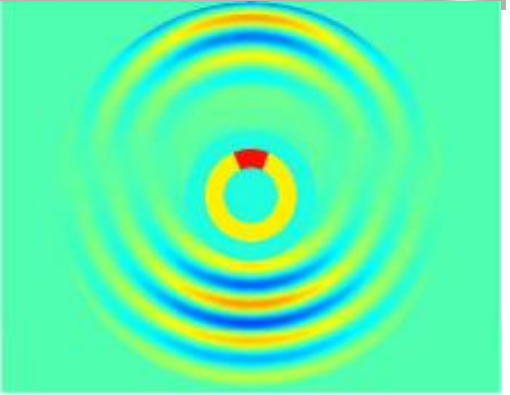
Use of Laser Doppler Vibrometry for Ultrasonics



Ultrasonics Industry Symposium

Eric Lawrence, Polytec Inc.





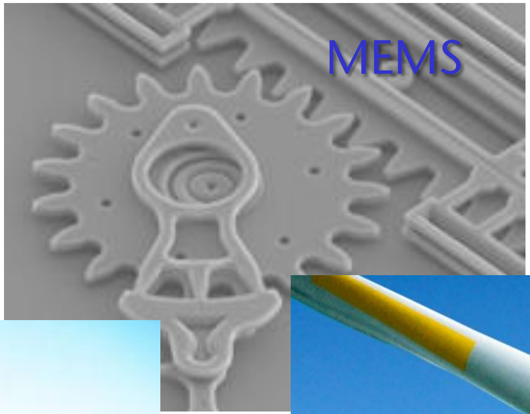
Contents

- Introduction to Laser Vibrometry
- Polytec Scanning Vibrometer (PSV-400)
- Application: Ultrasonic Bonder
- Application: Dental Descaler
- Application: Medical Instruments
- Application: Non-Destructive Testing
- Application: Sound Field Mapping
- Application: Surface Accoustic Wave Filter

Tools for Vibration Analysis

Polytec Scanning Vibrometer

Fast, accurate visualization and analysis of structural vibration



What is Laser Doppler Vibrometry?

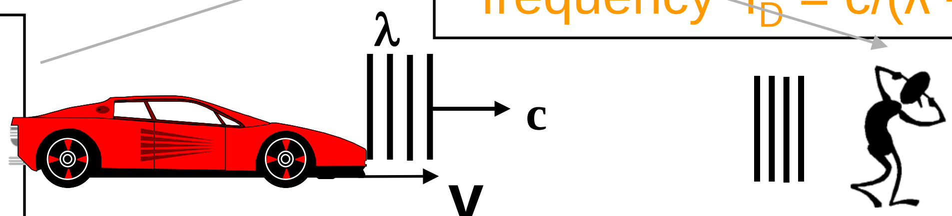
PDV-100 Portable Digital Vibrometer

Laser **D**oppler **V**ibrometry is a non-contact, "point and shoot" technology that directly measures the vibration of a test object using the Doppler effect.

Analogy: Acoustic Doppler Effect

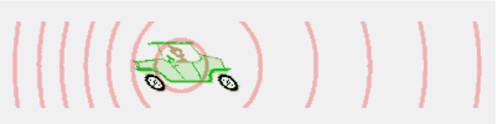
For car moving at velocity V, the observer hears the frequency $f_D = c/(\lambda - V/f)$.

Sound emitted from stationary car has frequency $f = c/\lambda$



Emitted frequency f

Observed frequency f_n



c: velocity of the sound wave

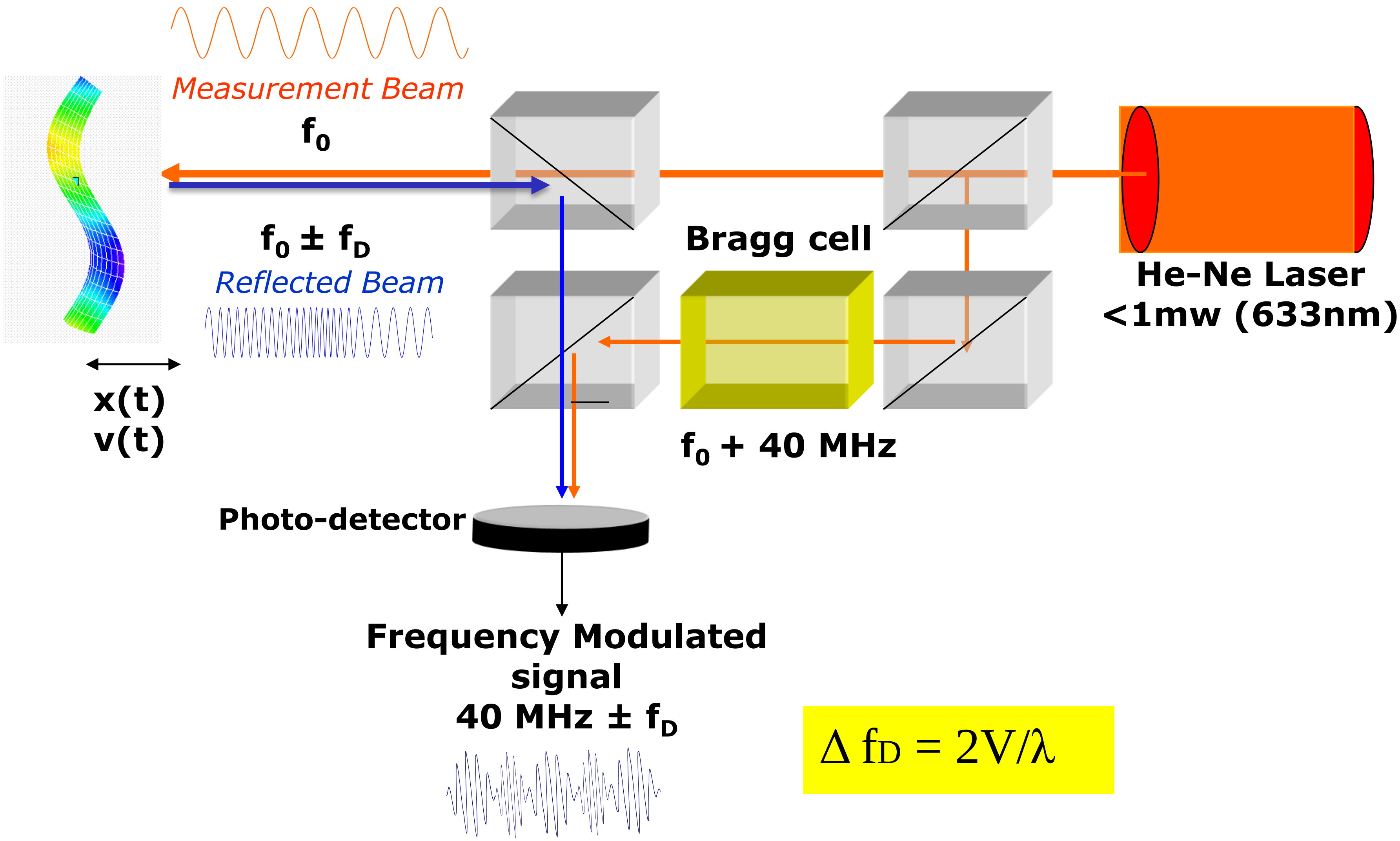
λ: emitted wavelength

f: emitted frequency

For a vibrometer: $\Delta f_D \propto V$

$$\Delta f_D = 2V/\lambda$$

The Heterodyne Interferometer



Signal Demodulation

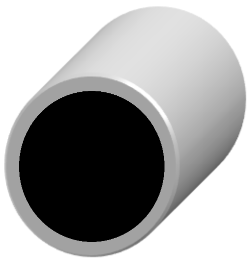
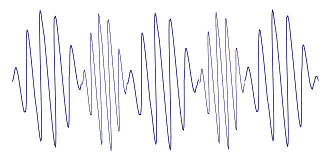


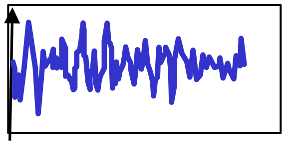
Photo-detector system



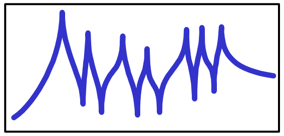
FM Doppler signal

Controller

Voltage ~ Velocity



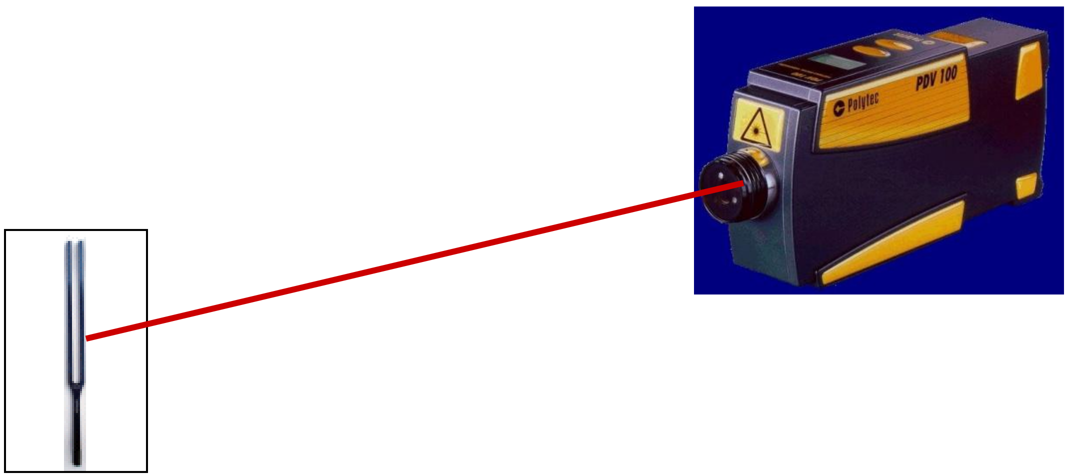
AM electrical signal

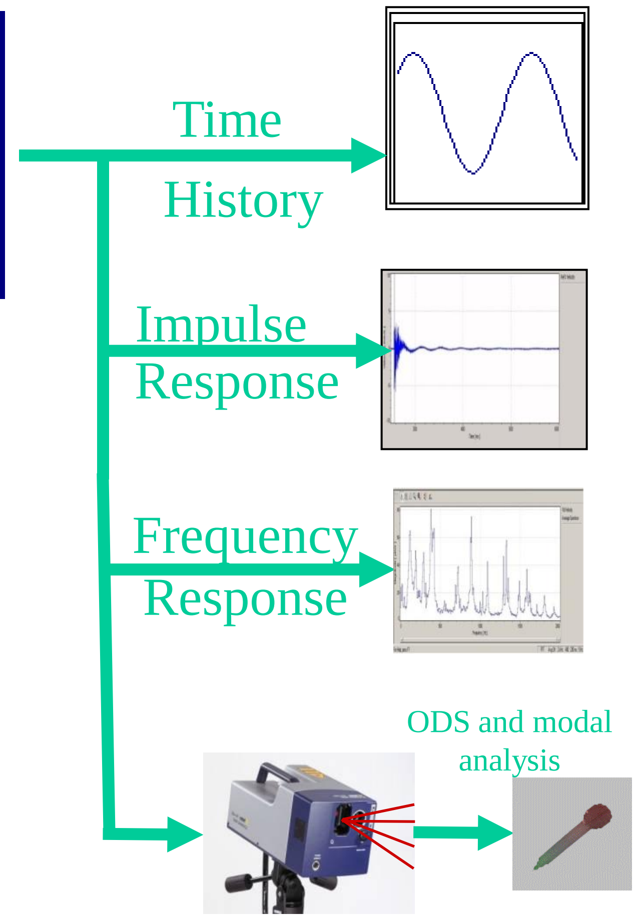


FFT Spectrum

Voltage ~ Displacement

What does Laser Vibrometry Provide?





Vibrometers convert changes in the laser frequency to a voltage output proportional to instantaneous **velocity**

Changes in optical phase are converted to signals proportional to **displacement**

Why use Vibrometry for Ultrasonics?

