University of Glasgow

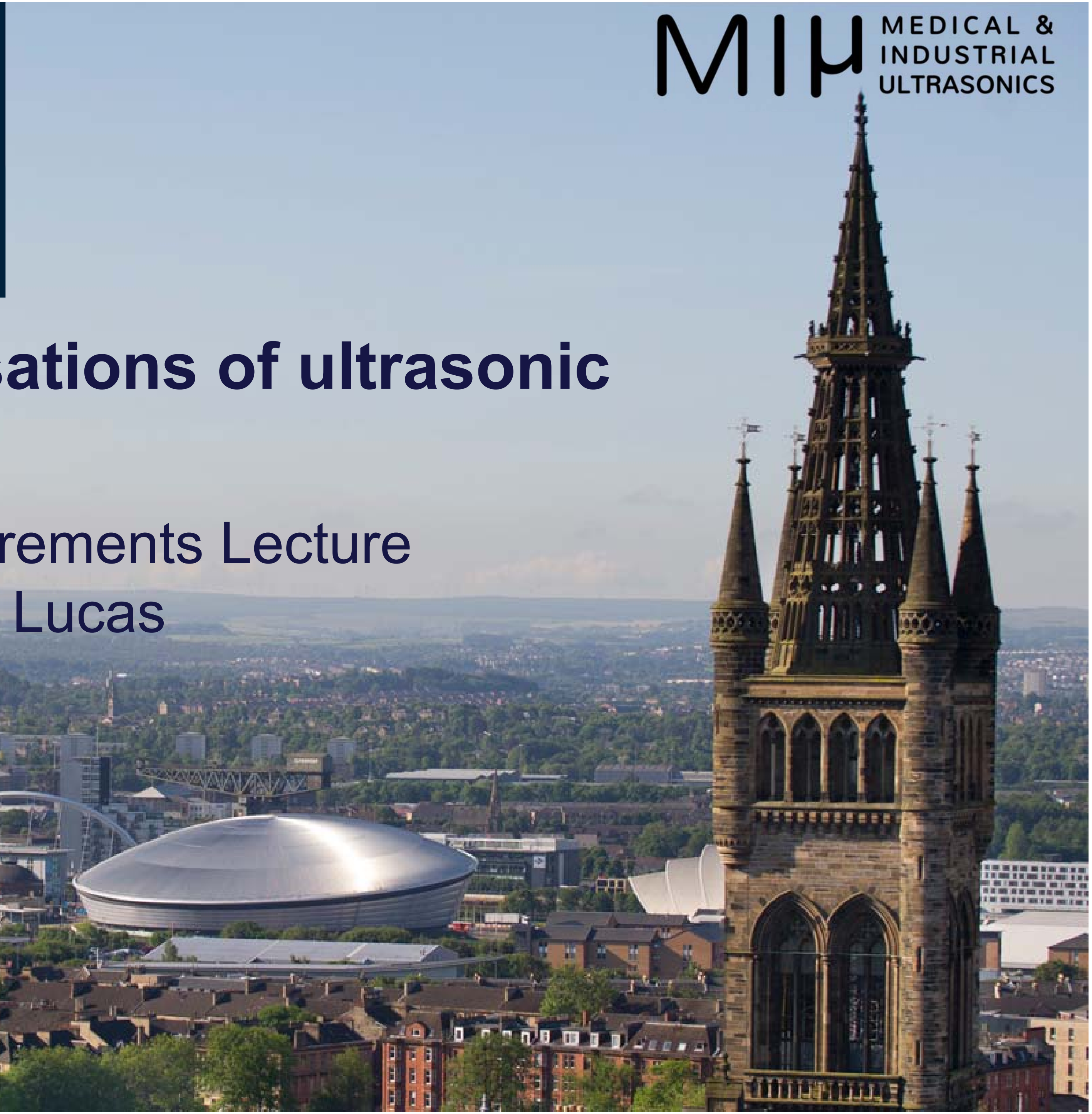
School of Engineering

MEDICAL & INDUSTRIAL ULTRASONICS

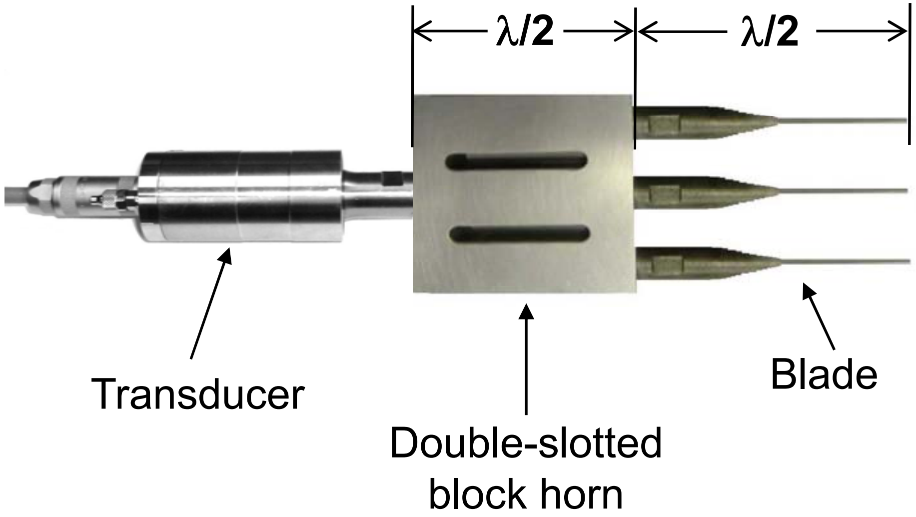
Characterisations of ultrasonic devices

BSSM Measurements Lecture

Prof Margaret Lucas



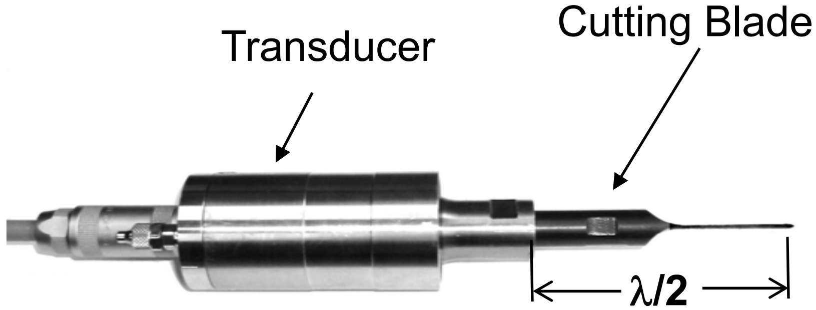
In the beginning there was Violet Crumble



- Violet Crumble was a friable sugar honeycomb bar that easily shattered when cut into bars
- Product wastage was as high as 40%
- Ultrasonically excited resonant cutting devices were able to cut with better accuracy and minimal waste
- But ……………
- Blade failures were common

…… and then came surgical devices

- In their simplest form, they are simply single-blade cutting device
- that also suffer from modal interactions
- But we also started to characterise other nonlinear behaviours



