University of Glasgow | Faculty of Engineering

Ultrasonic Cutting of Bone

BSSM Seminar: 23rd June 2009

Experimental Mechanics in Biological Tissues

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Dept. Mechanical Engineering

Low power ultrasonics: usually > 1MHz

eg. imaging ultrasound, NDE, therapeutic ultrasound

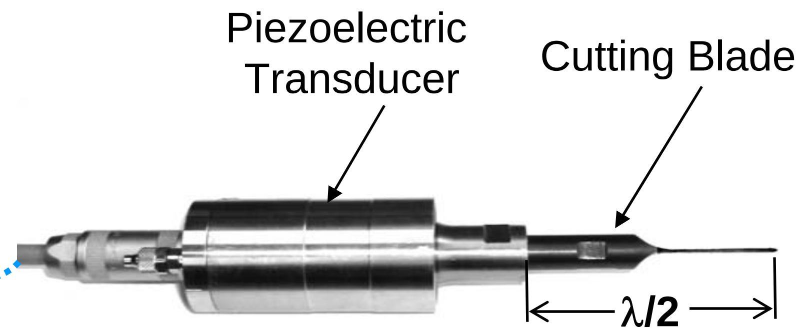
Power ultrasonics: usually 20 – 100 kHz

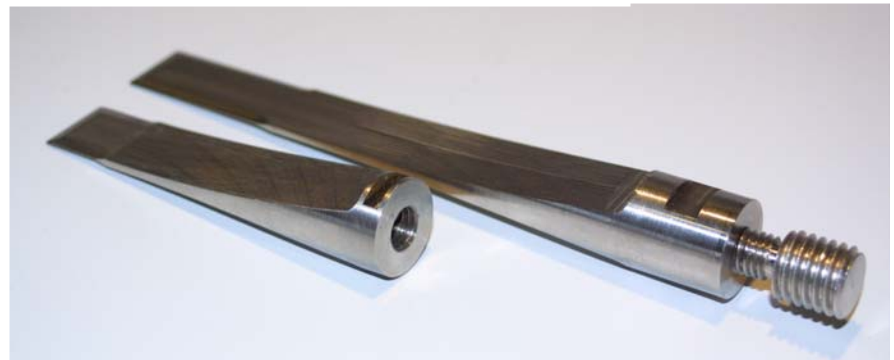
eg. cleaning, metal forming, food processing, welding, machining, cutting, surgery

Power ultrasonic devices are usually tuned to resonate at the operating ultrasonic frequency, often in a longitudinal mode of vibration, and are therefore constructed from one or multiple half-wavelength components.

Ultrasonic cutting blades

Ultrasonic Generator

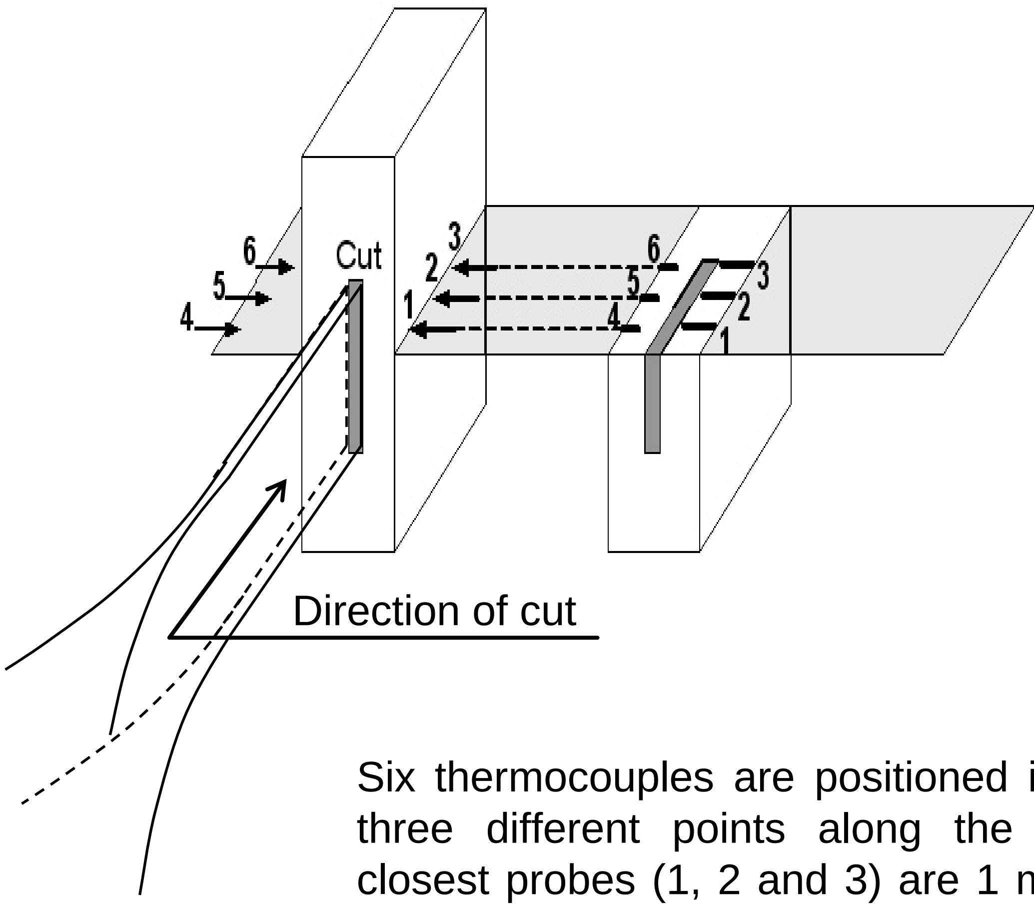


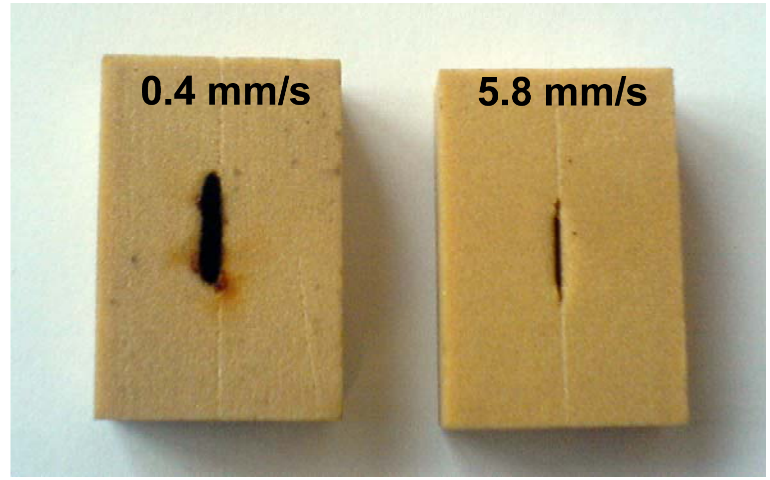


35kHz and 20kHz tuned ultrasonic cutting blades manufactured in titanium

50kHz tuned ultrasonic cutting blade and handpiece

Temperature measurements during cutting



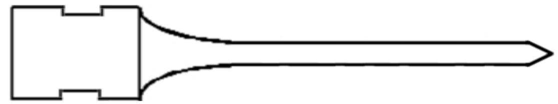
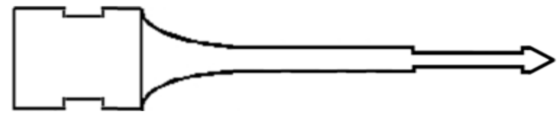


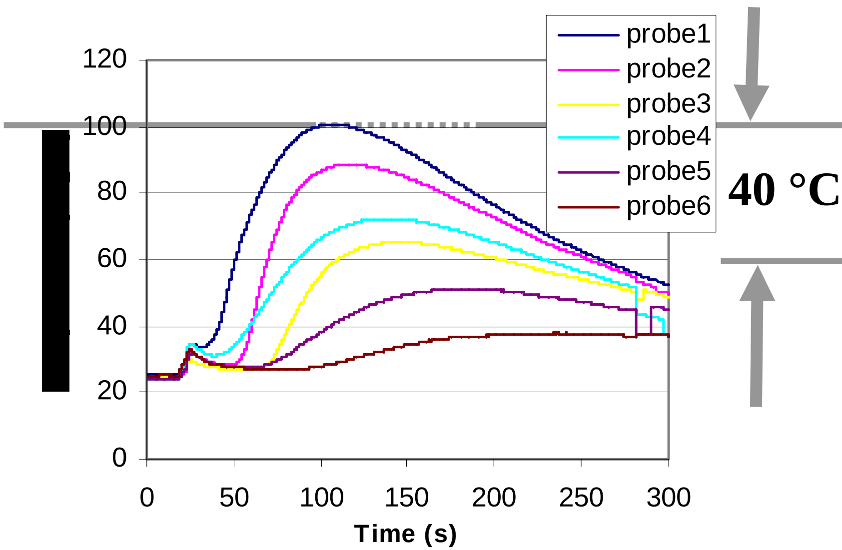
Cutting at 0.4mm/s

Cutting at 5.8mm/s

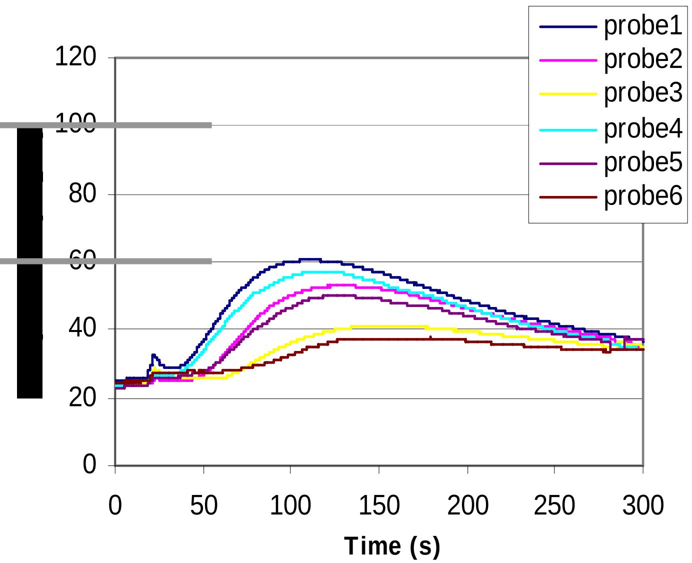
Six thermocouples are positioned in the specimen at three different points along the cutting axis. The closest probes (1, 2 and 3) are 1 mm, and the others (4, 5 and 6) are 2 mm from the cutting axis.