The only technology that offers:

Flat frequency response to 1.2GHz

High spatial resolution (≥0.7μm)

Wide dynamic range (.02pm/√Hz to 30m/s)

Instantaneous, easy, pre-calibrated, reliable, non-invasive, full-field scanning

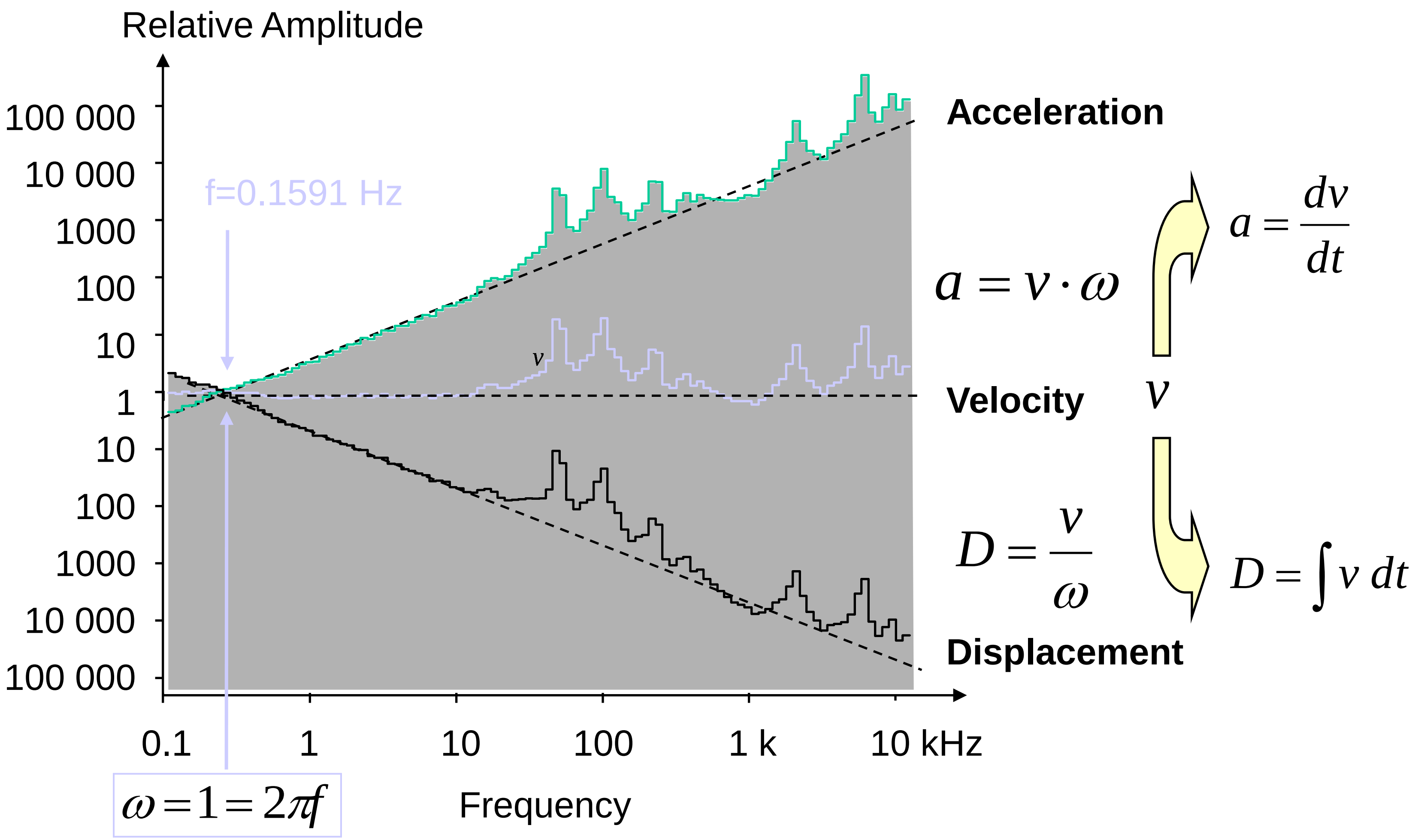
Ultrasonic transducers –

- Contact alternative
  - heavy, single point, big (fractions of an inch versus fractions of a micrometer), can't handle amplitudes, limited frequency range, temperature dependant (~125F max)

Fotonic sensors –

- Non-contact alternative
  - calibration varies with stand-off and surface reflectivity, tricky to position, poor resolution, limited frequency response ~150kHz max.

Why use Vibrometry for Ultrasonics?



Why use Vibrometry for Ultrasonics?

- High measurement accuracy (gold standard)
- In-situ measurements (water , environmental chamber). Accuracy unaffected by conditions.
- Easy to use point-and-shoot operation
- Scanning measurements used to verify FE Models
- 3D measurement of longitudinal/transverse modal coupling
- High spatial resolution allows measurement at antinodes in high modal orders and gradients
- Signal-based measurement allows continuous monitoring during high cycle fatigue tests
- Sound field characterization

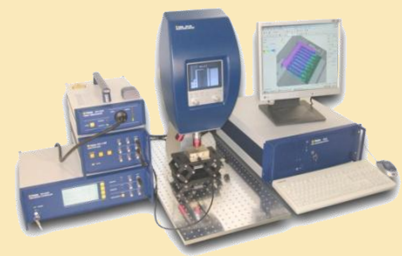
Polytec

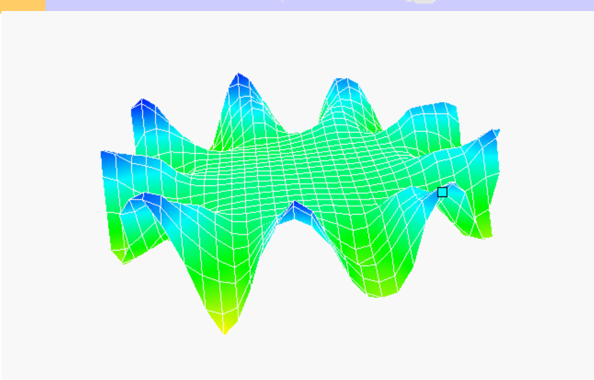
From Macro to Micro to MEMS

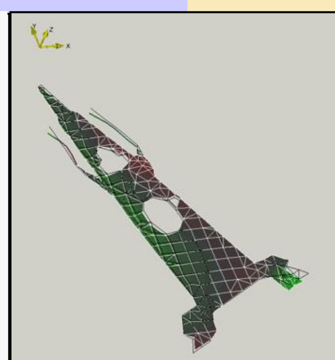
m² | mm² | µm²

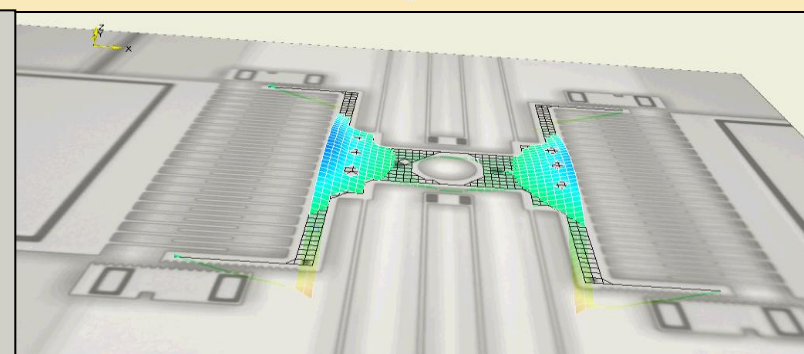
single point

scanning

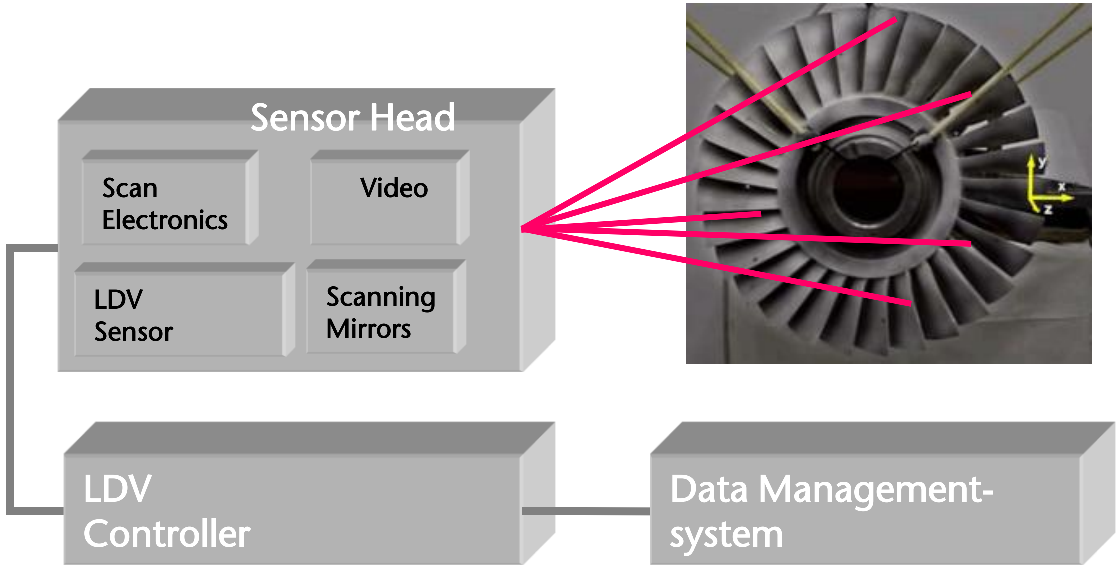




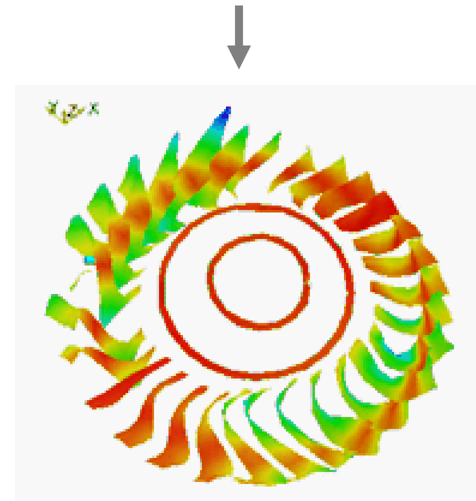




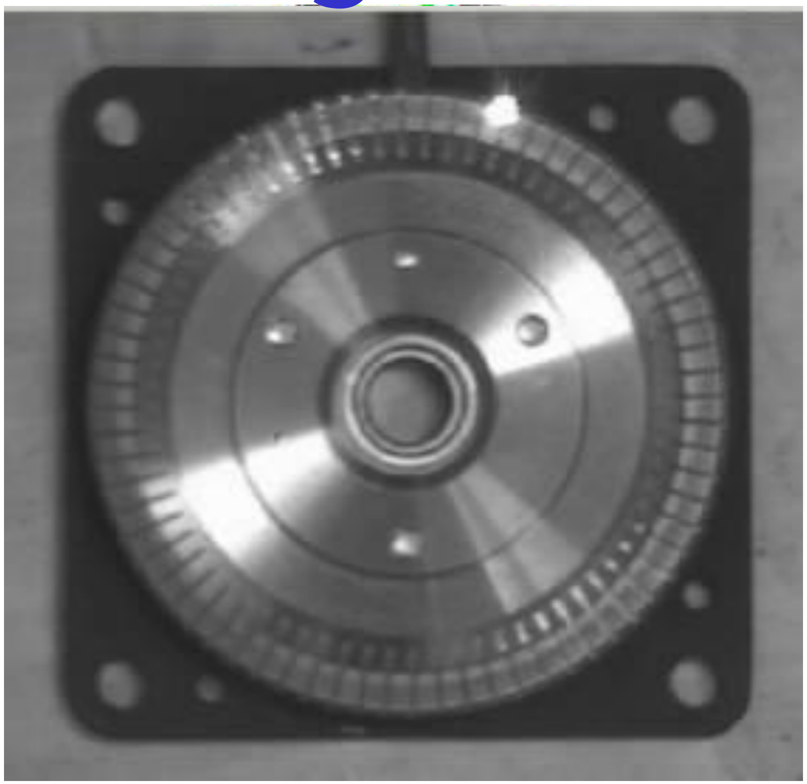
SLDV = Scanning Laser Doppler Vibrometry



- Up to 250,000 points scanned
- Easy-to-use software for data acquisition, display & manipulation
- Animated data visualization
- Efficient interfaces for modal analysis or FEM validation
- Geometry file imported or measured