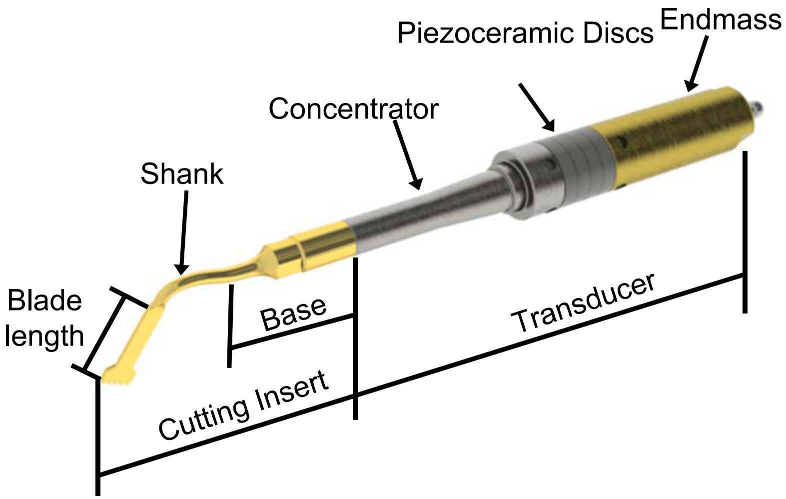
50kHz tuned ultrasonic cutting blade and handpiece

Ultrasonic cutting inserts (Mectron tips)

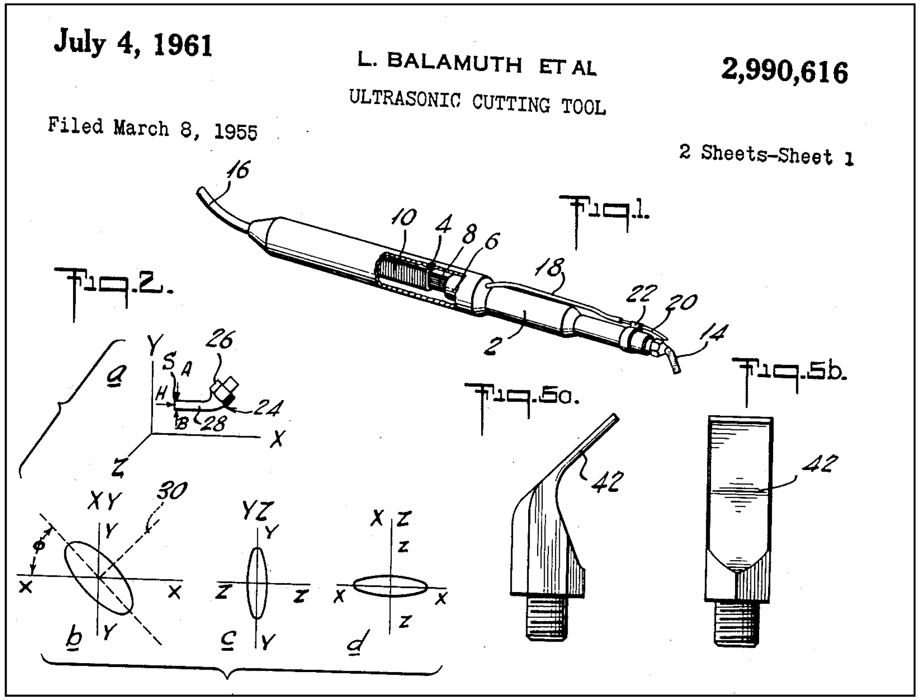
Ultrasonics in bone surgery

In the 1950's Lewis Balamuth proposed and patented a cutting tool for "ultrasonic dental cutting operations".

2001 saw the first commercial device designed for bone cutting applications: Piezosurgery® from Mectron SpA.

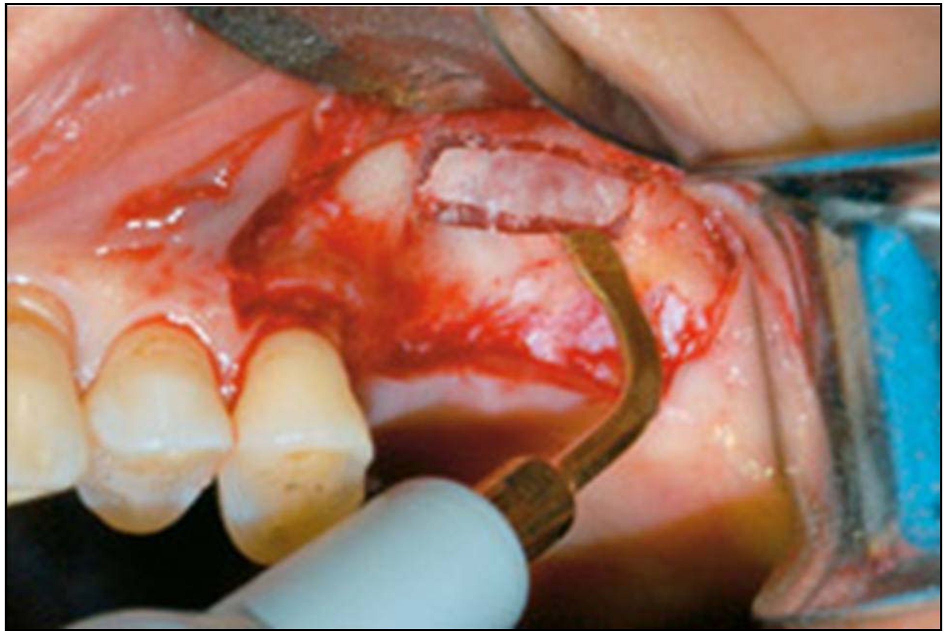


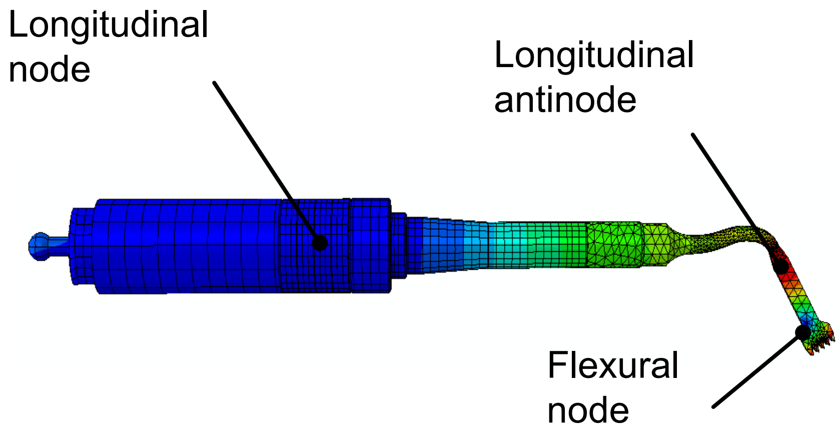
Piezosurgery® Device, courtesy of Mectron SpA