Effect of blade profile

	35 kHz Tuned blades	20 kHz Tuned blades
		
indented profile		

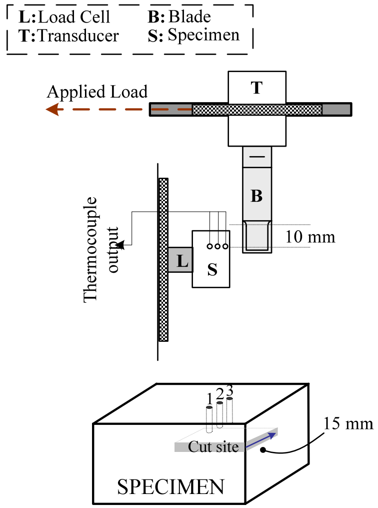


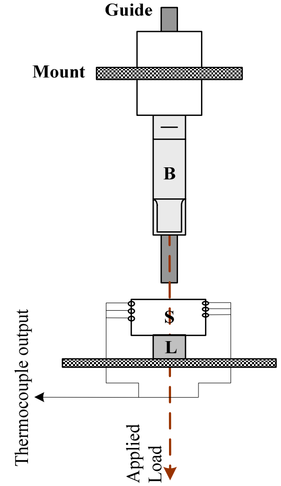
35 kHz tuned blade

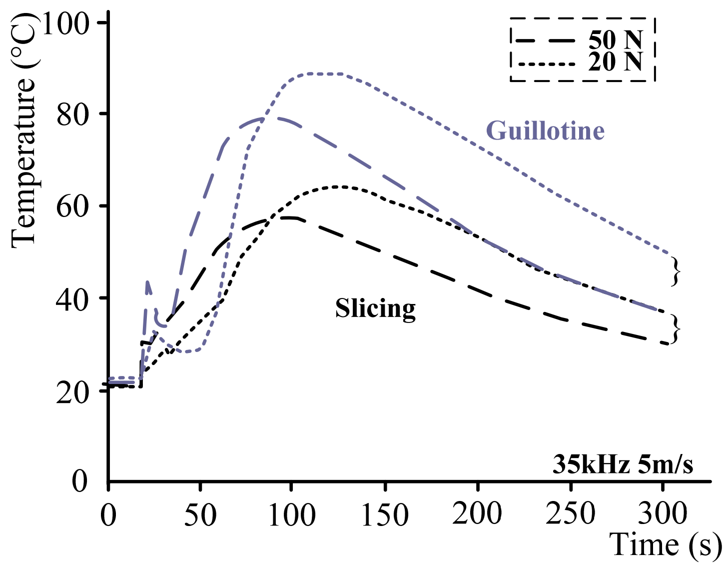


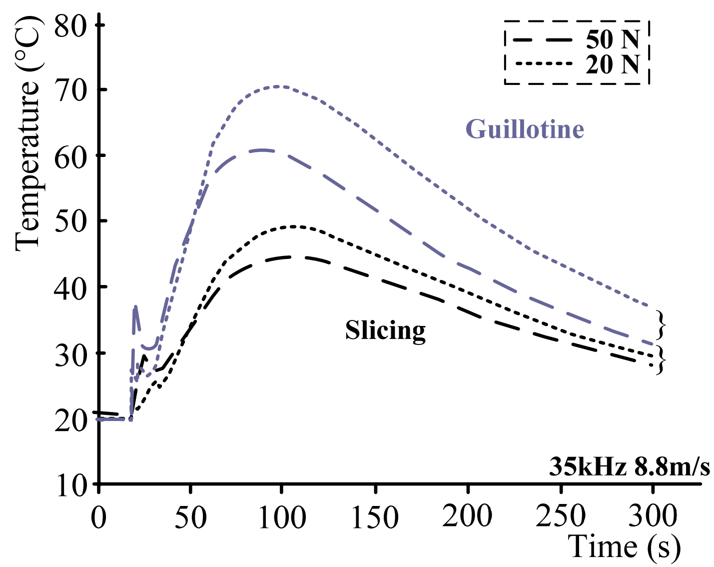
35 kHz tuned blade with indented cutting profile