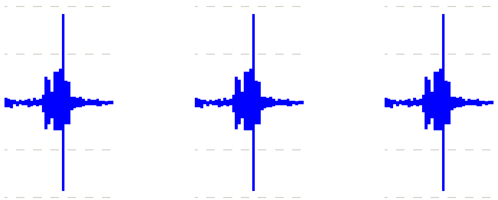


Scanning Vibrometer

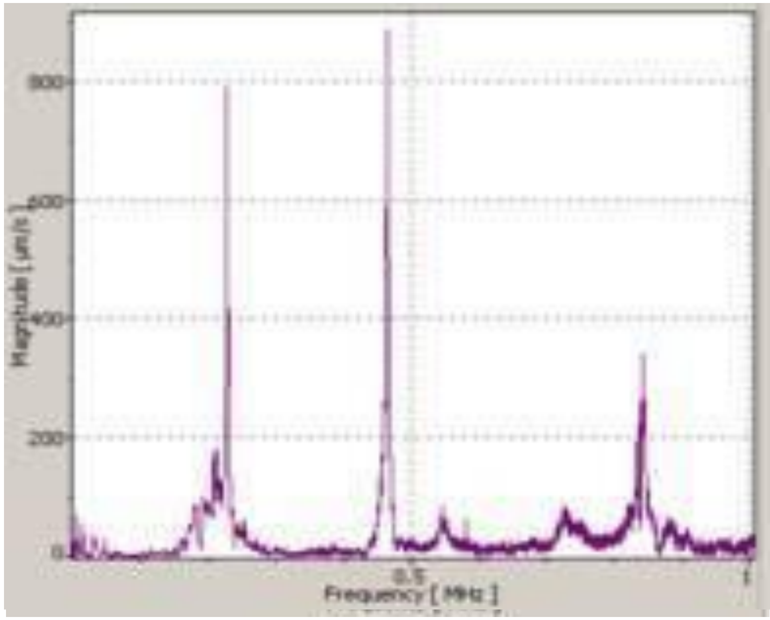


piezo motor

Vibration Time Signal



sequential measurement at all points.
Excitation for all points



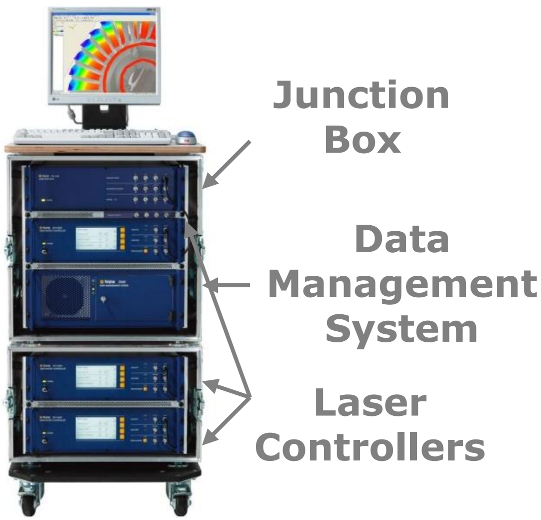
Vibration Spectrum

Scanning Vibrometer

Operational steps:

- Define measurement points
  - using video image and draw program
  - by geometry import
- Excite structure
  - using internal or external function generator signal
- Scan to acquire vibration response at each point
  - time history or
  - FFT spectrum
- Visualize
  - animated operating deflection shapes at selected frequencies of interest
  - time domain animations
- Export for post-processing (e.g. modal analysis or FEM validation)

1 MHz 3-D Scanning System

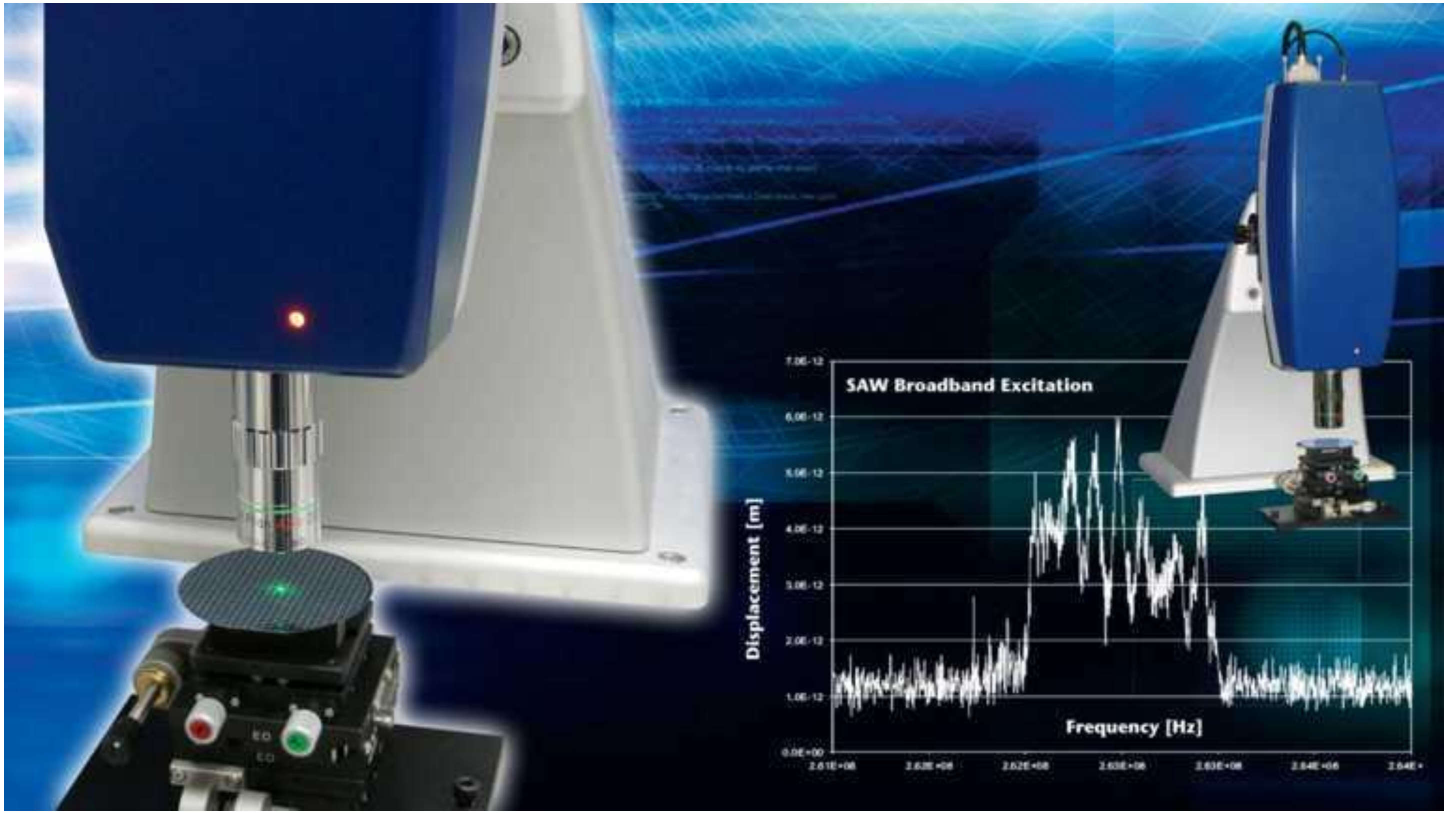


- 3-D data acquisition system and scanning heads
  - 4-channel data acquisition system
  - DC – 1 MHz vibration frequency range
  - 10 m/s max. velocity
  - High definition camera and triangulation software

NEW!!

Polytec

UHF-120
Ultra High Frequency Vibrometer



Ultrasonics Applications

Examples

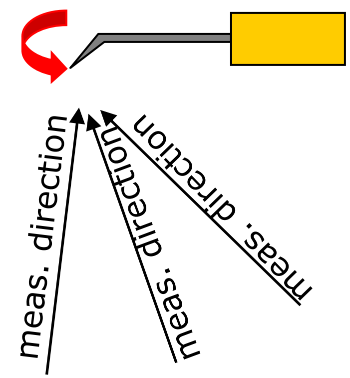
- Wire bonding
- Ultrasonic welding
- AFM tips
- Ultrasonic motors
- Military sonar transducers
- Structural health monitoring and NDE
- Communications antennas
- Ultrasonic level, volume and flow transducers
- Ultrasonic machining
- Ultrasonic sound projection
- Inkjet printers
- Hard disk drives
- Wildlife emissions and detections (bats, moths & grasshoppers)

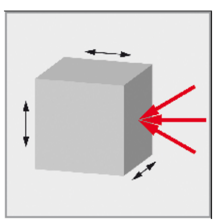
Vibrometer Selection

Appropriate vibrometer setup used depends on direction of vibration and accessibility of the ultrasonic device

Example: Dental Scaler (rotating)

Motion is in 3 Axis

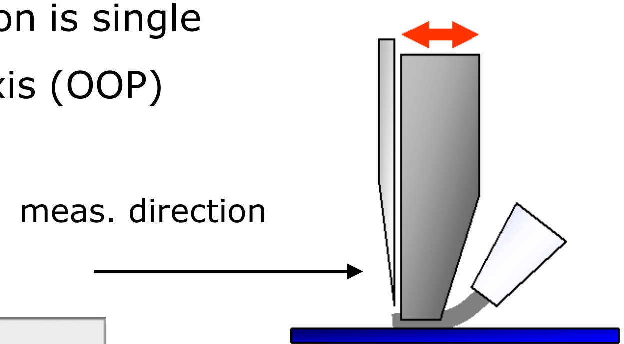


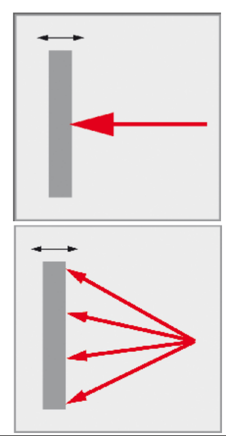


→ Use 3D Vibrometer

Example: Wire Bonder

Motion is single axis (OOP)



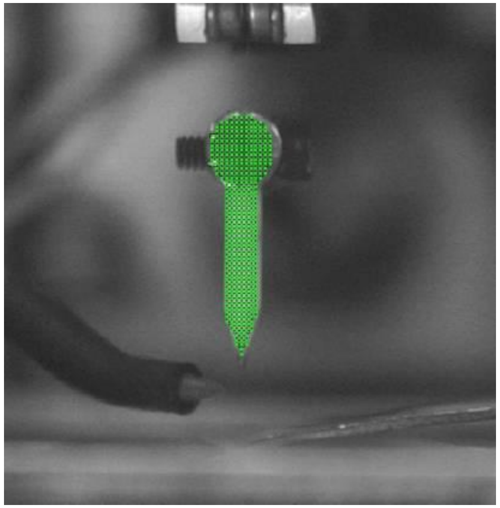


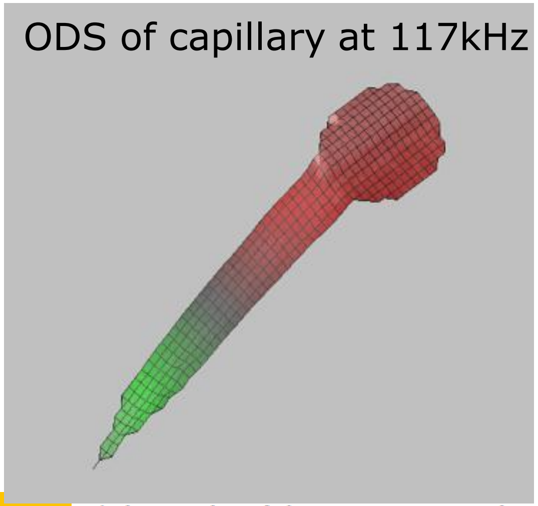
→ Use 1D Vibrometer

Ultrasonic Tools

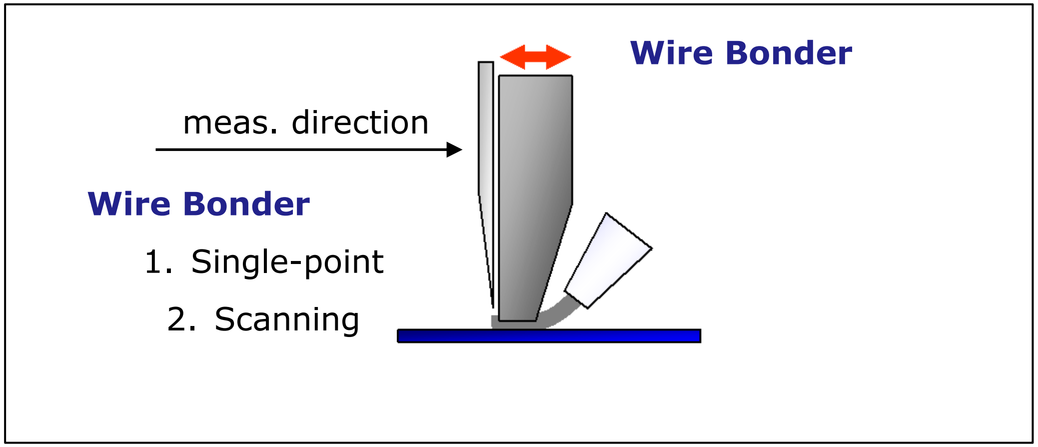
- Wire Bonder
- Ultrasonic Welder
- Dental Descaler