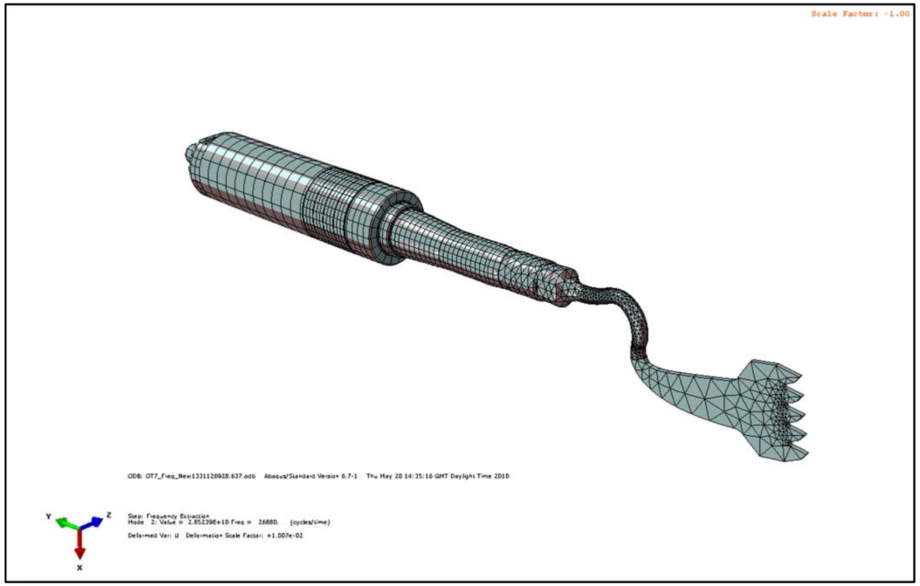


Ultrasonics in bone surgery

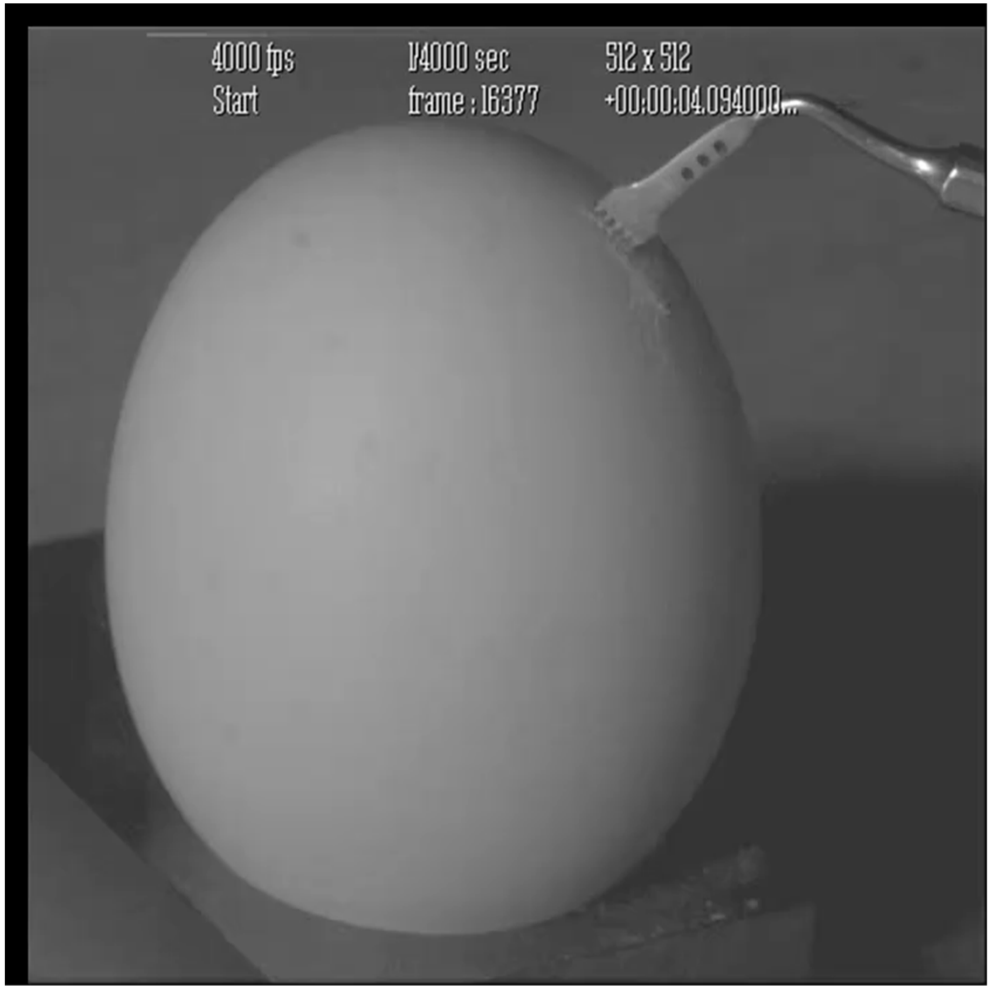
Bone cutting combining a longitudinal-flexural vibration allows delicate and accurate bone cuts without damage to soft tissue structures.