Effect of blade orientation

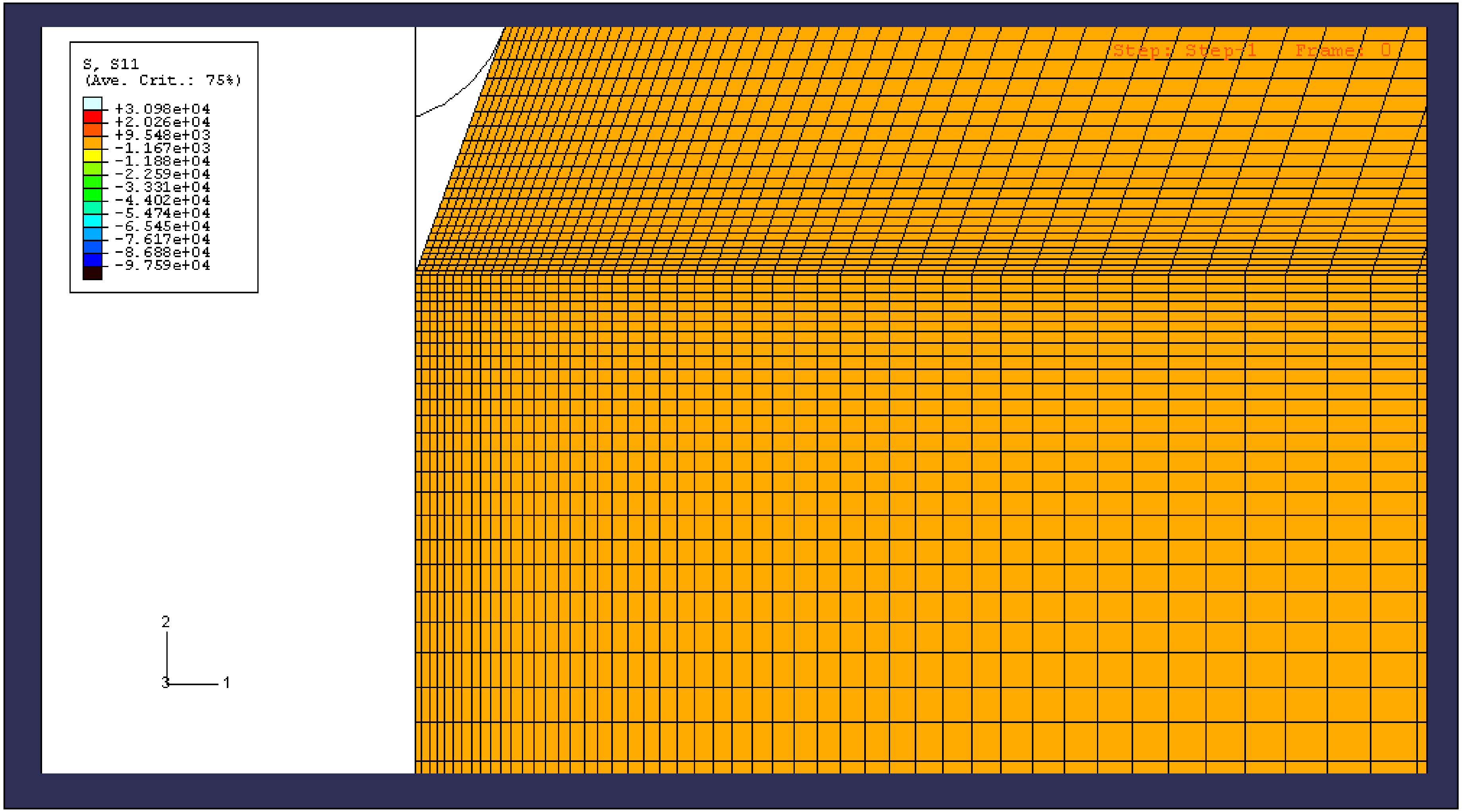




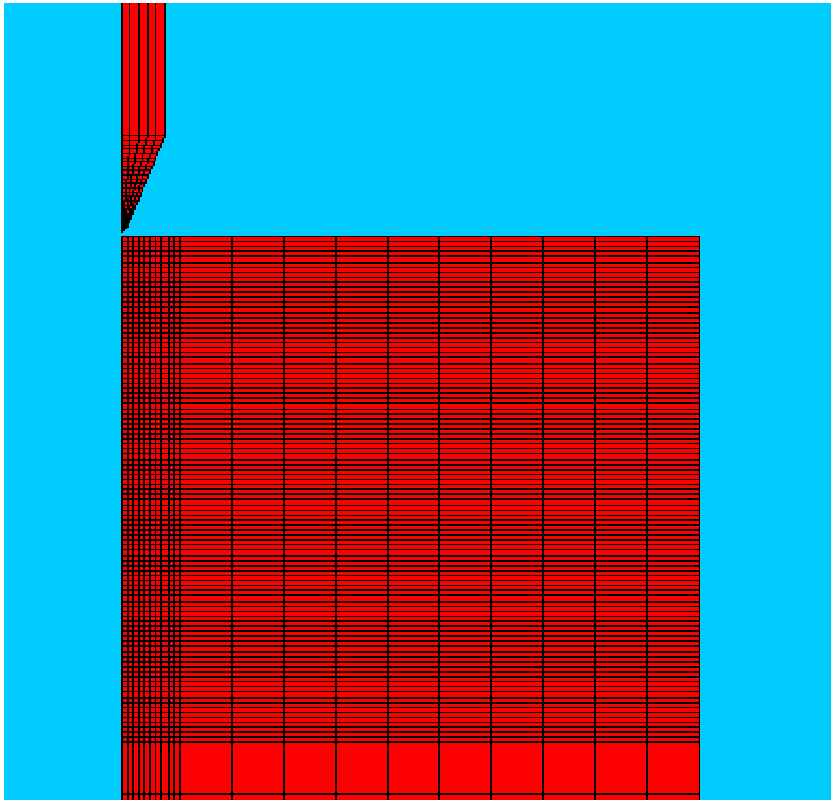




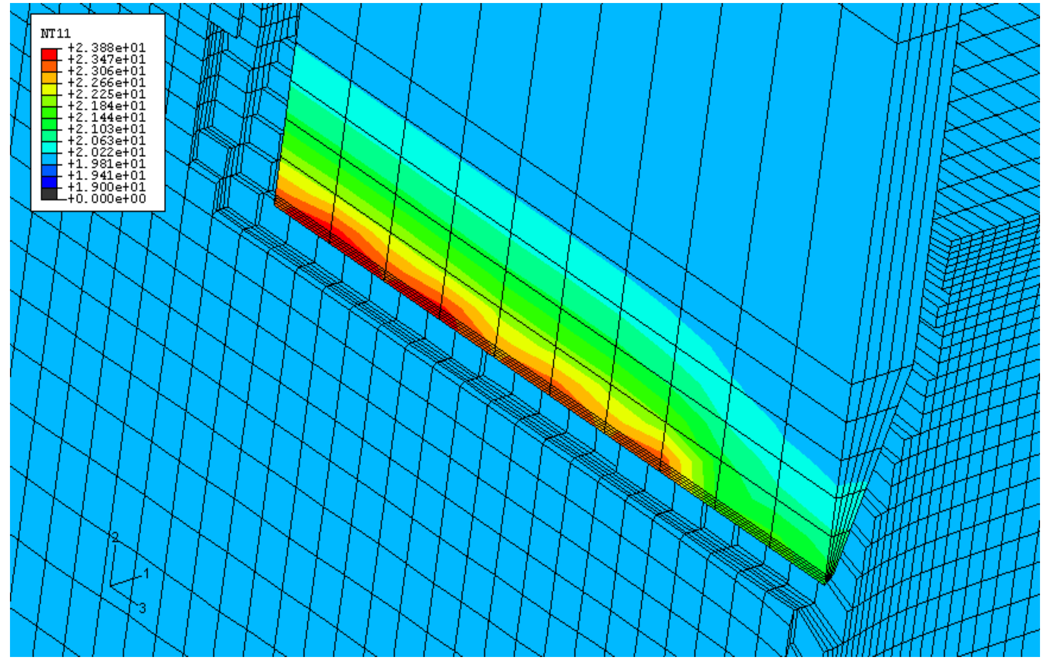
Debond finite element model of cutting



2D and 3D Ultrasonic Cutting Simulations



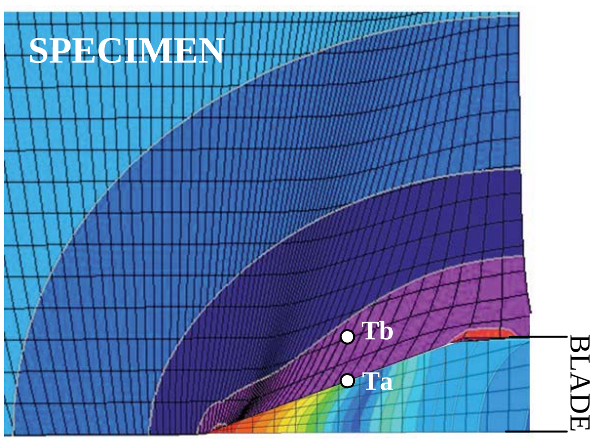
- Uses Abaqus explicit solver
- Utilises symmetry about cutting plane
- Uses shear failure criterion in plastic region of stress-strain curve
- Uses adaptive meshing if required

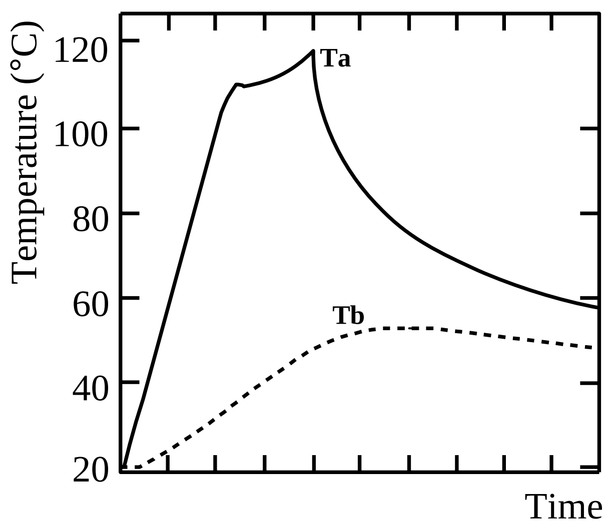


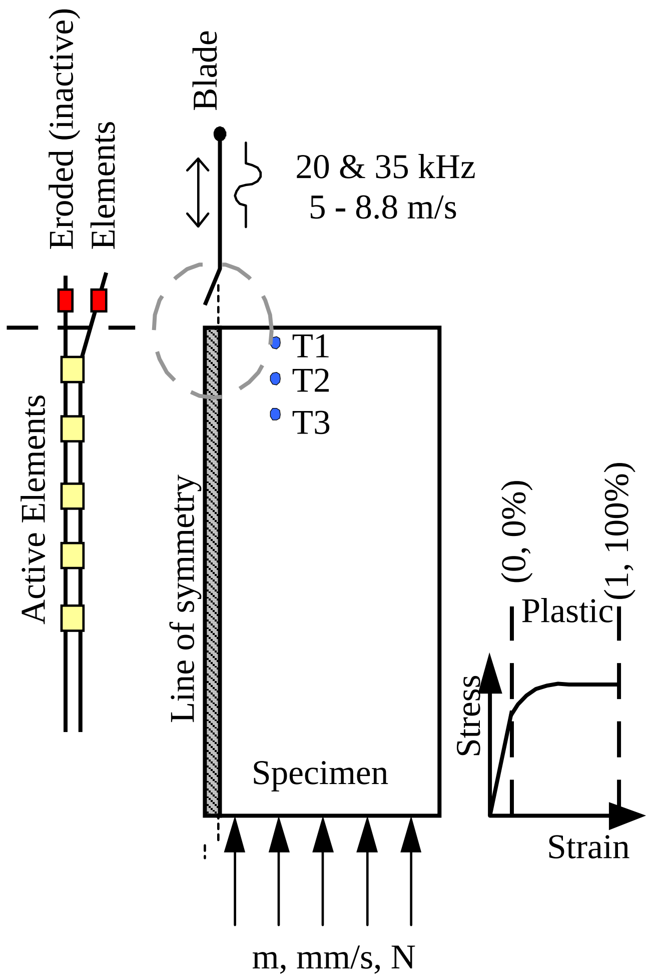
Blade temperature in 3D fully coupled thermal stress FE model of ultrasonic cutting

FE model of ultrasonic cutting of bone

- 2D fully coupled thermo mechanical modelling approach.
- Cutting simulated in guillotine configuration.
- Temperature dependent material data.
- Uses element erosion.
- Removes elements when shear failure criterion reached.