Wirebonder Applications





- R&D: Optimizing and tuning design of bonding tool to avoid nodes at tool tip (Scanning Vibrometry)
- Maintenance: tool tip amplitude (Single-point vibrometer)



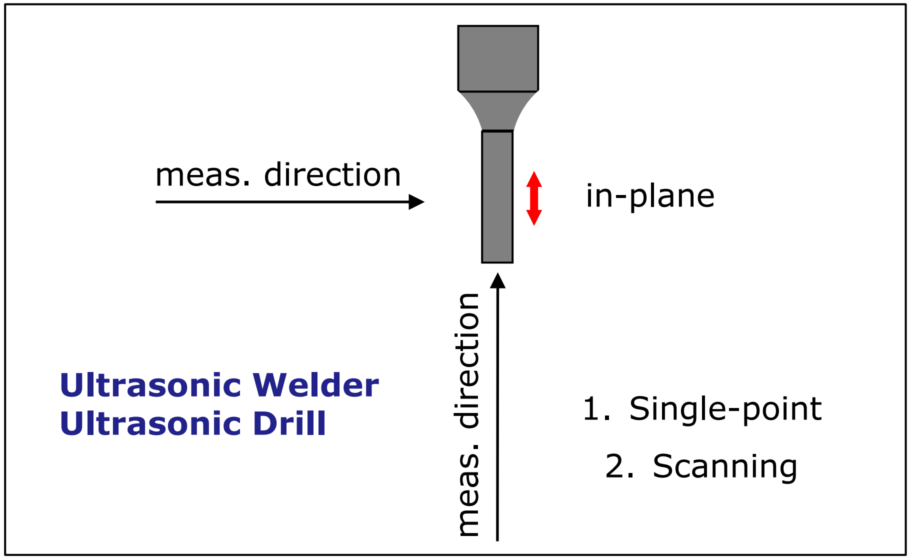
Ultrasonic Welding Horn

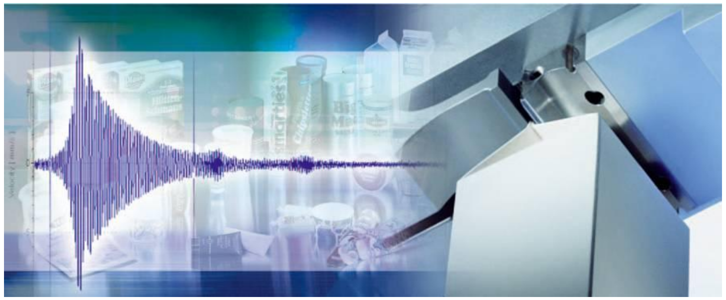
Sonotrode, Herrmann Ultrasonics

used for ultrasonic welding of plastic parts

Goals

- consistent welding quality
- controlled manufacturing of the horns themselves





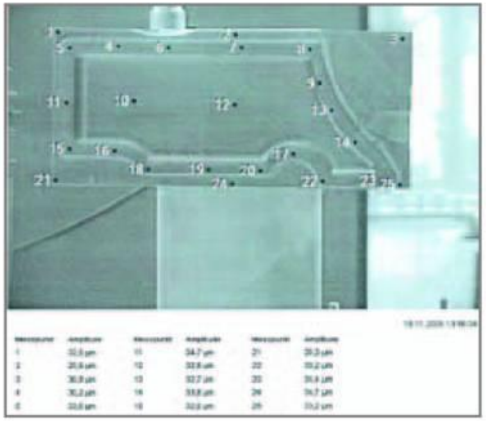
Ultrasonic Welding Horn

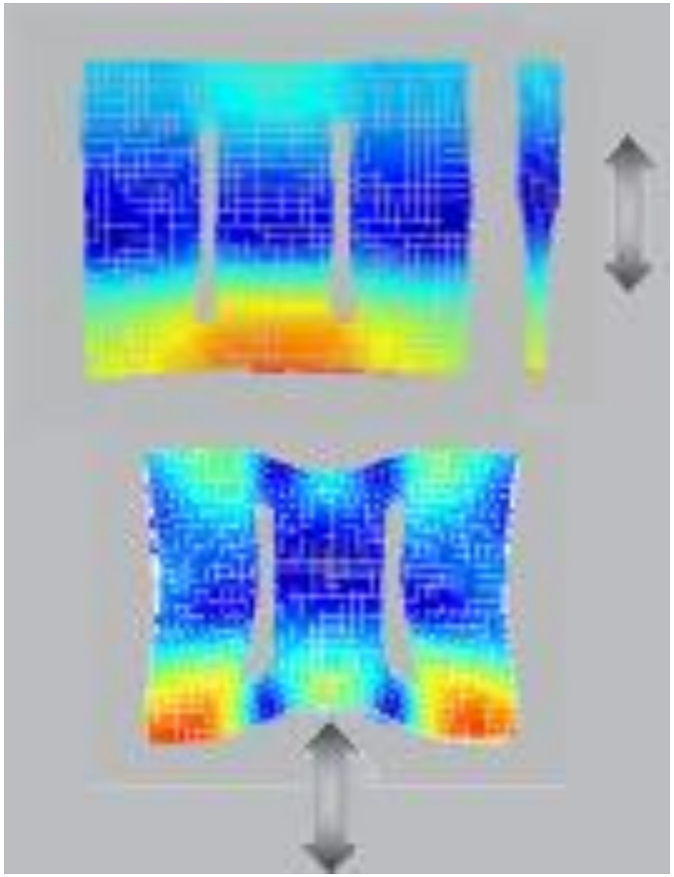
Measurement approach

- Scanning Vibrometry used for R&D … and QC in end-of-line test

Messaufbau zur Charakterisierung der Sonotroden

Amplitudenverteilung an der Oberfläche der Sonotrode



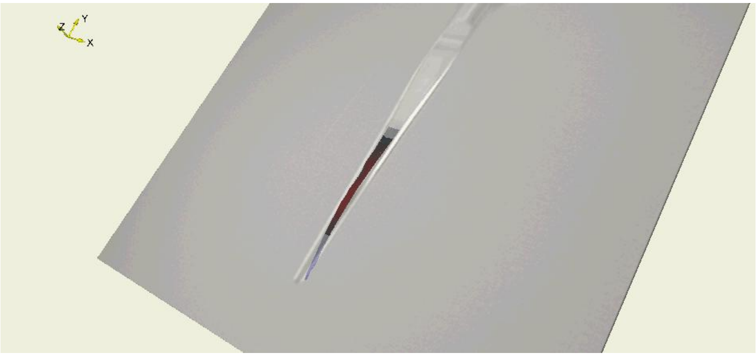


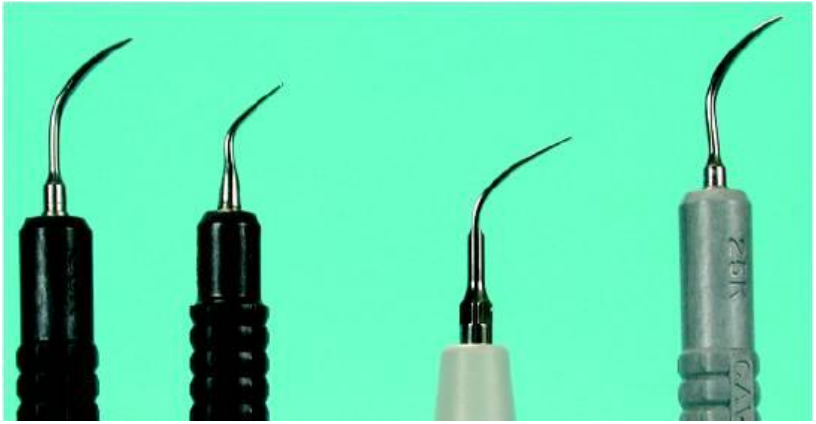
Dental Descaler

Tartar removal

- Vibrometry for optimizing and tuning tool performance
- 3-D vibrometry used

ODS of the tip at
28 kHz (PSV)

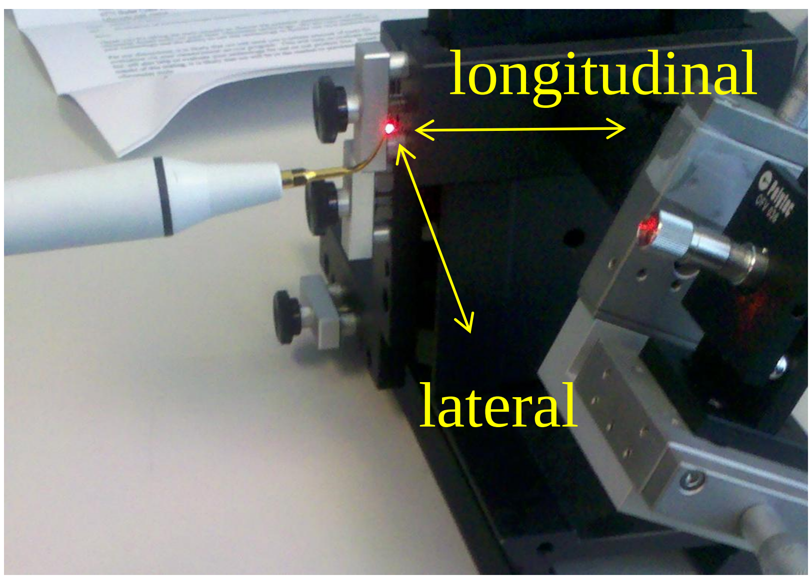




source: LM Info Special 2/2005

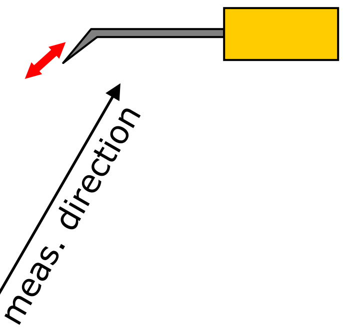
Dental Descaler

AMERICAN EAGLE INSTRUMENTS® INC.



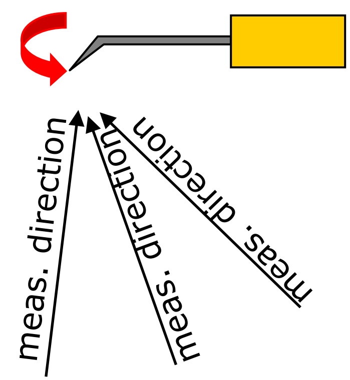
Dental Scaler (linear motion)

1. Single-point
2. 1-D scanning



Dental Scaler (rotating)