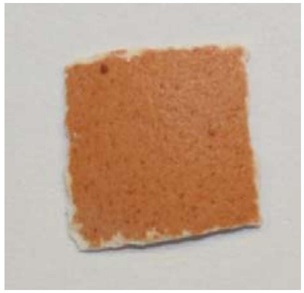


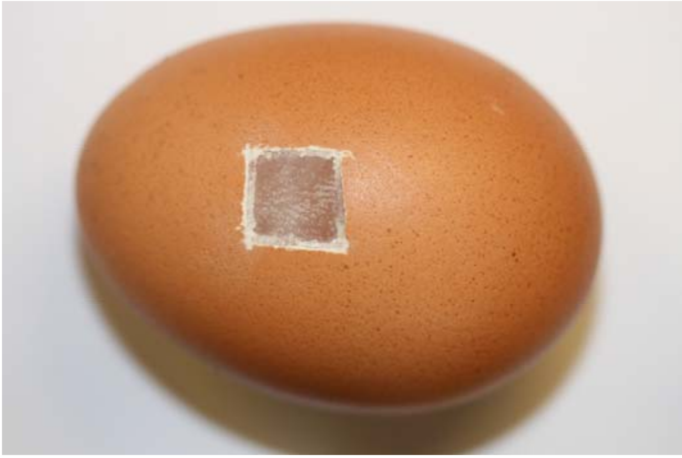


Device precision and selectivity



Window cut in egg – membrane intact

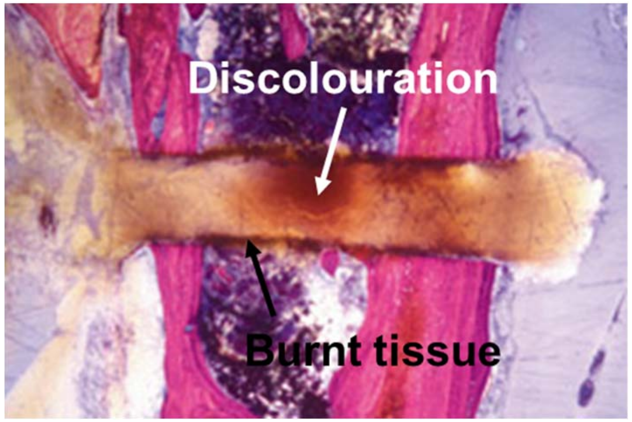


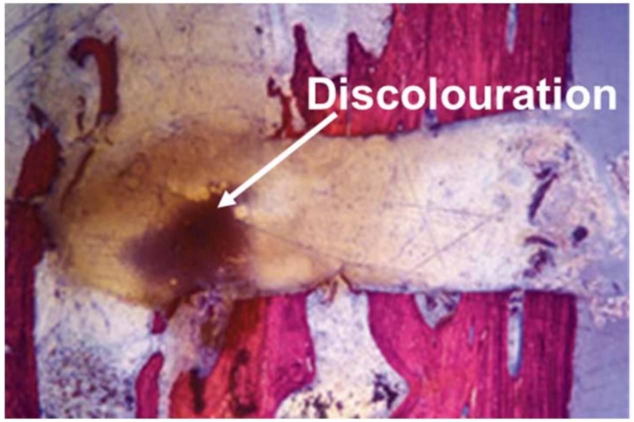


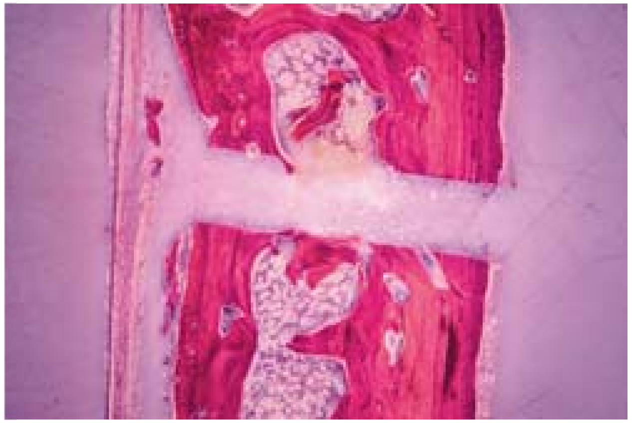
Mectron transducer with OT7 cutting insert

Clinical procedures: Osteotomy

Comparison with traditional cutting methods







Images courtesy of Mectron S.p.A

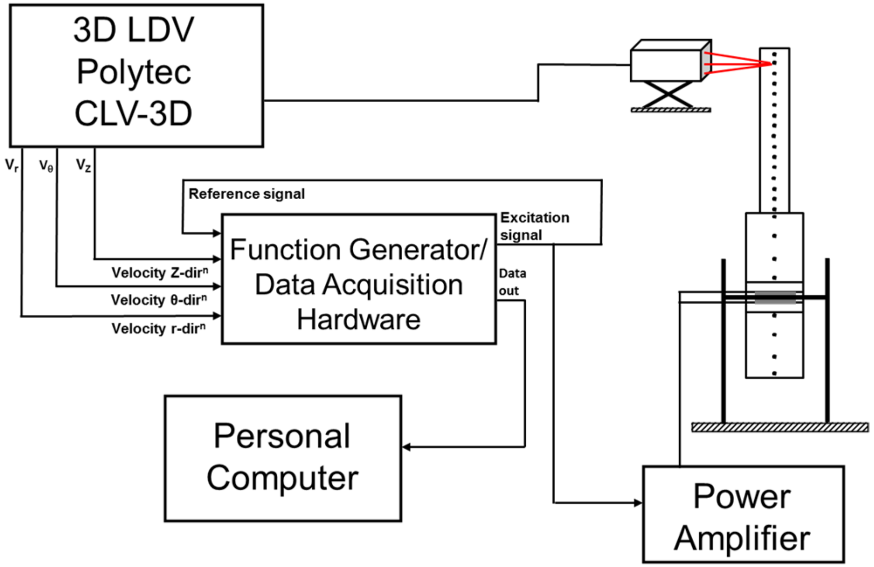
<u>Bone saw</u>

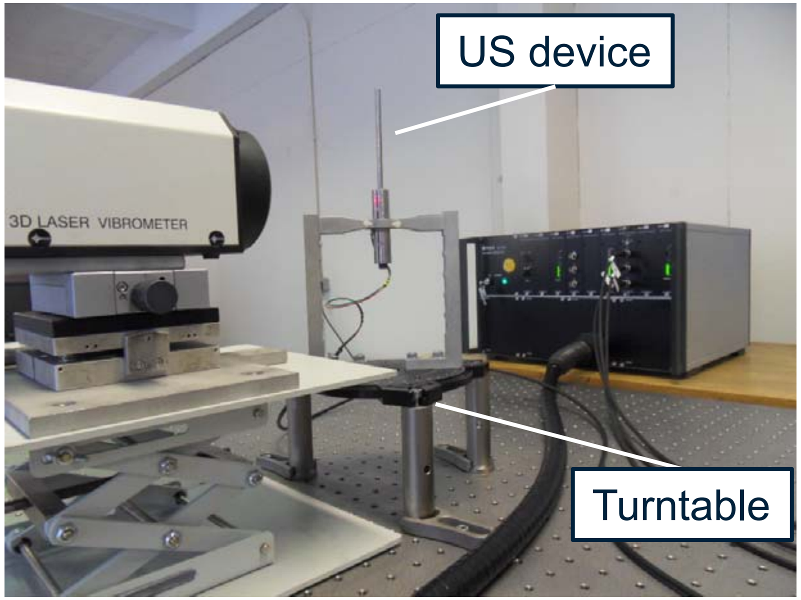
<u>Bone bur</u>

<u>Ultrasonic device</u>
<u>(Piezosurgery® Device)</u>

Representative histologic photomicrographs of decalcified specimens characterising the appearance of the cut edges of osteotomy incisions baseline (original magnification 2.5x, stain hematoxylin-eosin)

The set-up for vibration measurements ….