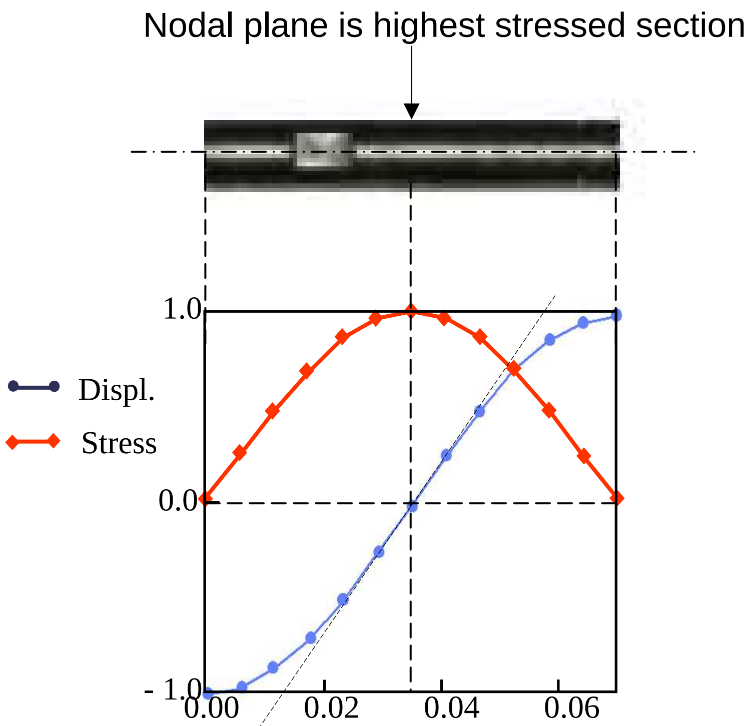




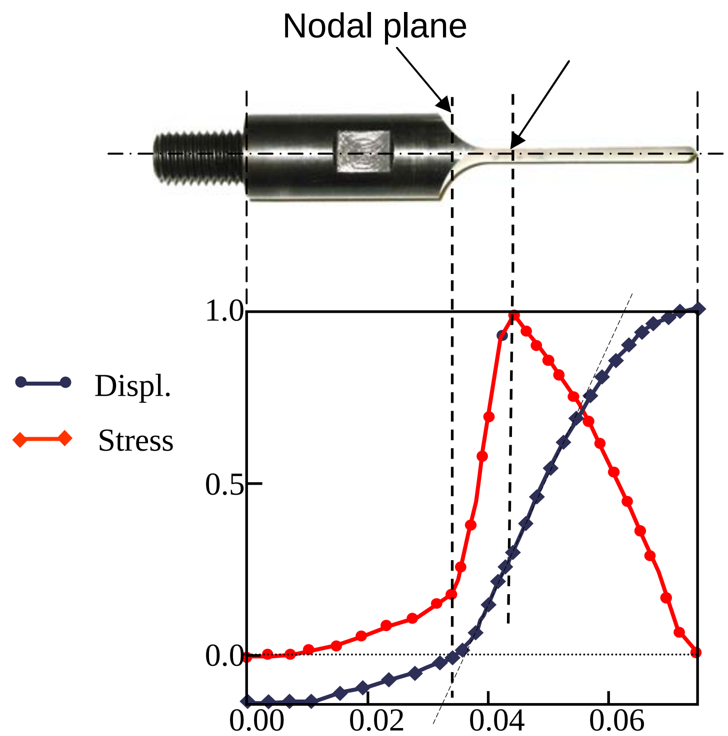


Normalised Stress and Displacement

Bar Horn of Constant Section



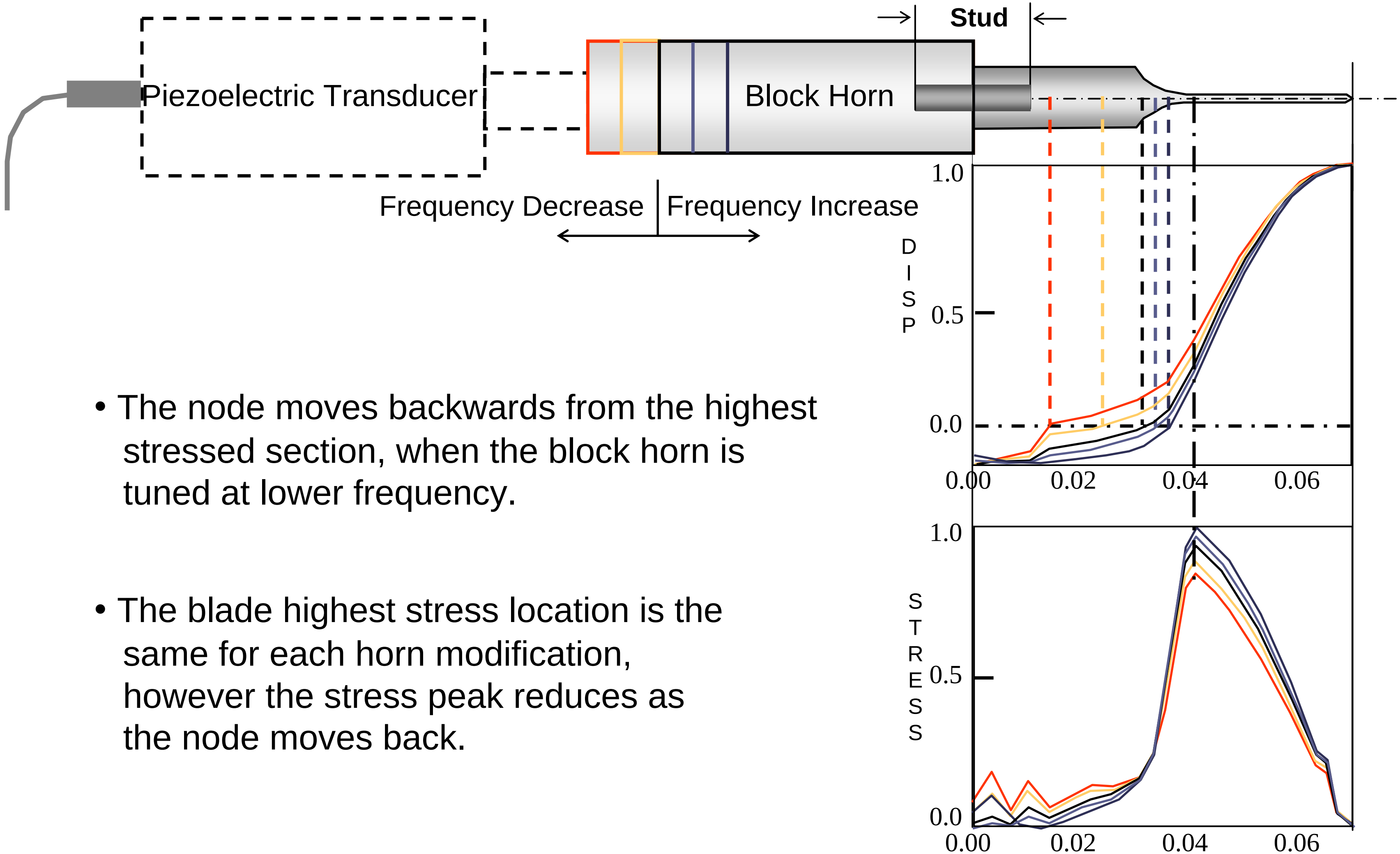
High Gain Blade



- In a cylindrical horn the longitudinal node corresponds to the highest stressed section.

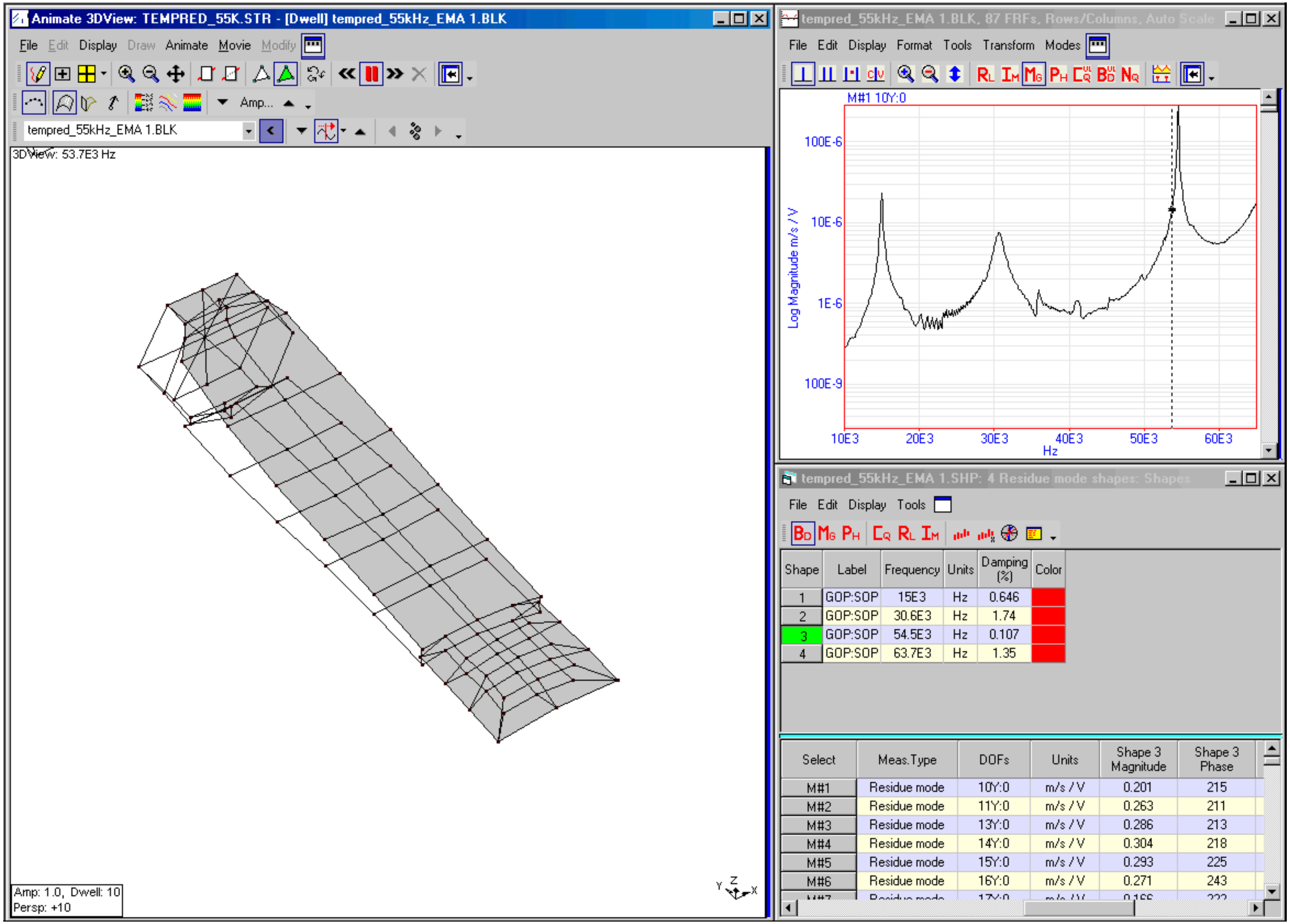
- The highest stress occurs at the end of the blade tapering because of the steep section reduction.