1. 3-D single-point
2. 3-D scanning



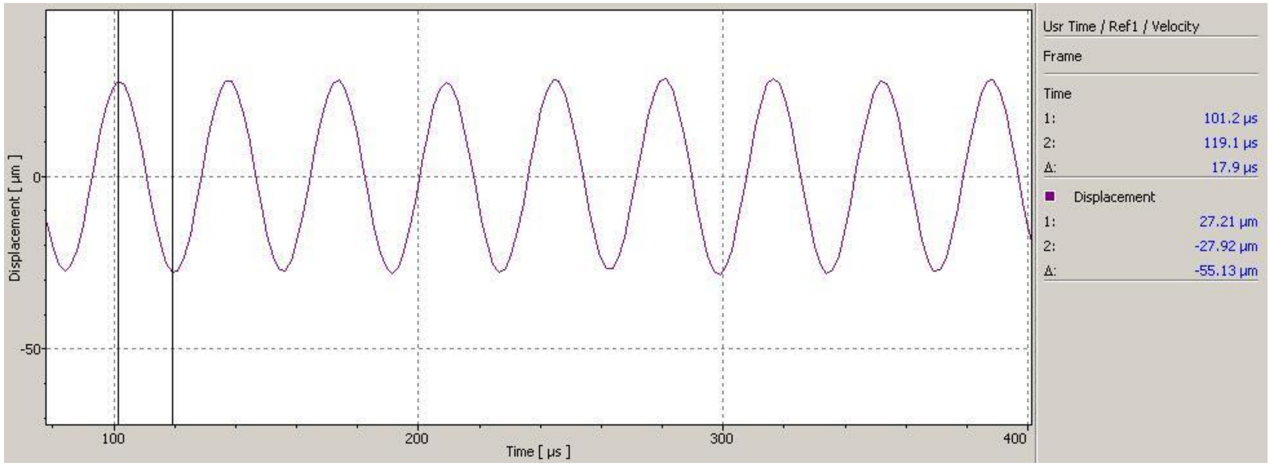
Dental Descaler

Single Point Measurement

Using new **OFV-534 Compact Sensor Head**

- Longitudinal Measurement
- Water cooled
- Amplitude vs. power setting

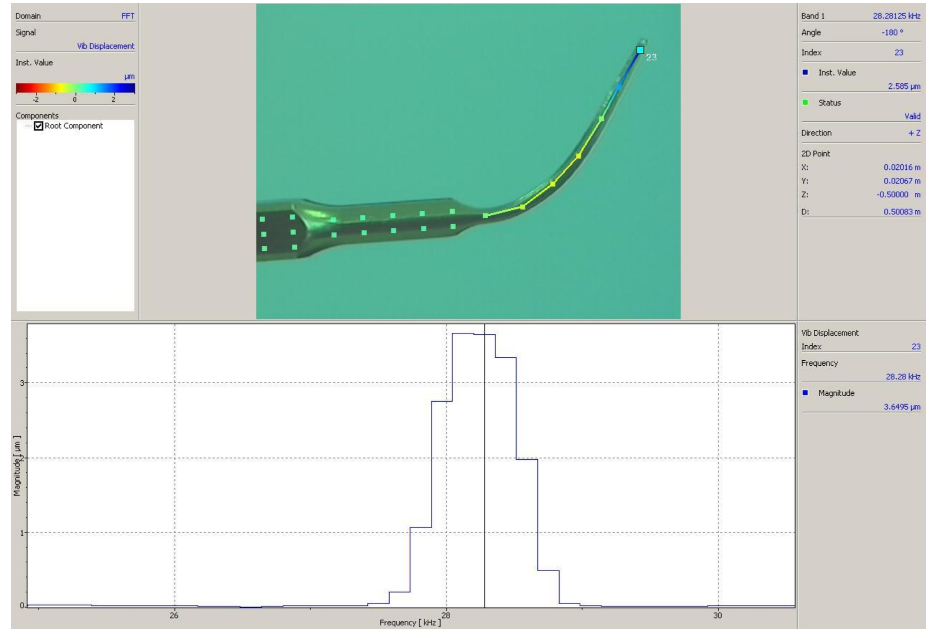
Direct Read Out of Displacement Amplitude

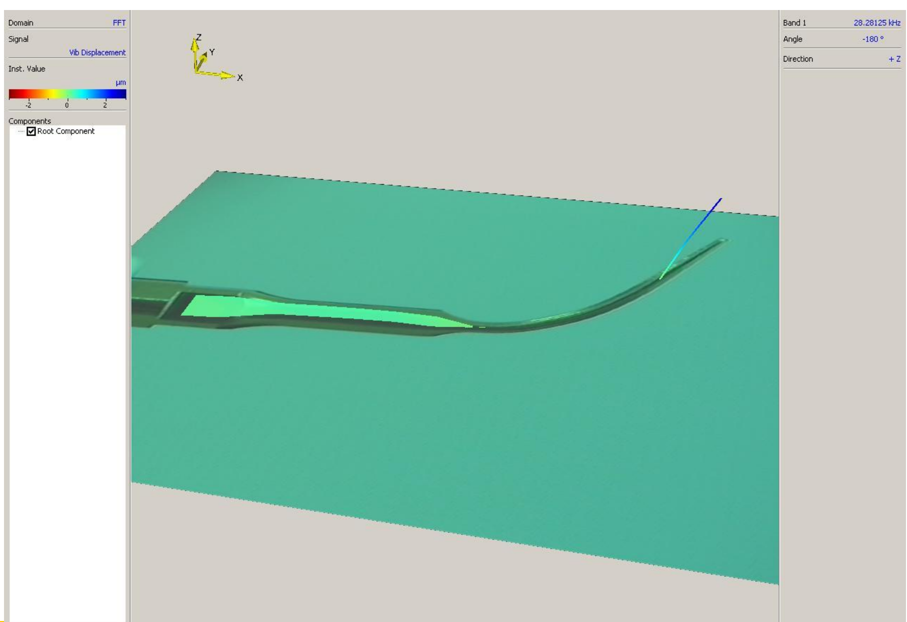


Polytec

Dental Descaler

- Scan Measurement over surface of tip to measure deflection shape at 28 KHz
- Aligned in lateral direction
- Measured at 25 points along tip length





- Results shown as 3D animation of deflection shape at selected frequency (28 KHz)
- Shape is second bending mode with maximum displacement at tip

Medical Applications

- Imaging
- Therapeutics
- Surgery

Medical Imaging

- Conventional piezoelectric ultrasound transducers
- Piezoelectric micro-machined ultrasound transducers (PMUTs)
- Capacitive micro-machined ultrasound transducers (CMUTs)
- Trend towards higher frequencies, smaller elements
- Intravascular ultrasound (IVUS) transducers

Stages Used to Scan PZT-Transduced Contour-Mode Resonators to >1GHz

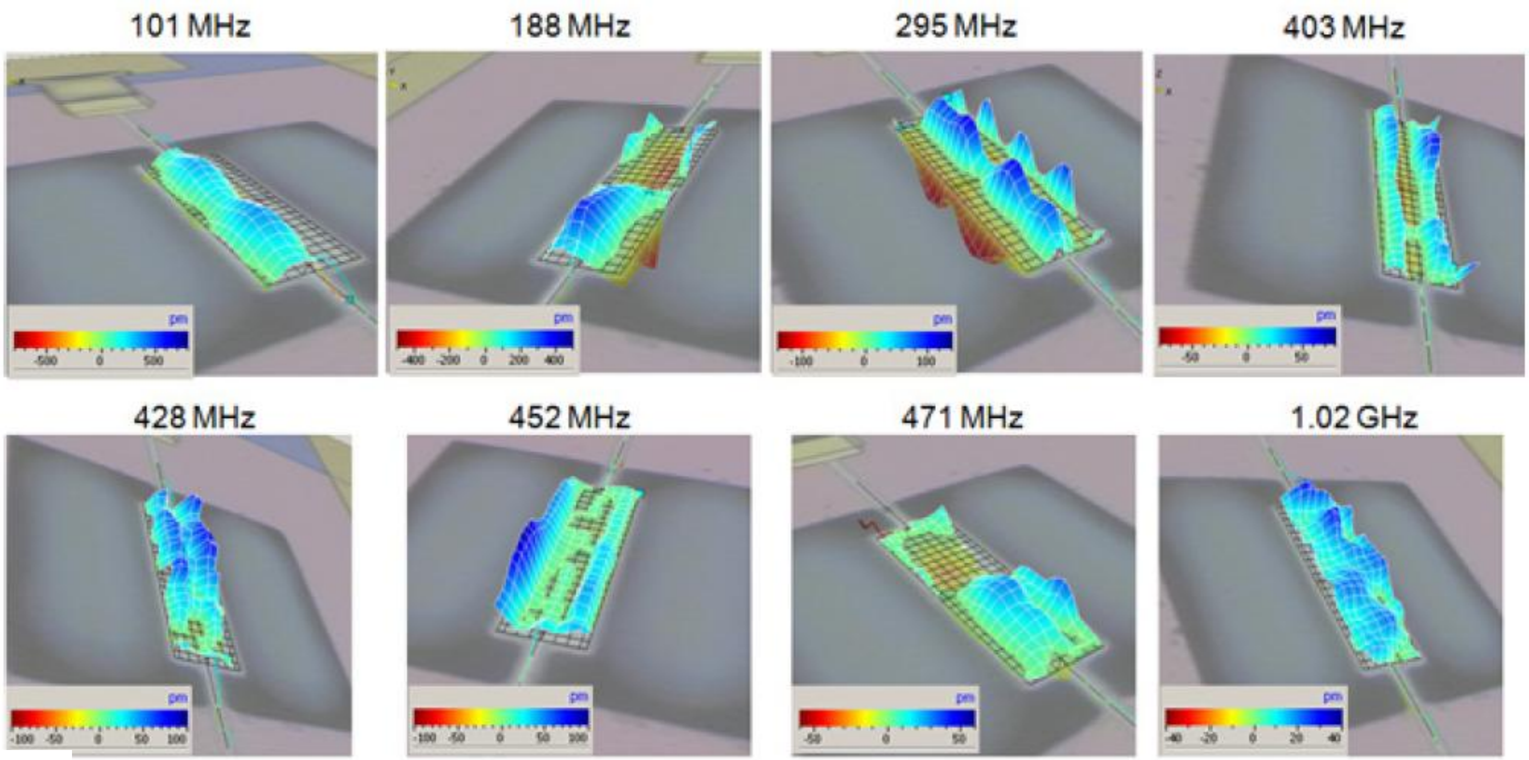
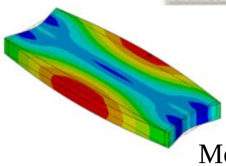


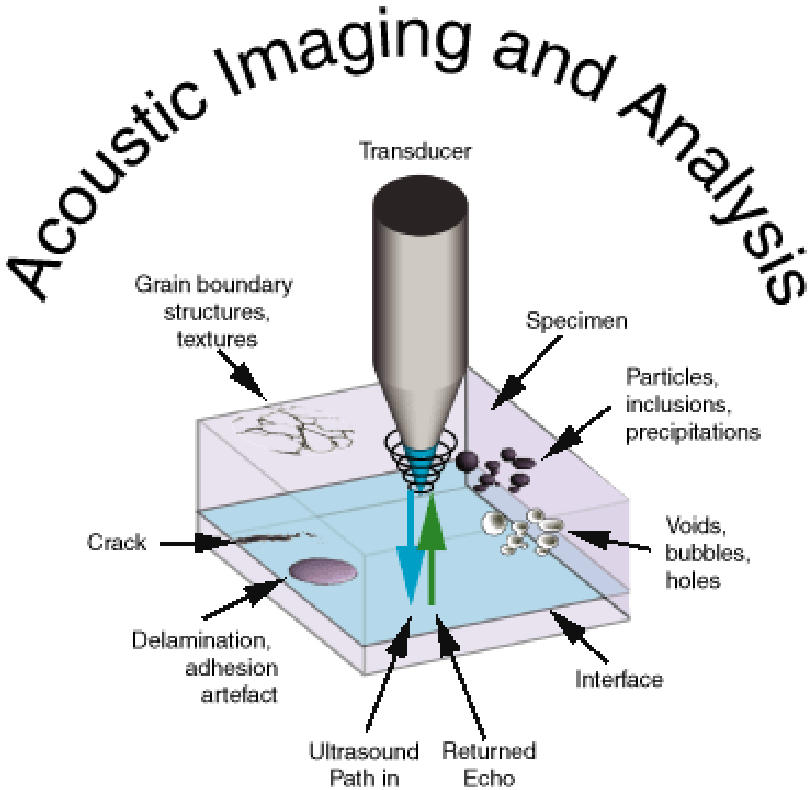
Fig. 9. 3D images of the rich frequency response of a width-extensional mode resonator with improper anchor design.