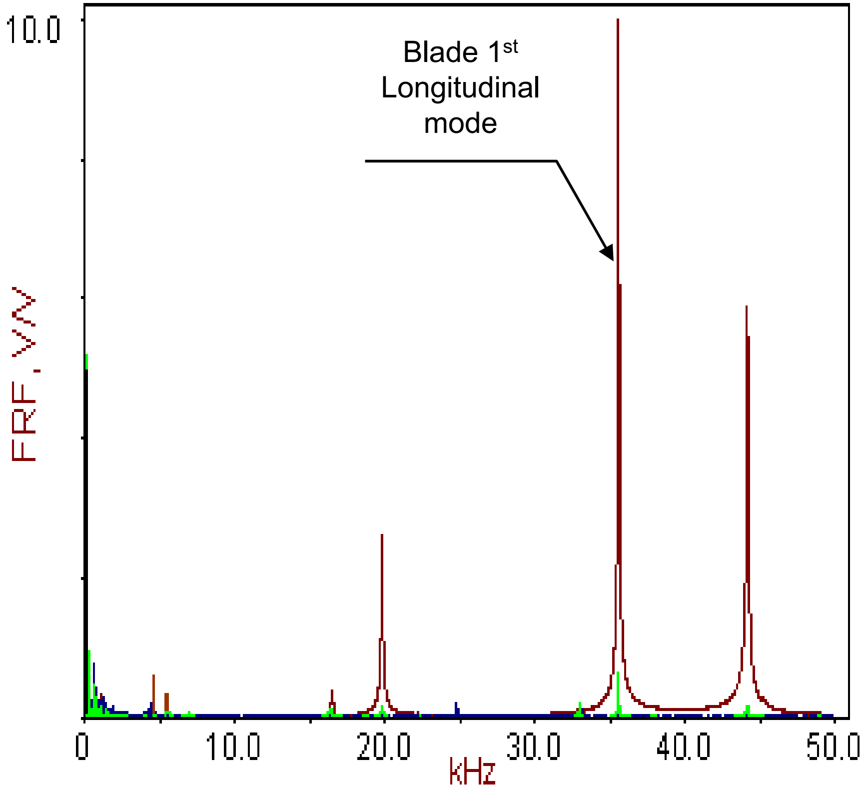




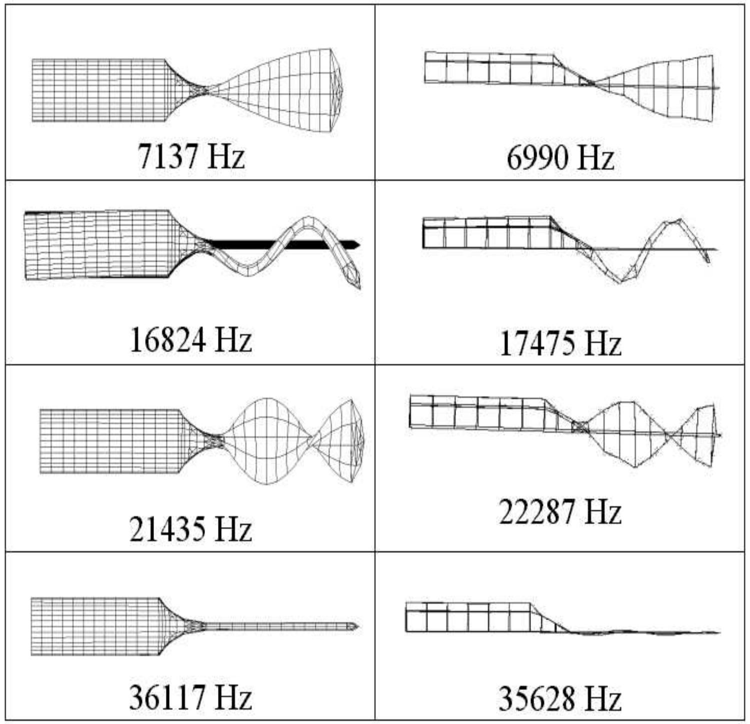
3D and 1D laser Doppler vibrometers allow us to carry out a large number of characterisations of ultrasonic devices:

- Experimental modal analysis
- Operational mode
- Amplitude measurement
- Nonlinear response analysis
- Identification of unstable regions
- Modal interactions

Experimental and FE modal analysis

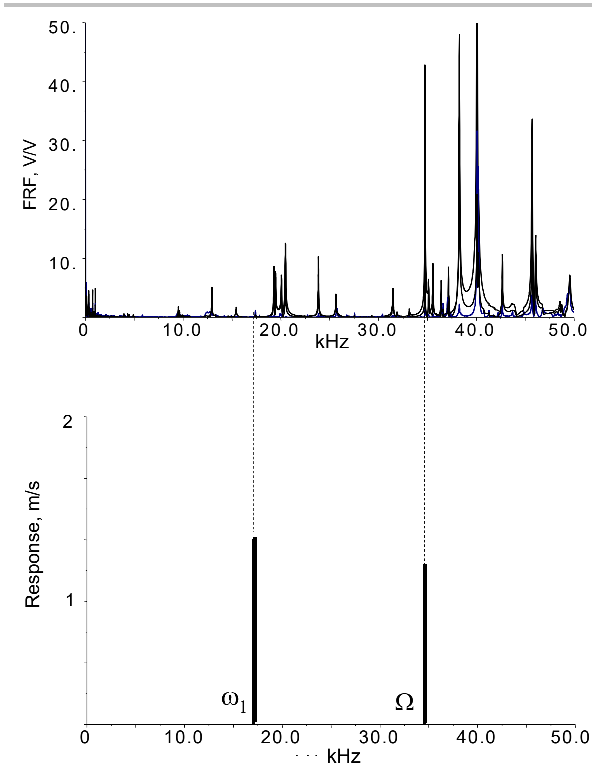


FRF from transducer-blade assembly measured using 3D laser vibrometer

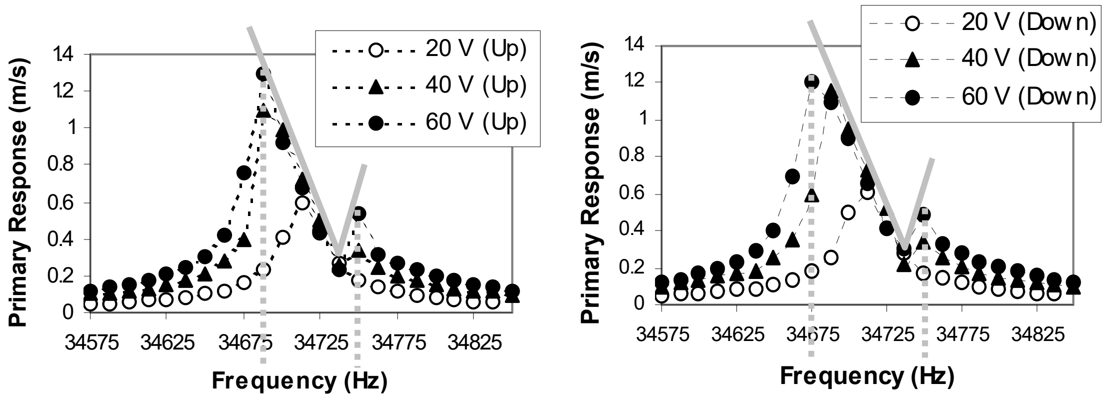


FE predicted and EMA measured blade modes of vibration

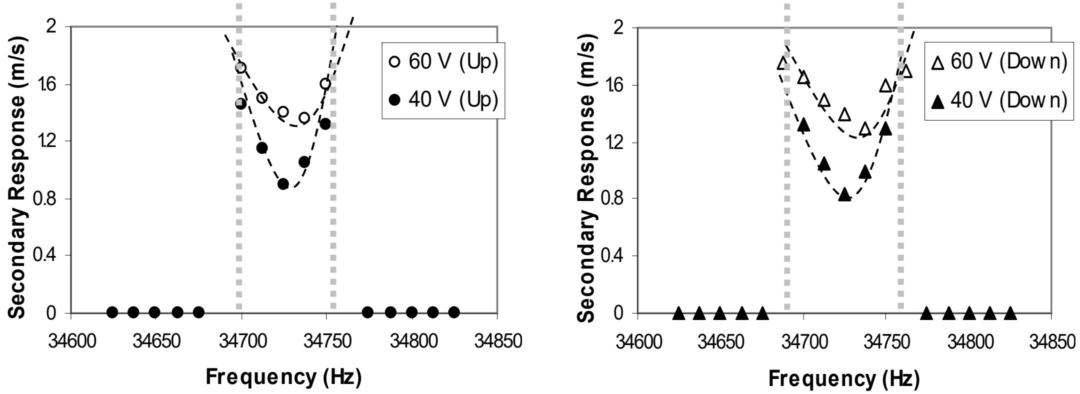
Principal parametric resonance: $\Omega \approx 2\omega_1$