Reducing Stress - Moving the Nodal Position



- The node moves backwards from the highest stressed section, when the block horn is tuned at lower frequency.
- The blade highest stress location is the same for each horn modification, however the stress peak reduces as the node moves back.

LDV modal analysis of cutting blades



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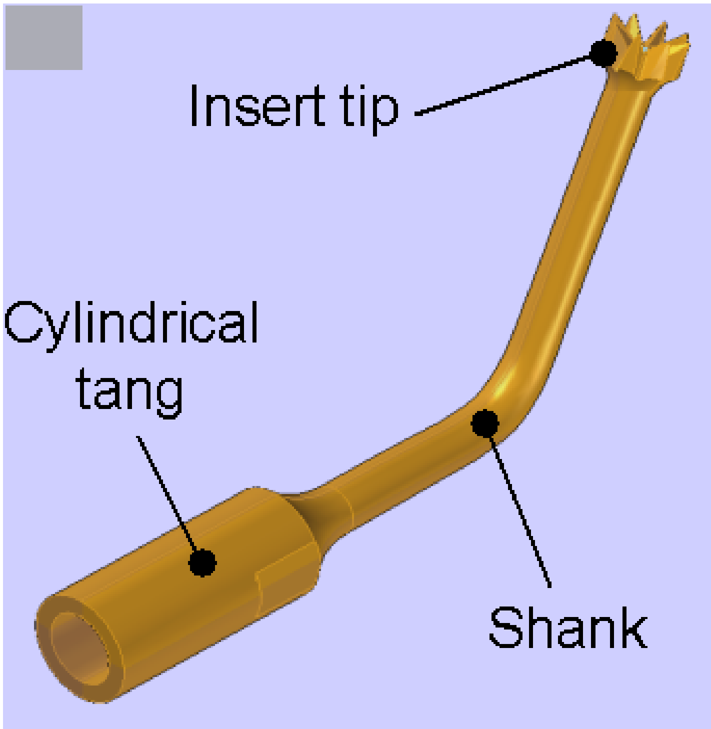
Ultrasonic Bone Cutting System

Mectron ultrasonic osteotome

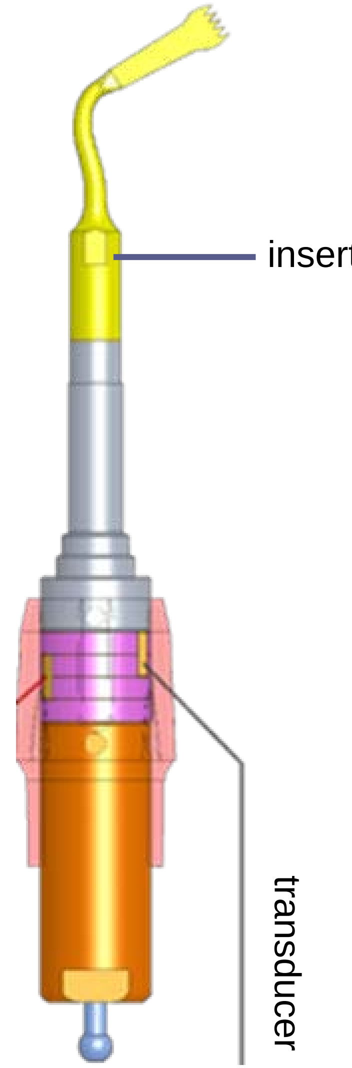
Hand-piece with cutting insert

Ultrasonic cutting inserts (Mectron tips)