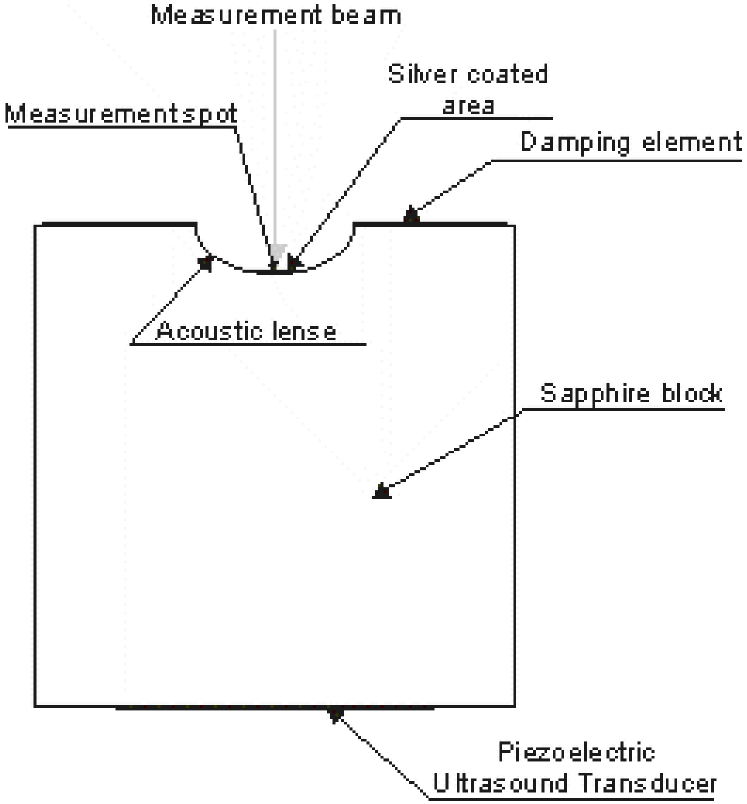
Modal analysis using ANSYS

Acoustic Microscope

Application of Acoustic Microscope



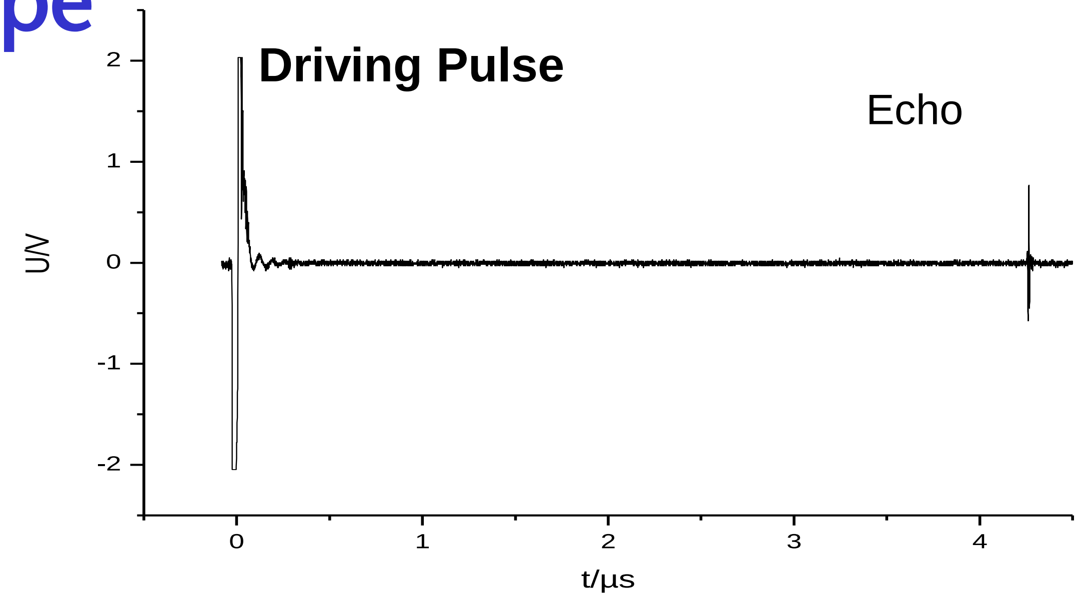
150 MHz Ultrasonic Probe (PVA TePla AG)

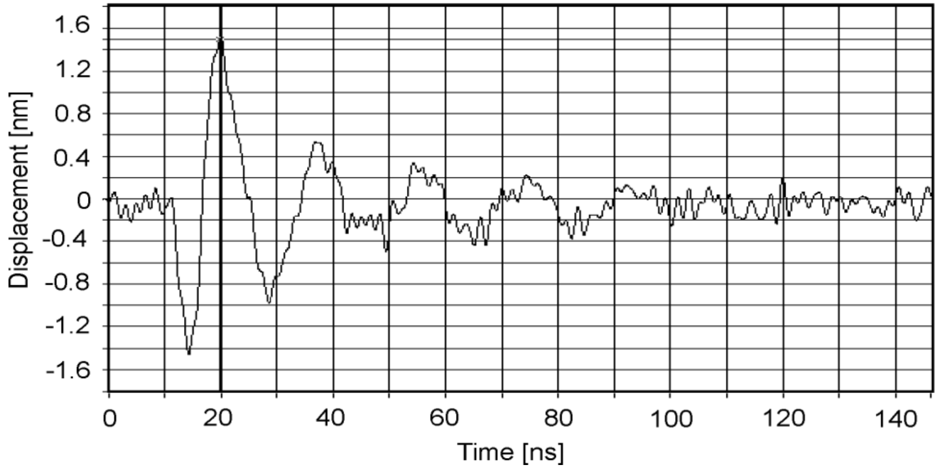


Acoustic Microscope

Measurement Settings

- 100x microscope objective
- 28 averages of the time domain data
- Triggered on the driving pulse of the acoustic microscope transducer

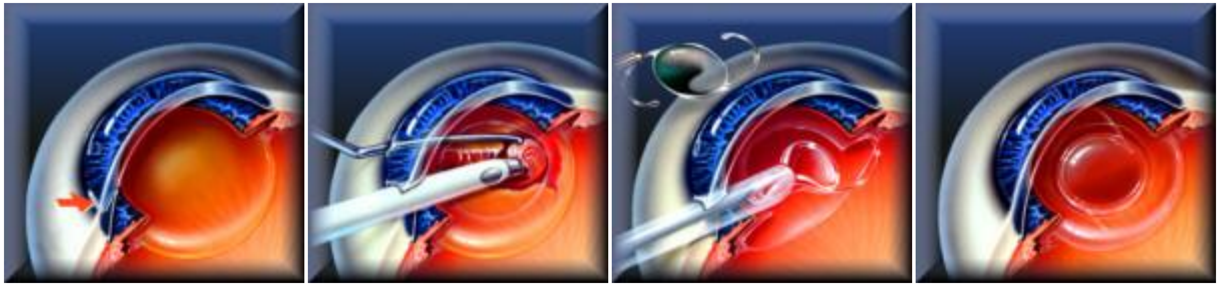


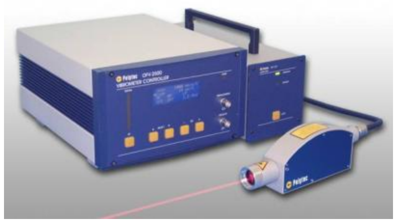


Medical Surgery

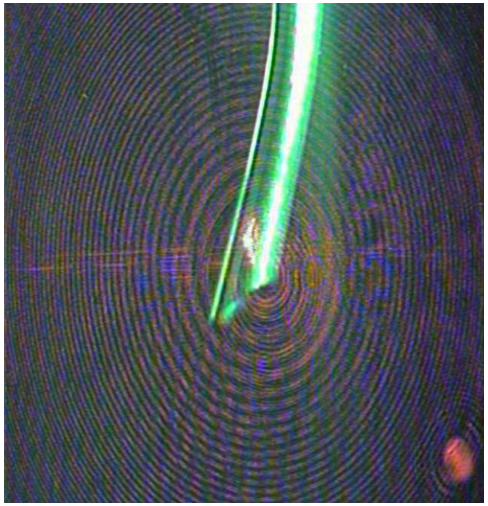
- Phaecoemulsifiers (removal of cataracts)
- Liposuction (removal of large volumes of fat)
- High intensity focused ultrasound (HIFU)
- Lithotripsy (probe for kidney stones)
- Aspirator (tissue disintegration & removal)
- Catheters for clot removal (during operations, deep vein thrombosis, peripheral arterial disease)
- Laparoscopic cutters (minimally invasive surgery)

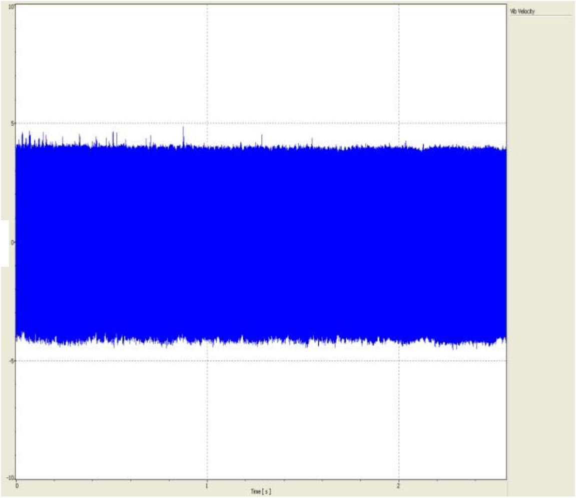
Phaeco-Emulsification

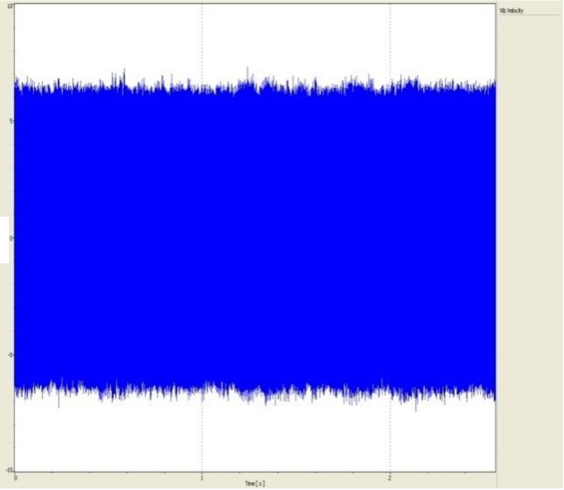




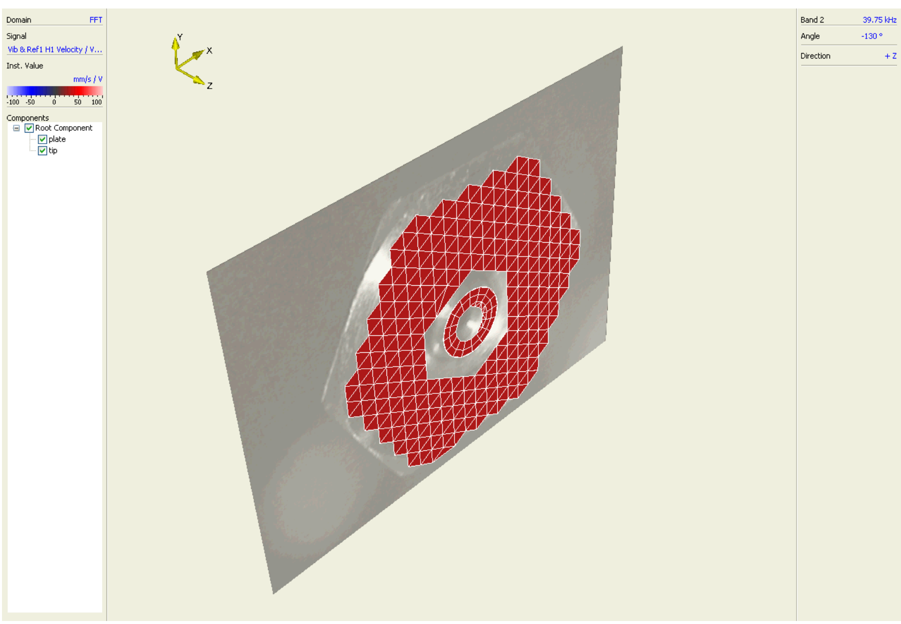
OFV-2570 + OFV-534

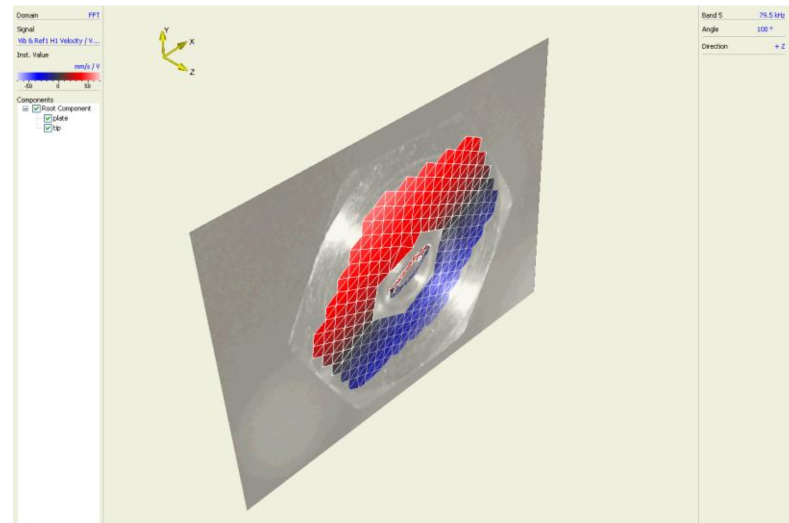






Catheter Wire Actuator for Treatment of Vascular Occlusive Disease





Cavitational streaming removes thrombus

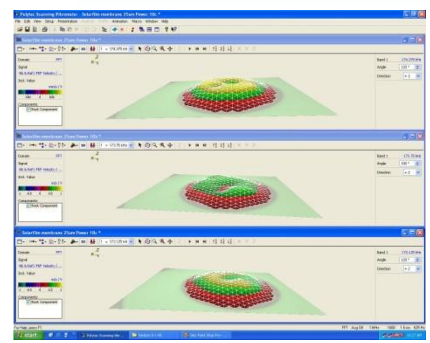
Data courtesy of Omnisonics Medical Technologies, Inc.