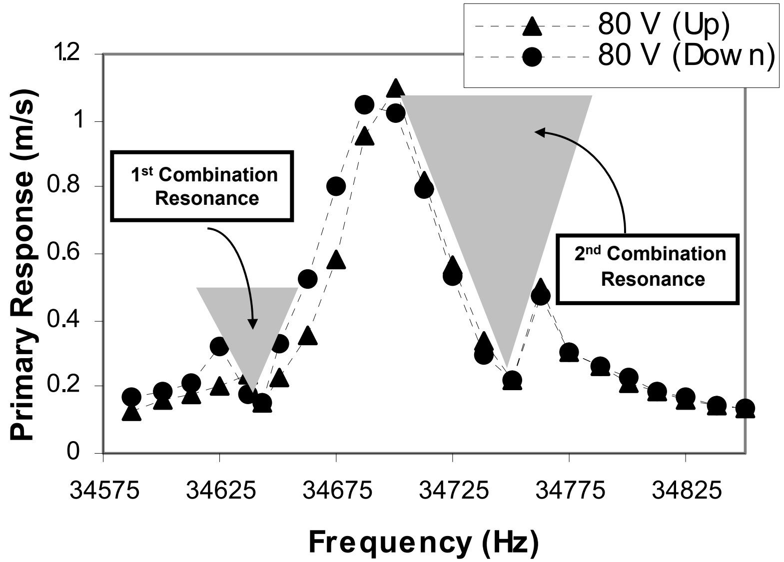
- Primary response measured at three excitation levels



- Secondary response measured at two excitation levels



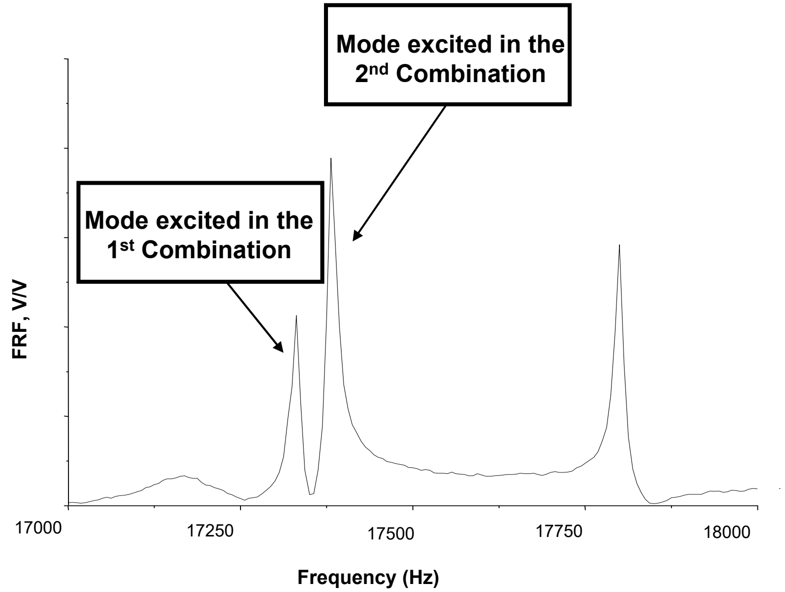
Double principal parametric resonance



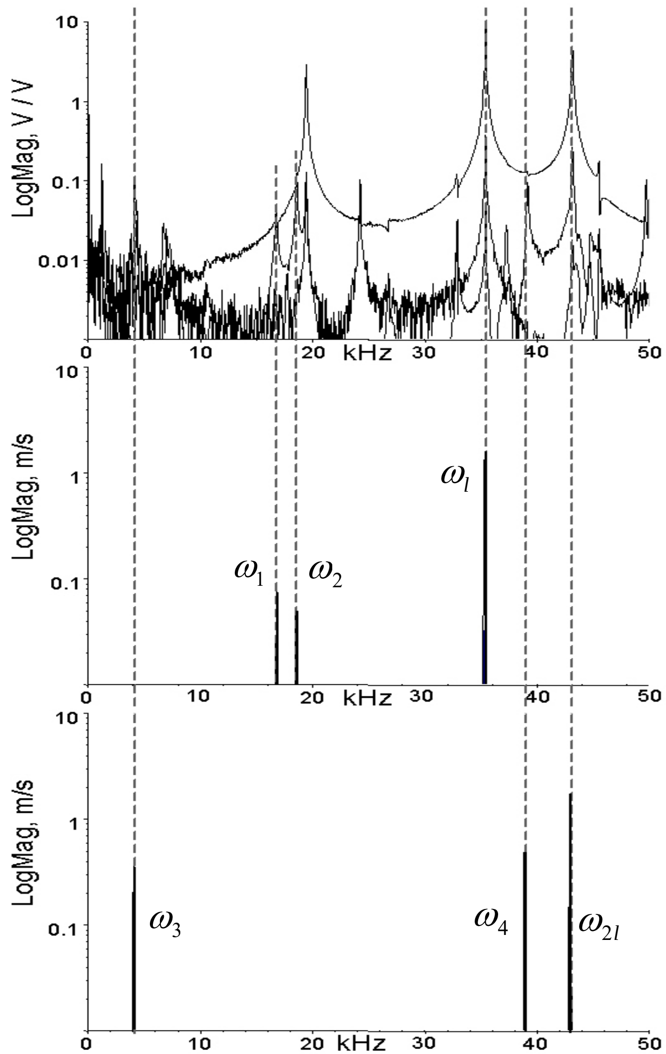
Two v-regions in two distinct frequency bands of the primary response indicate that the excitation level threshold for two modal couplings is reached.

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.