Ultrasonic Inserts

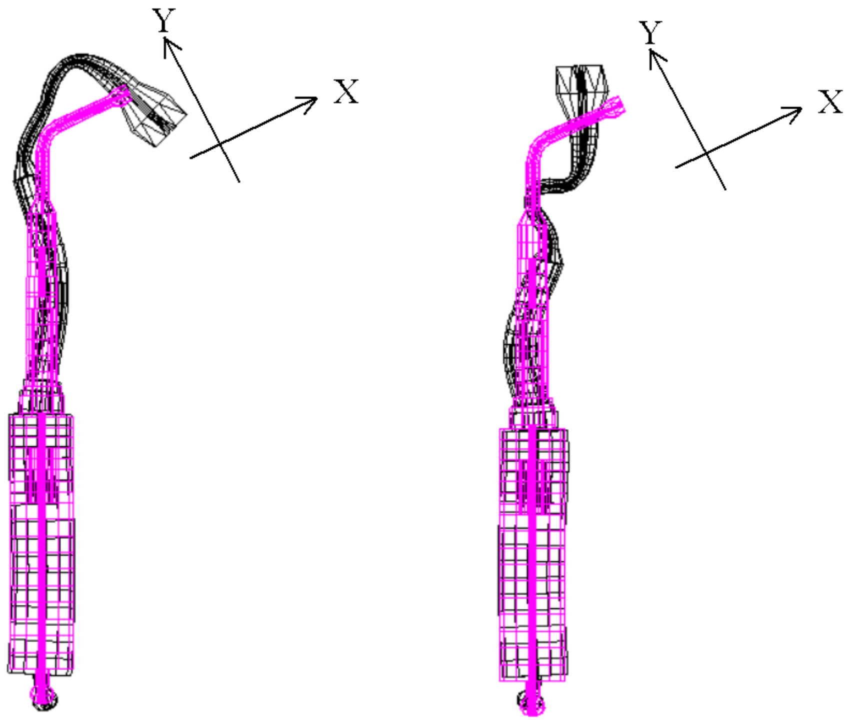


Insert for implantology



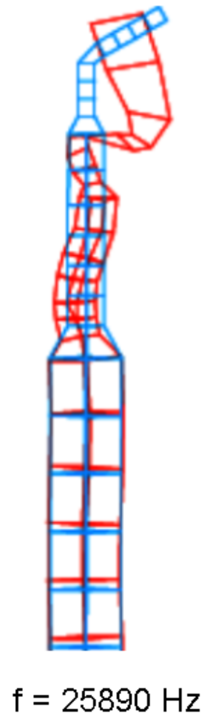
Insert for bone cutting

Experimental and FE Modal Analysis



FE predictions for the nominal mode

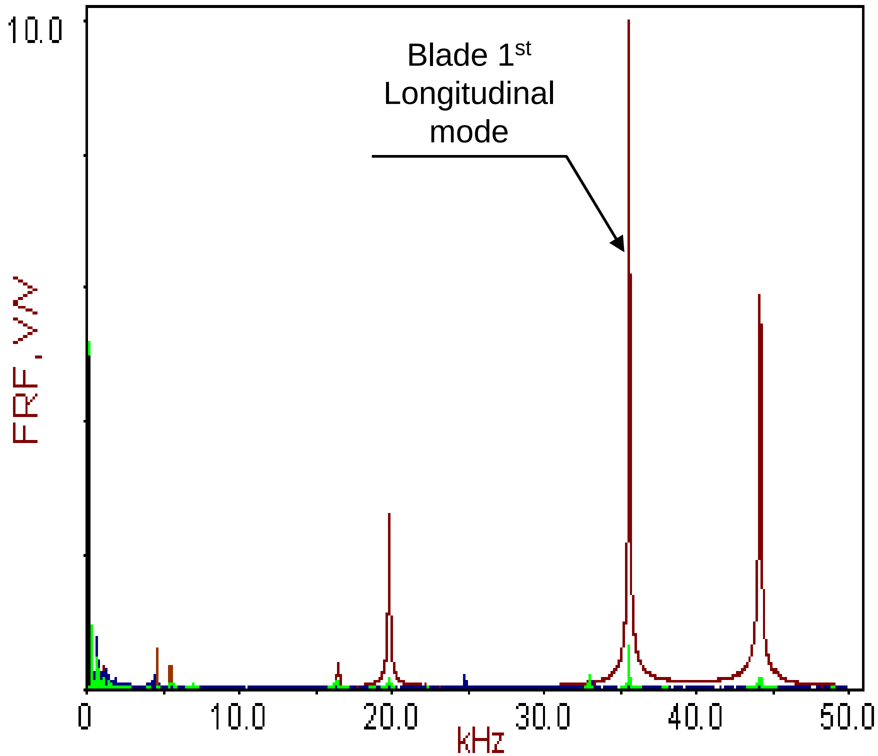
f = 25615 Hz



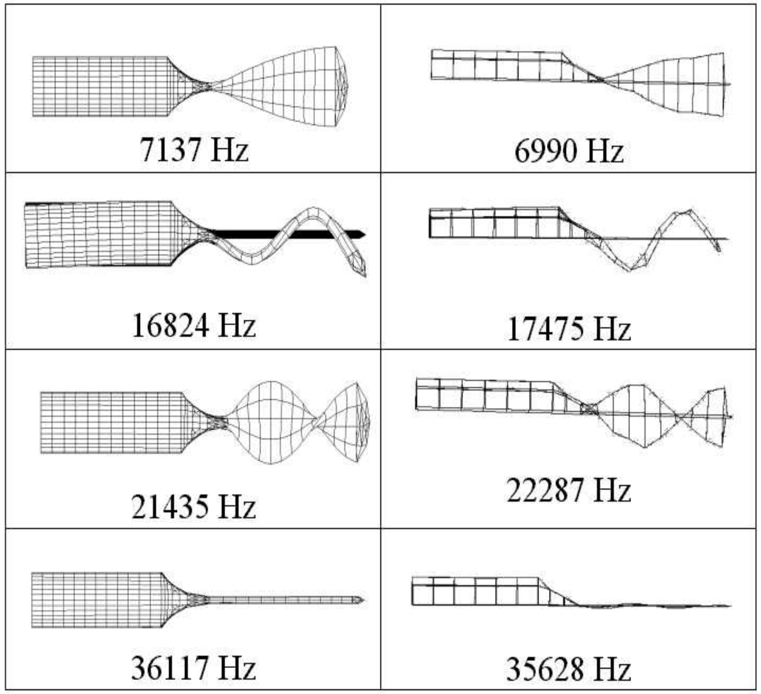
EMA using 3D LDV: nominal mode

f = 25890 Hz

Experimental and FE modal analysis

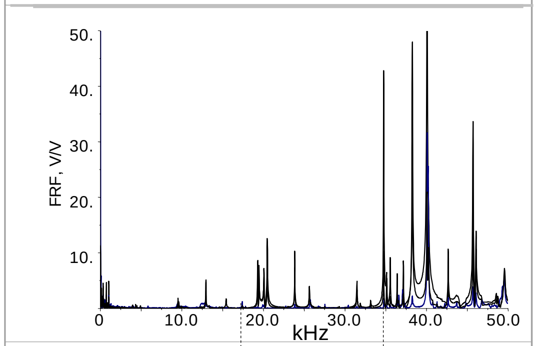


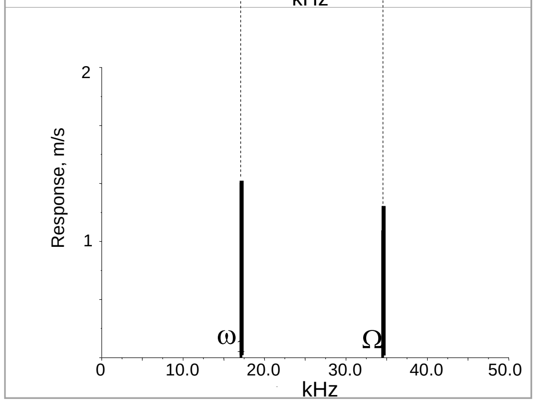
FRF from transducer-blade assembly measured using 3D laser vibrometer



FE predicted and EMA measured blade modes of vibration

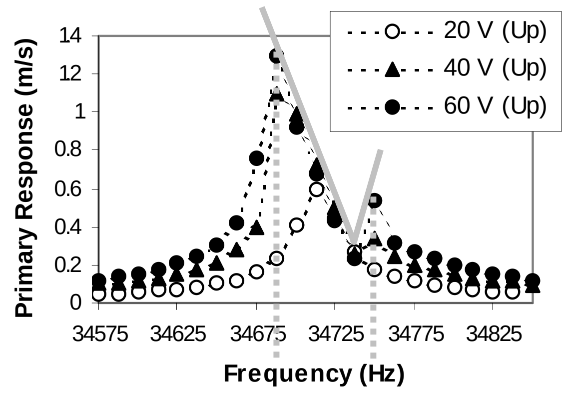
Principal parametric resonance

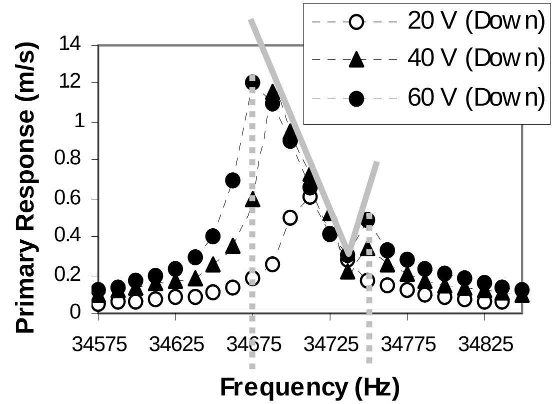




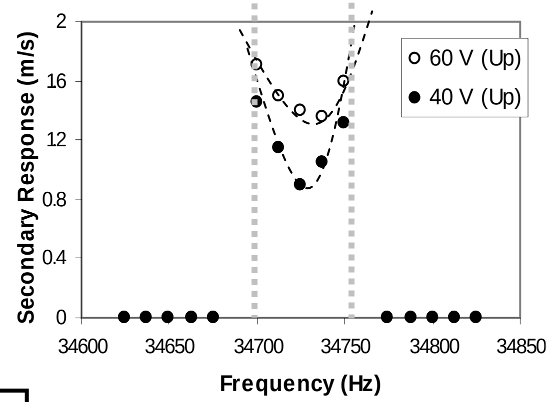
Principal parametric resonance: $\Omega \approx 2\omega$

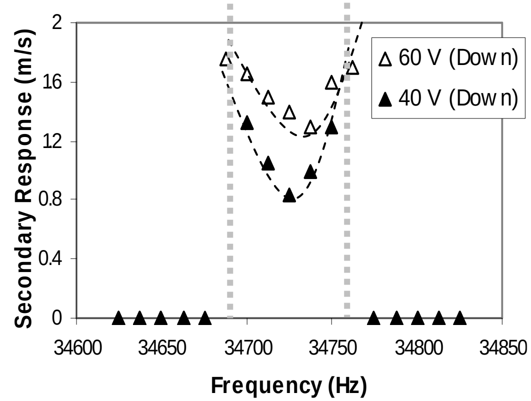
• Primary response measured at three excitation levels