Medical Therapeutics

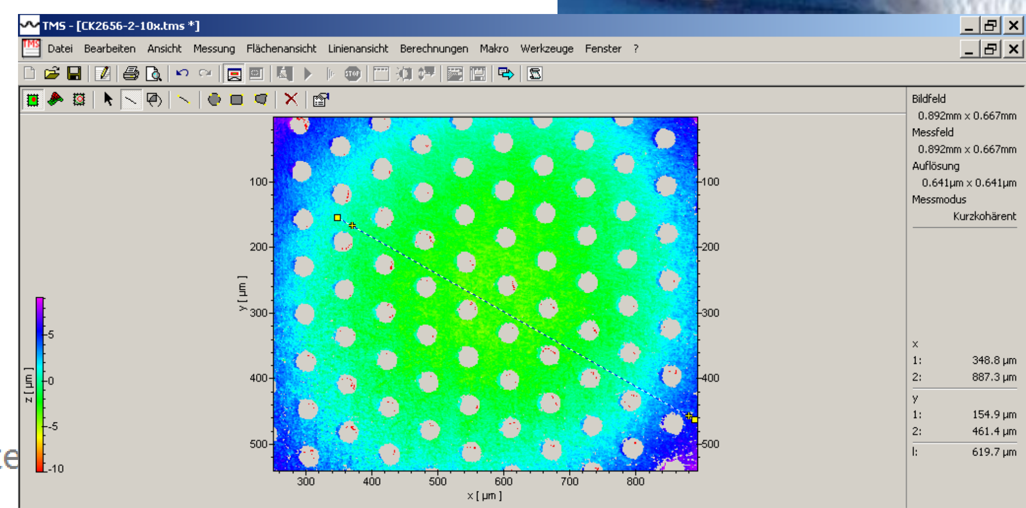
- Therapeutic ultrasound (physical therapy)
- Drug delivery (patches and wands)
- Hyperthermia treatment (cancer therapy)
- Nebulizers (drug delivery via inhalation)

Ultrasonic Nebulizer

- Quality Control
  - reduce rejects
  - measure amplitude and phase response of each membrane



- Research
  - Compare response of different membranes
  - Correlate results to droplet size and dosage



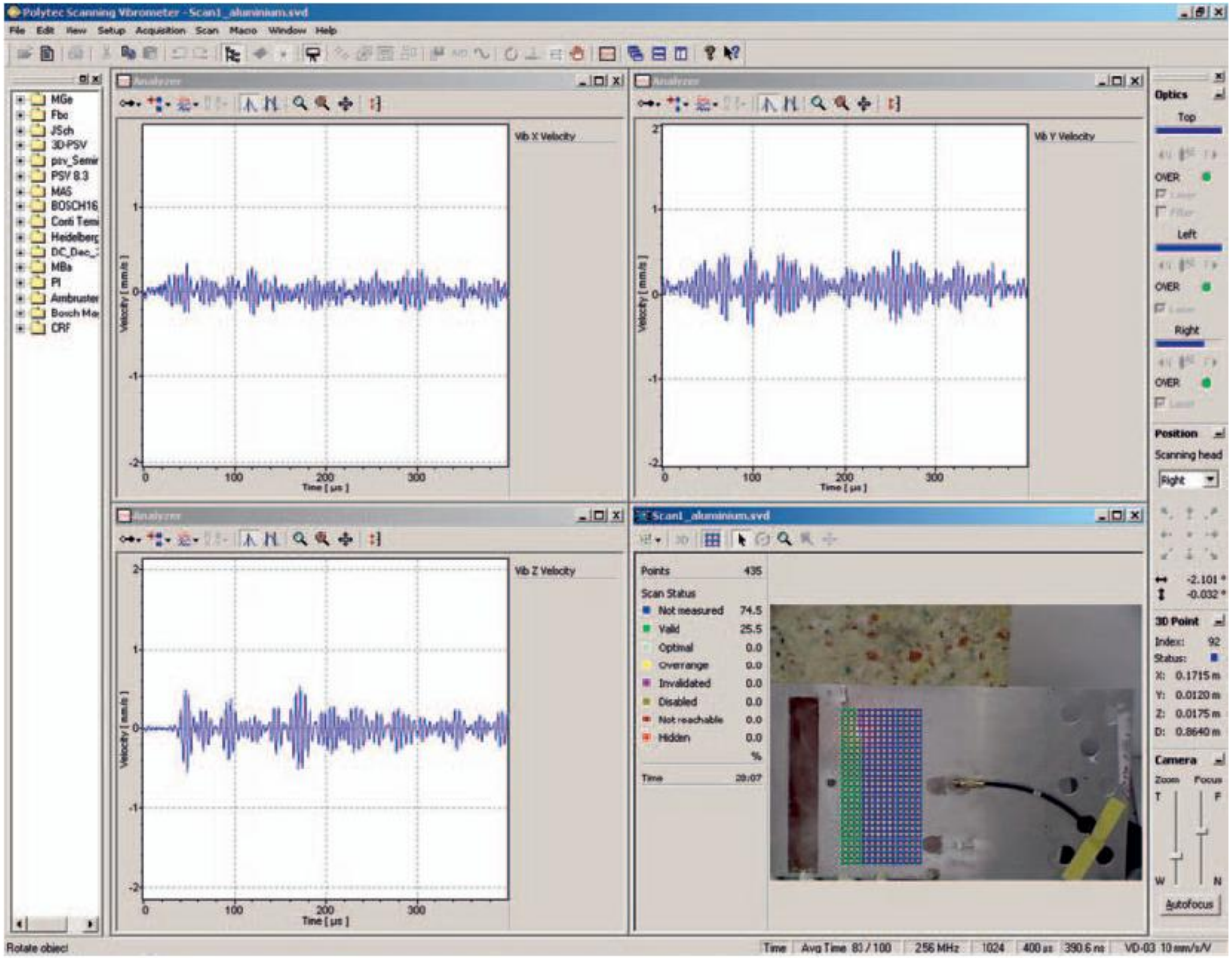
Guided Wave Applications

- Non-Destructive Testing
- Sound Field Measurement
- Surface Accoustic Wave Filter

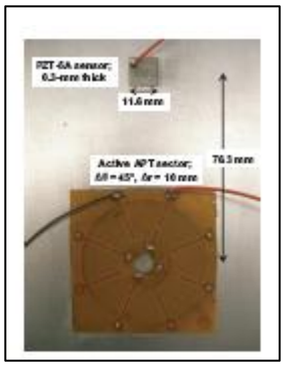
Damage Detection using Lamb Waves

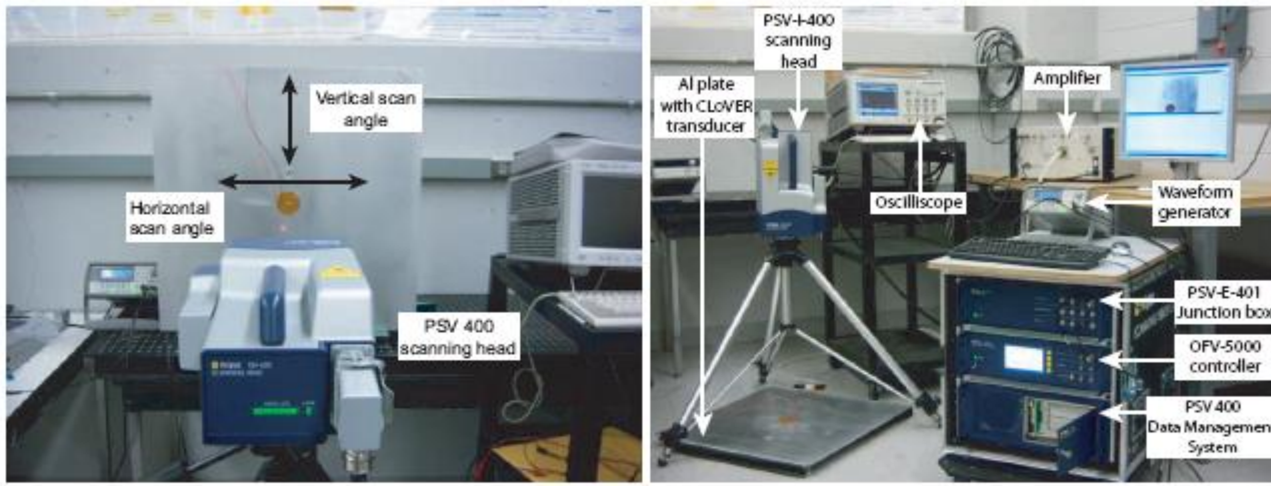
- Time reponse of ultrasonic pulse for hundreds of points
- Wave propagation visualized
- De/re-flection of propagating wave shows material defects

Damage Detection using Lamb Waves



Guided Wave Evaluation of Structural Health Monitoring Transducer

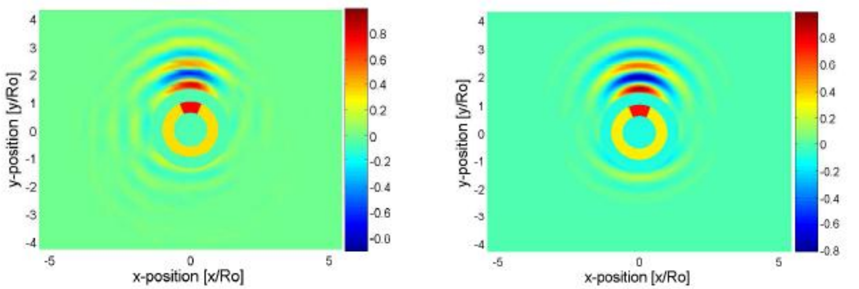




Experimental set-up for evaluating guided wave field generated by novel CLoVER transducer.

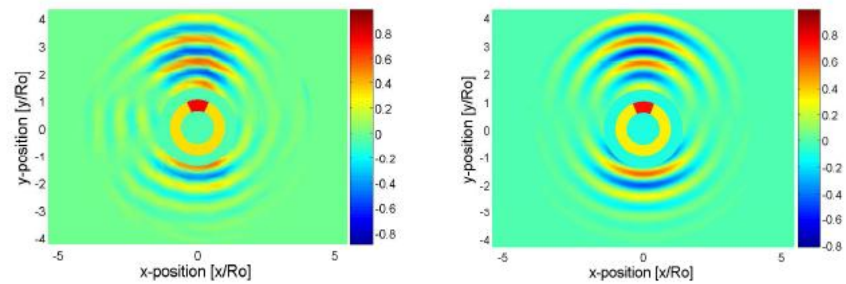
Images and data provided courtesy of C. Cesnik, University of Michigan

Guided Wave Evaluation of Structural Health Monitoring Transducer



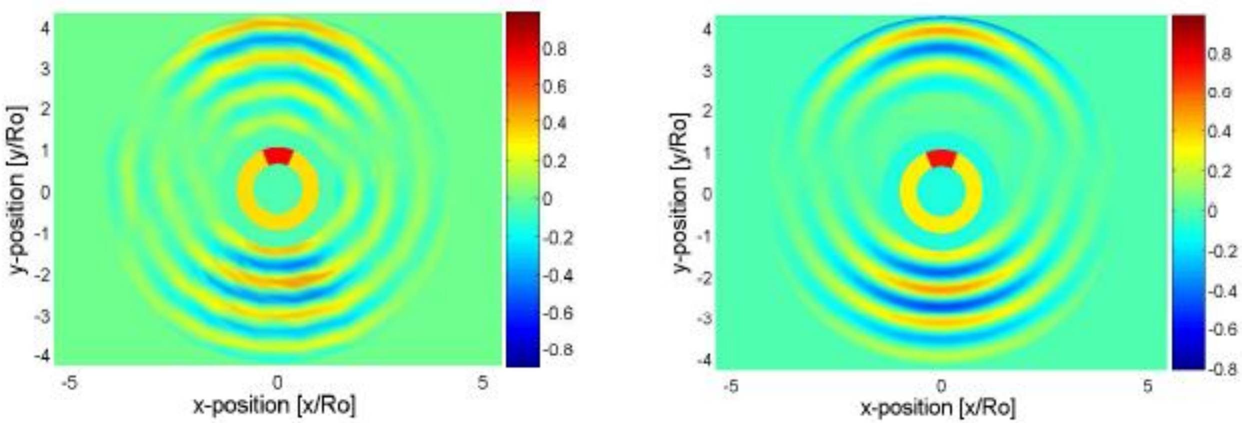
(a): Experiment (b): Theory

Figure 12. Full-field comparison between laser vibrometer and theoretical solution at time $t = 35\ \mu$