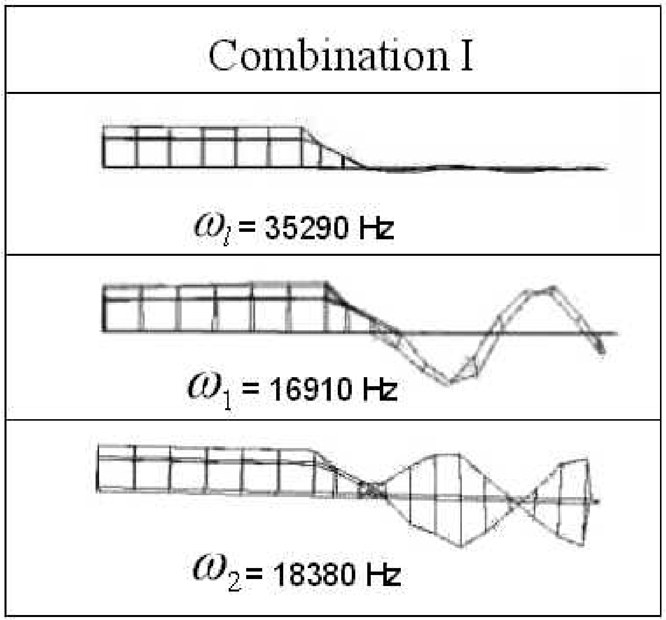


Parametrically excited combination resonances



- **System driven at 35.29 kHz**

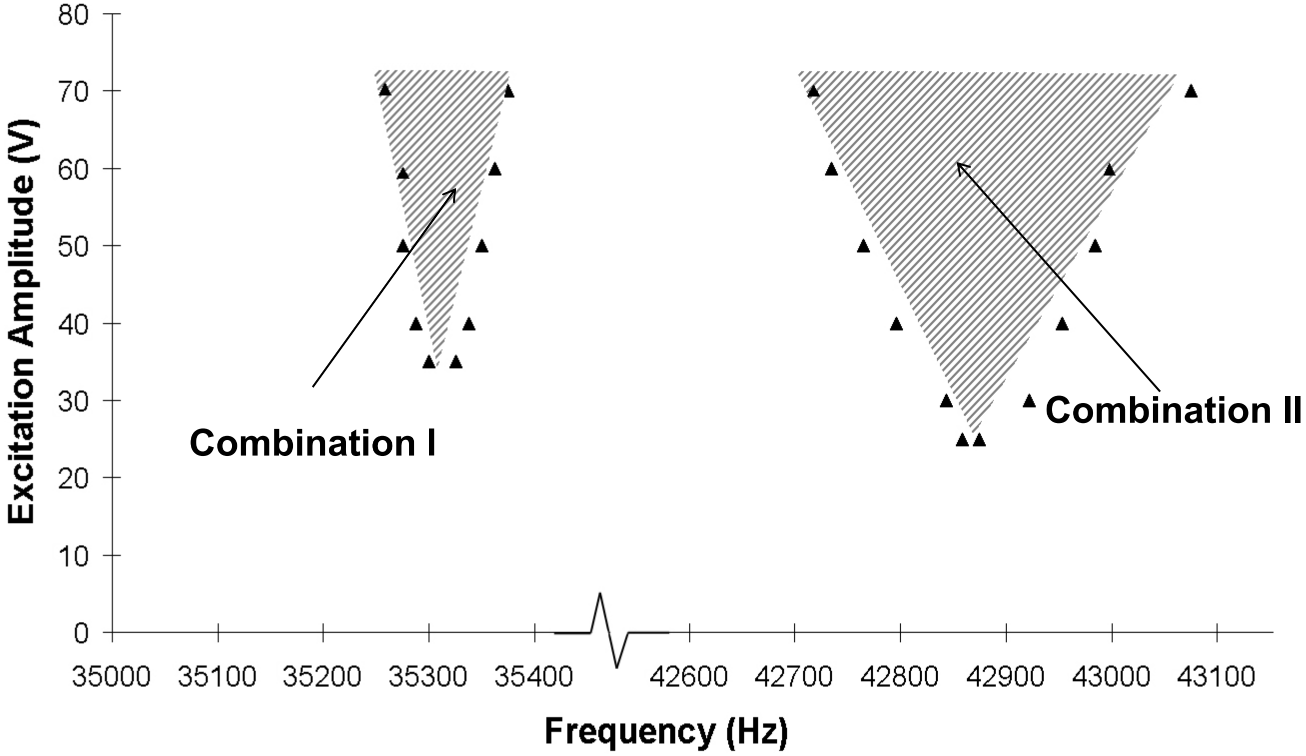
Combination I: $\omega_l \approx \omega_1 + \omega_2$



- **System driven at 43.1 kHz**

Combination II: $\omega_{21} \approx \omega_3 + \omega_4$

Characterising unstable regions

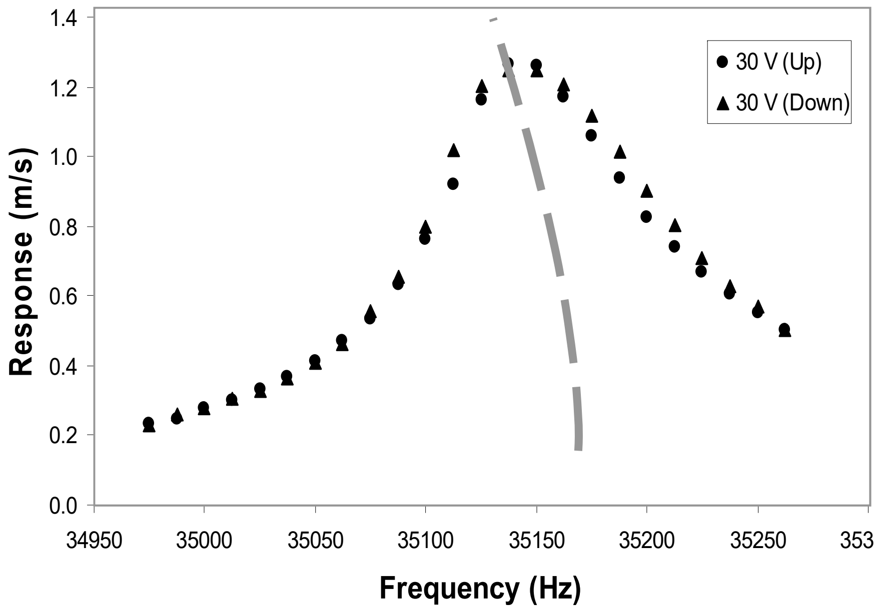


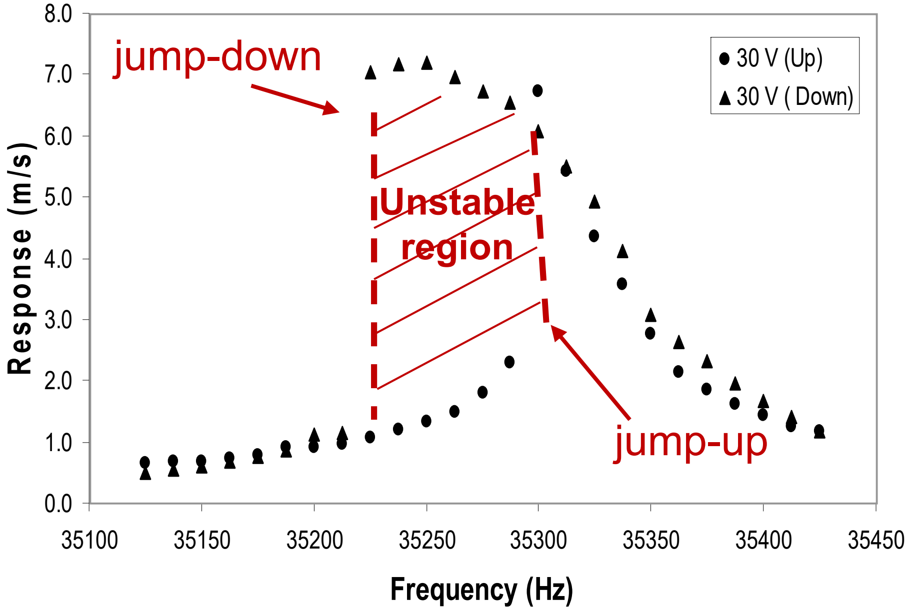
Mode combination II has a lower threshold and wider unstable region