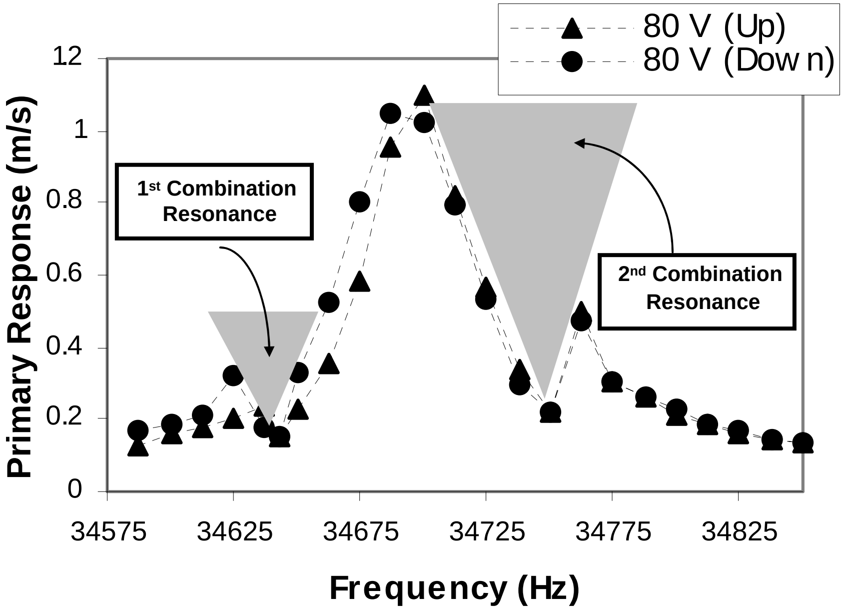


• Secondary response measured at two excitation levels

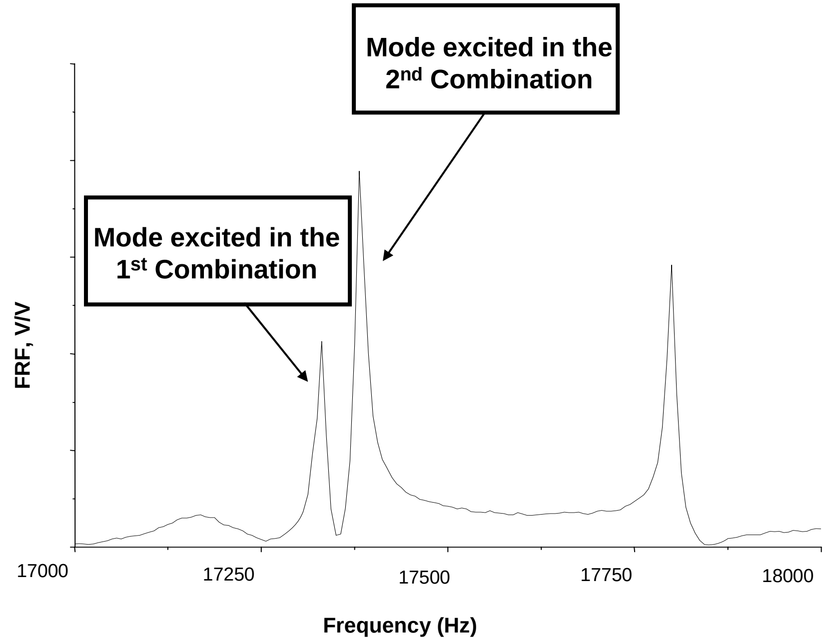




Double principal parametric resonance



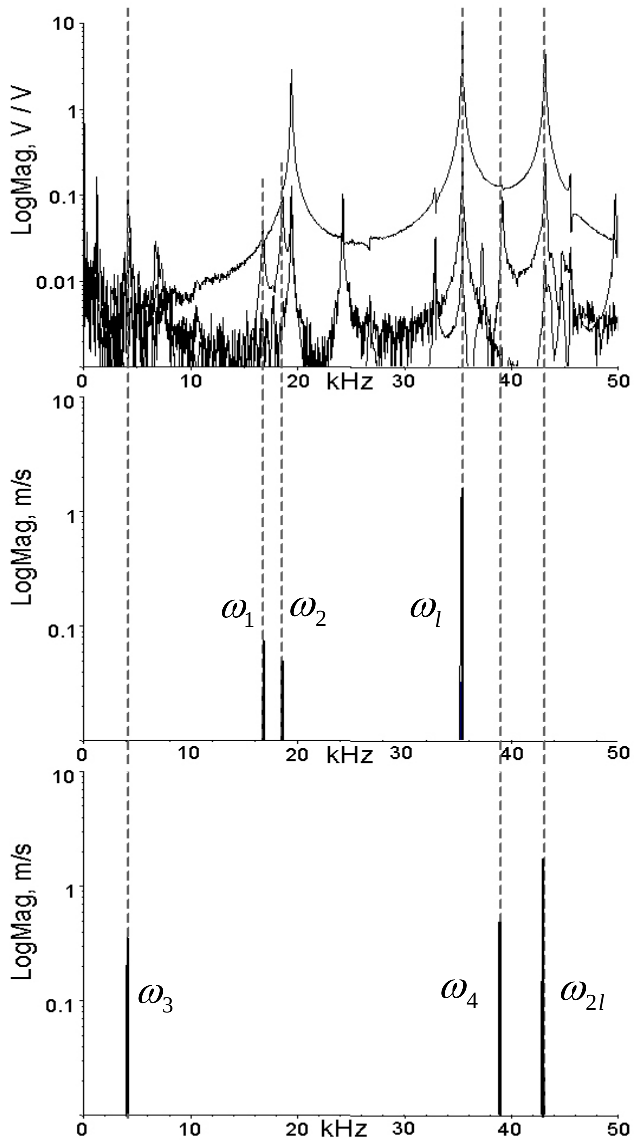
Two v-regions in two distinct frequency bands of the primary response indicate that the excitation level threshold for two modal couplings is reached.



The first combination resonance has a higher excitation level threshold and is weakly coupled.

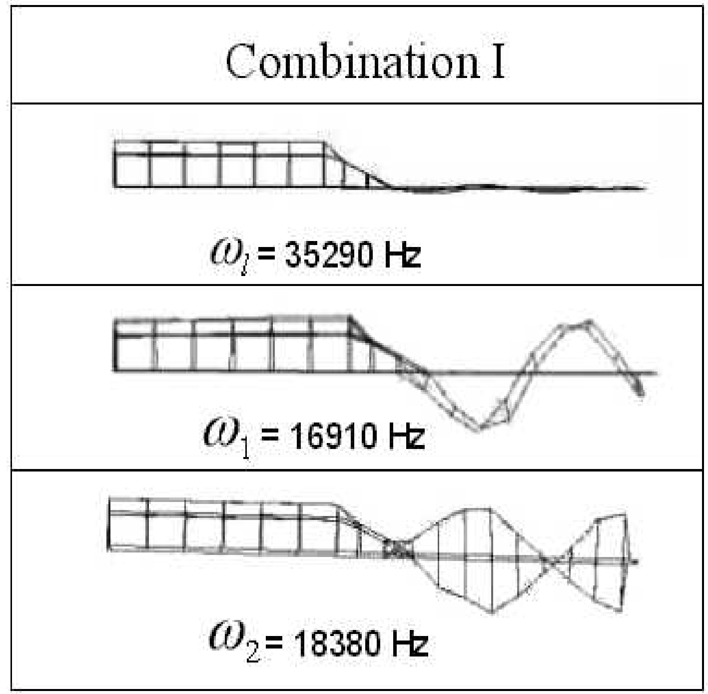
The second combination has a lower excitation level threshold and is strongly coupled.

Parametrically excited combination resonances



- **System driven at 35.29 kHz**

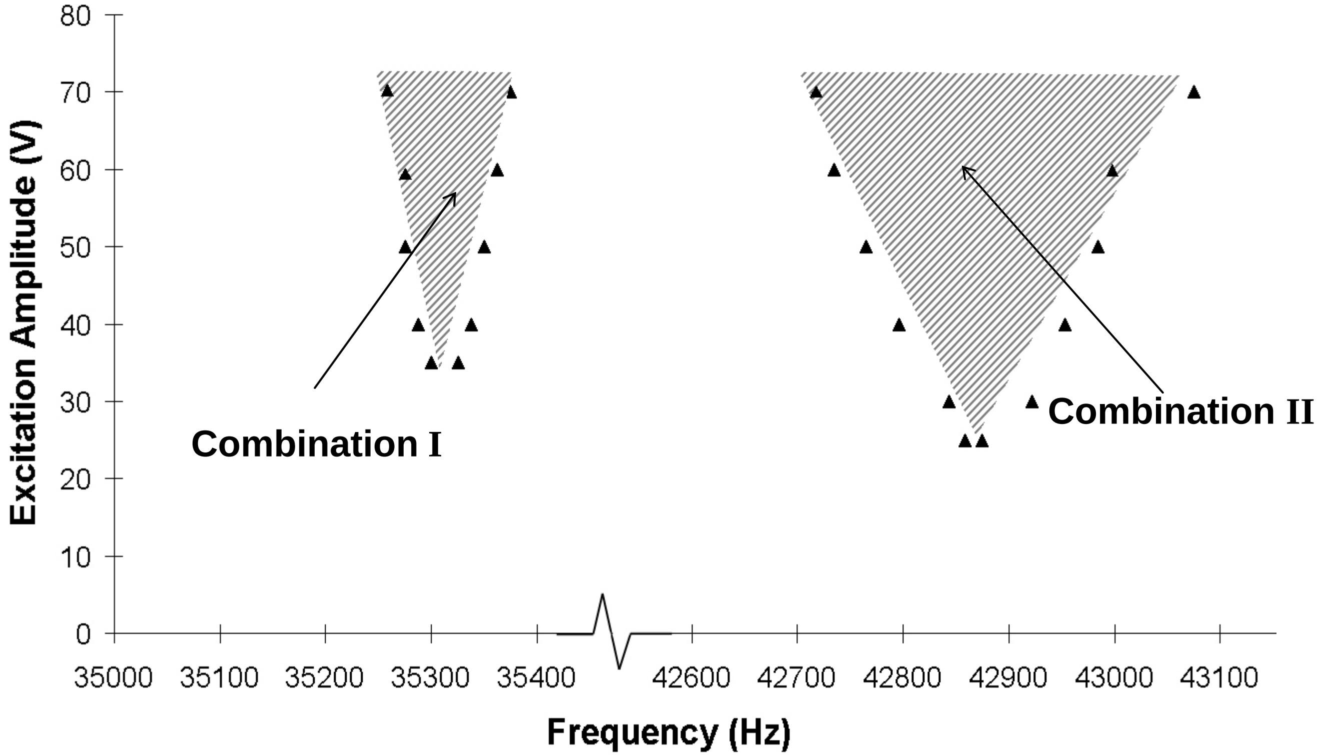
  Combination I: $\omega_l \approx \omega_1 + \omega_2$



- **System driven at 43.1 kHz**

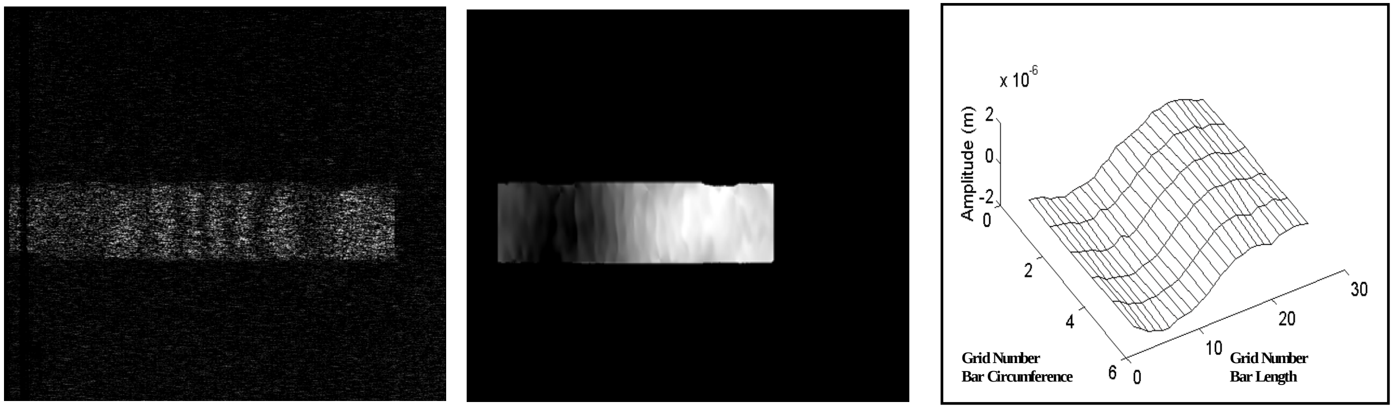
  Combination II: $\omega_{2l} \approx \omega_3 + \omega_4$