(a): Experiment (b): Theory

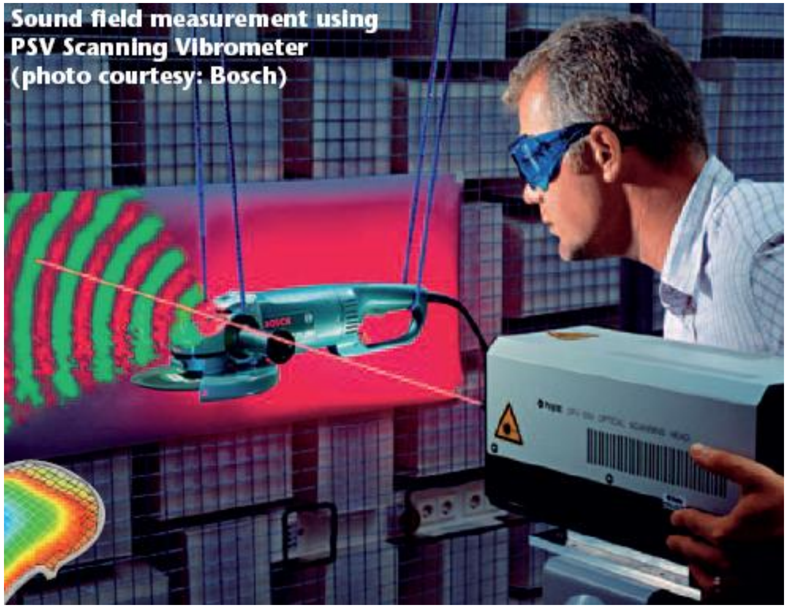
Figure 13. Full-field comparison between laser vibrometer and theoretical solution at time $t = 50\ \mu s$.



(a): Experiment (b): Theory

Images and data provided courtesy of C. Cesnik, University of Michigan

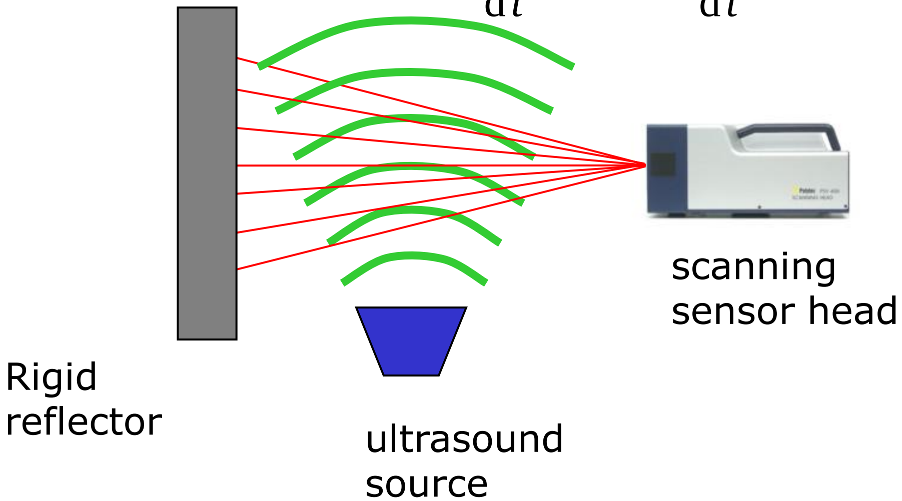
Sound Field Measurement

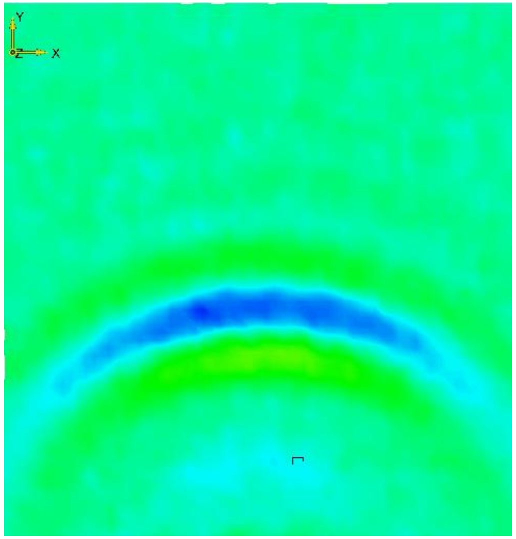


Sound Field Measurement

- Refractive index is locally modulated by sound pressure waves
- Example: distance sensors (Bosch)

$$\frac{dL}{dt} = \frac{d\left(2\int_0^z n(z,t)\,dz\right)}{dt}$$

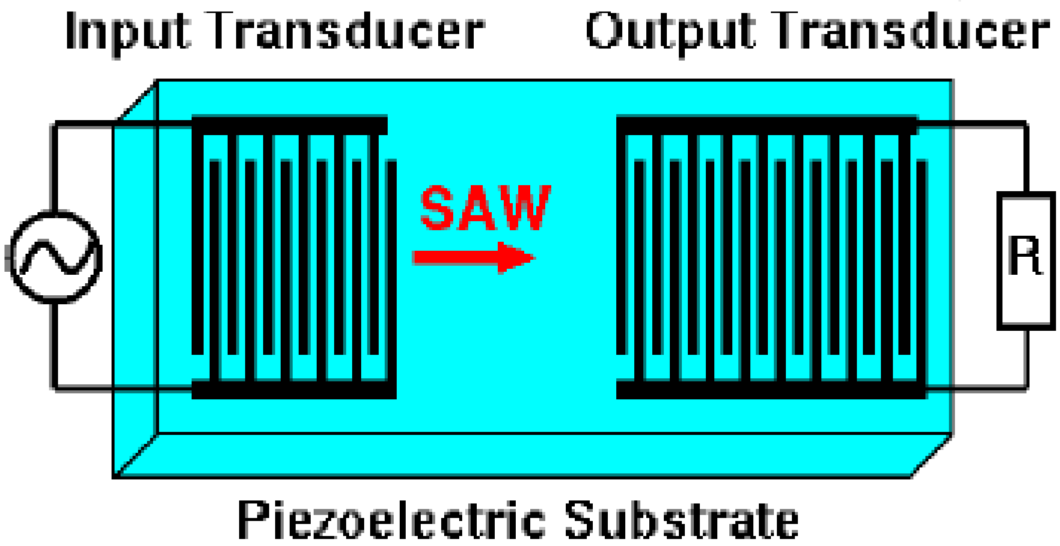




time domain visualization of sound field (pulsed excitation)

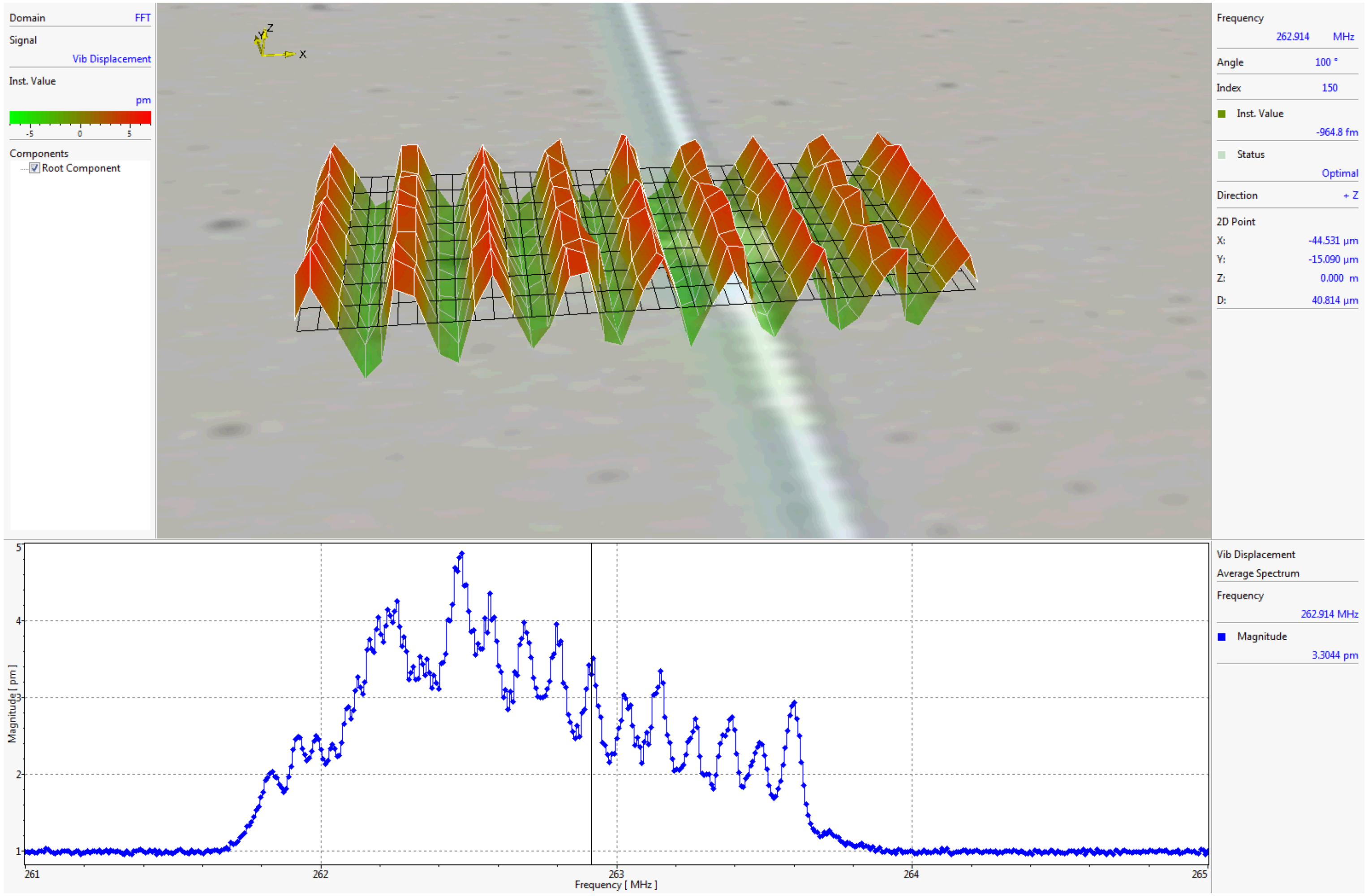
SAW Filter Measurement

A **surface acoustic wave** (SAW) is an acoustic wave traveling along the surface of a material having some elasticity, with an amplitude that typically decays exponentially with the depth of the substrate



Schematic picture of a typical SAW device design

SAW Filter Measurement



Conclusion

Laser Vibrometry:

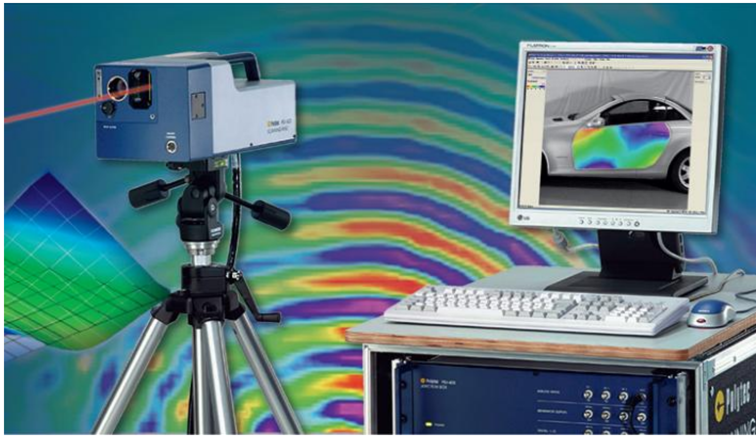
- is well suited for broad range of ultrasonic applications

- real-time, broadband measurement with frequency bandwith to GHz

- highly Sensitive measurement with resolution down to *picometer* level

-supported by Application Engineers knowledgeable with ultrasonic applications

-available for measurements services and rentals.



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