Stability regions

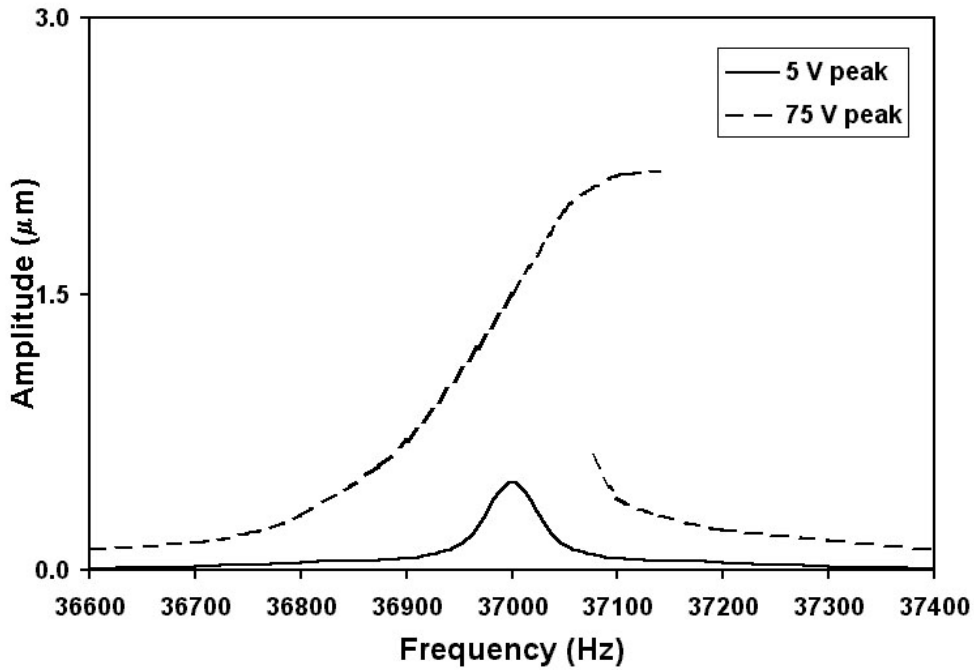


For the single blade system, mode combination II has a lower threshold and wider unstable region

Nonlinear response by in-plane ESPI

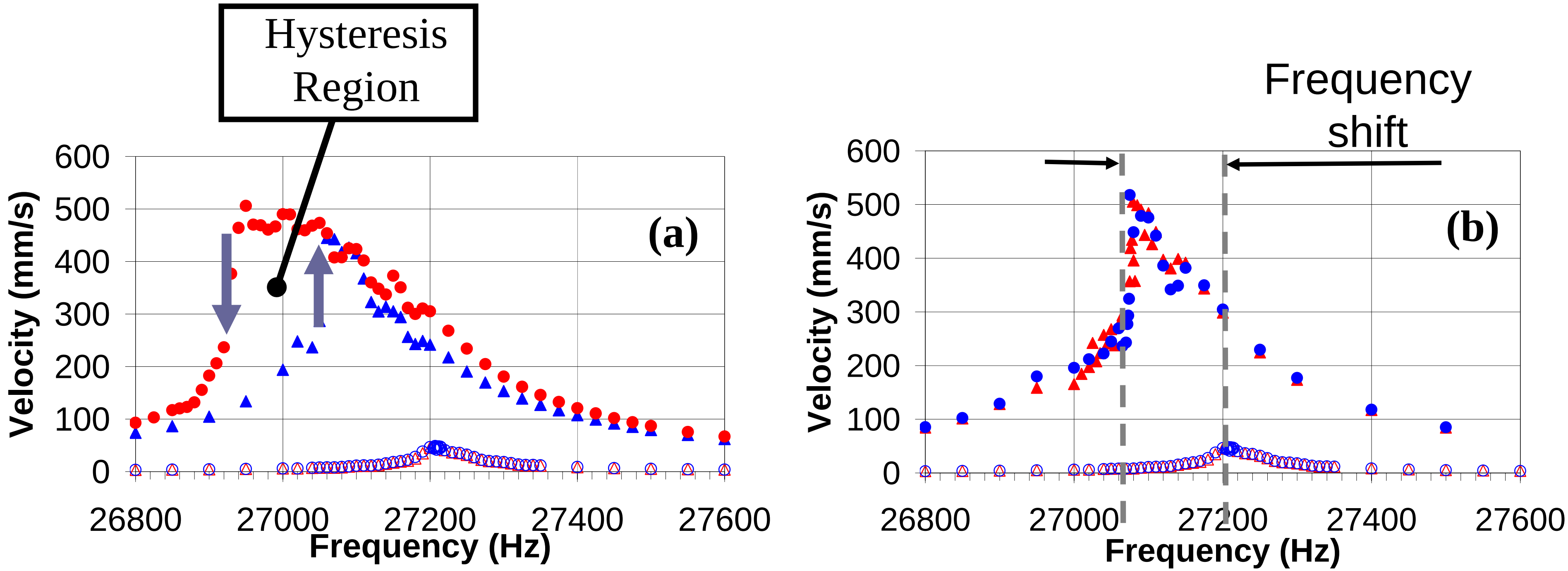


ESPI measured horizontal-in-plane response of an ultrasonic horn



ESPI measured in-plane nonlinear response of an ultrasonic cutting blade

Removal of thermal effects

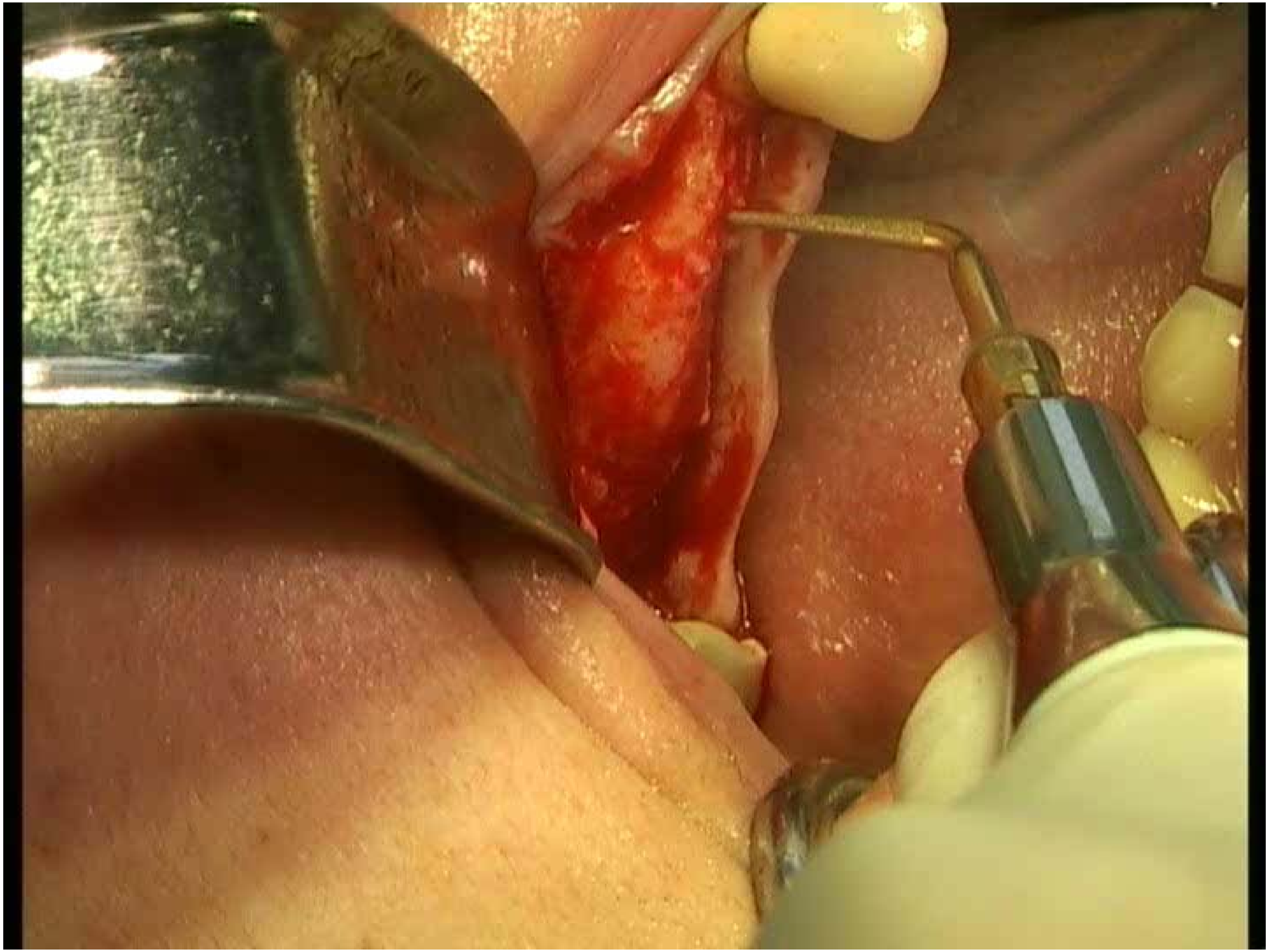


Sweep Up 5V
Sweep Down 5V
Sweep Up 100V
Sweep Down 100V

Mectron Transducer connected to cutting insert

(a) Continuous excitation (b) One-second long excitation with cooling

Ultrasonic Implant Surgery



THANK-YOU

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