The jump phenomenon

Transducer

Transducer and half wavelength blade system

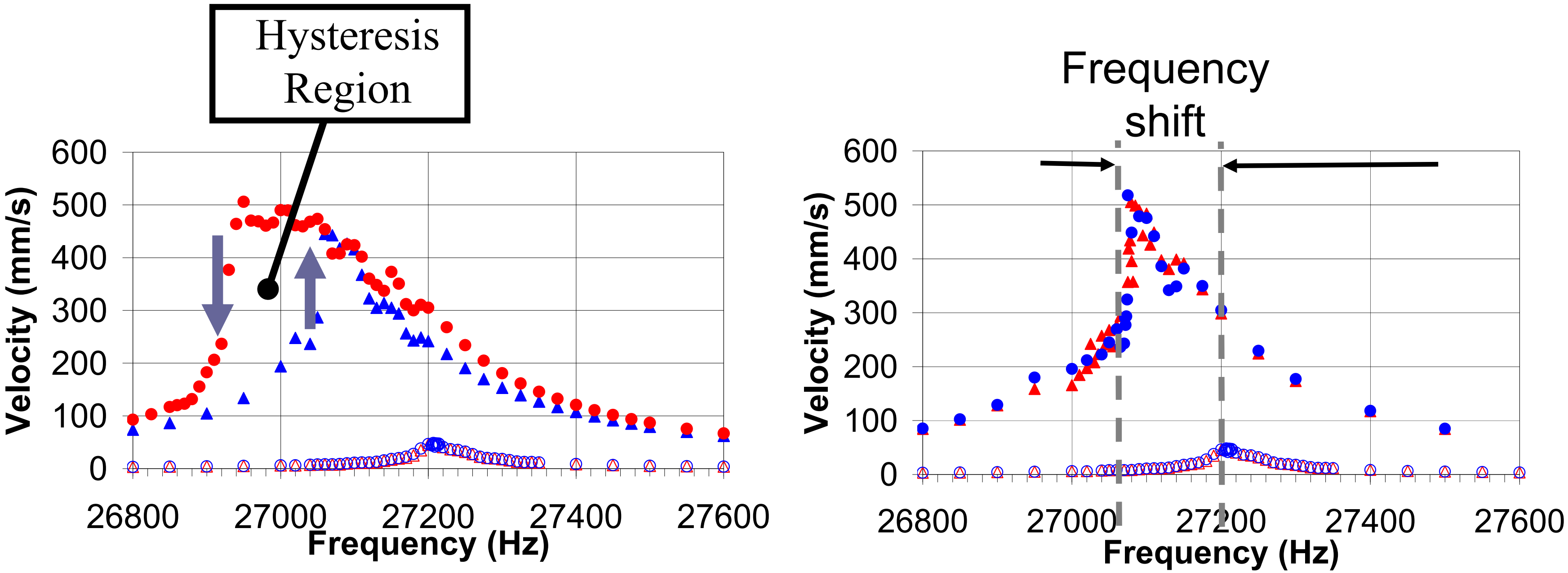




The transducer exhibits a softening characteristic

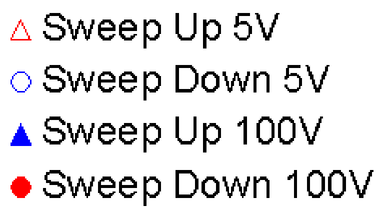
The transducer-blade exhibits a softening response characterised by the jump phenomenon and a wide unstable region

The jump phenomenon and thermal effects



(a) Continuous excitation

(b) Intermittent excitation with cooling

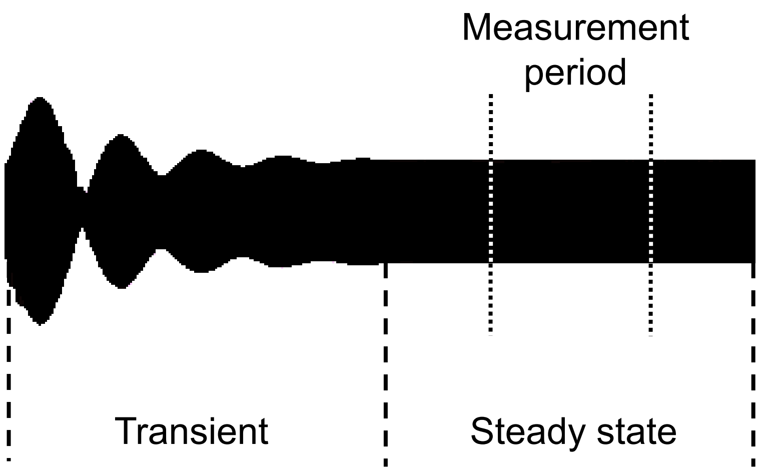


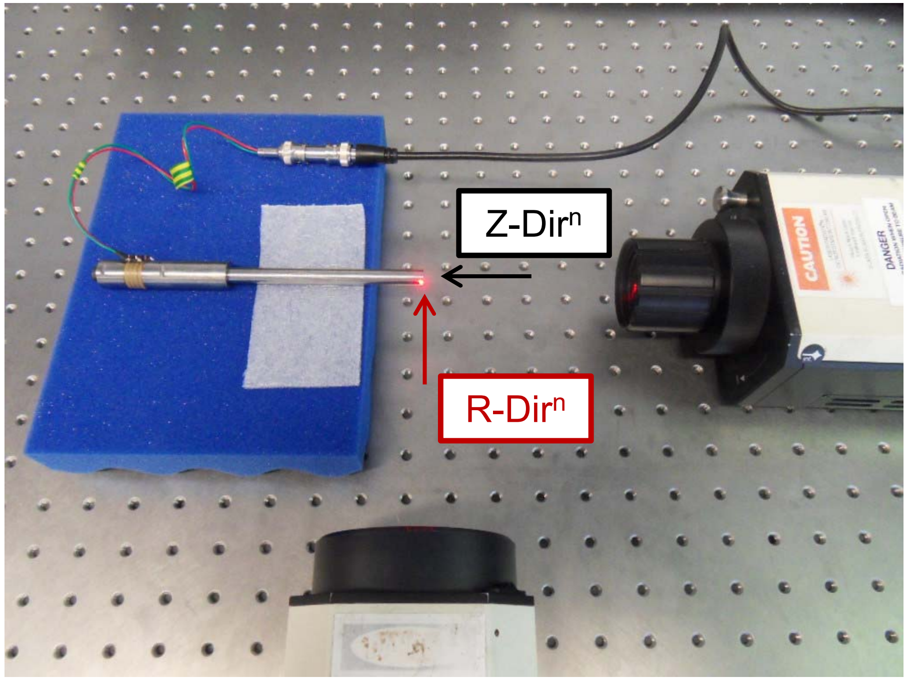
Removing thermal effects

Bidirectional frequency sweep technique

Sine burst

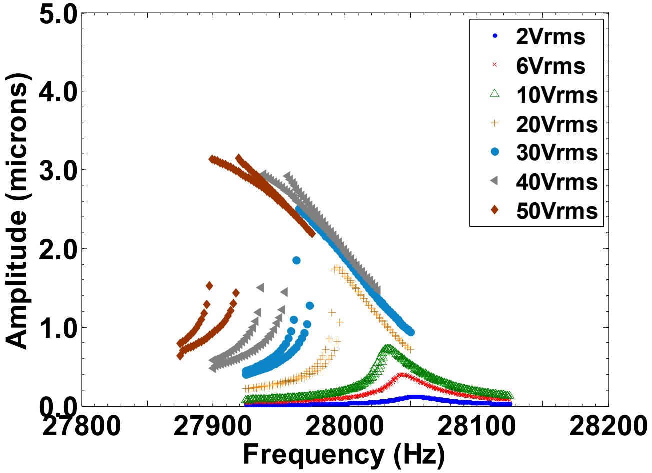
- 4000 cycles
- At 28 kHz, burst length 0.286 seconds
- A time delay between successive bursts

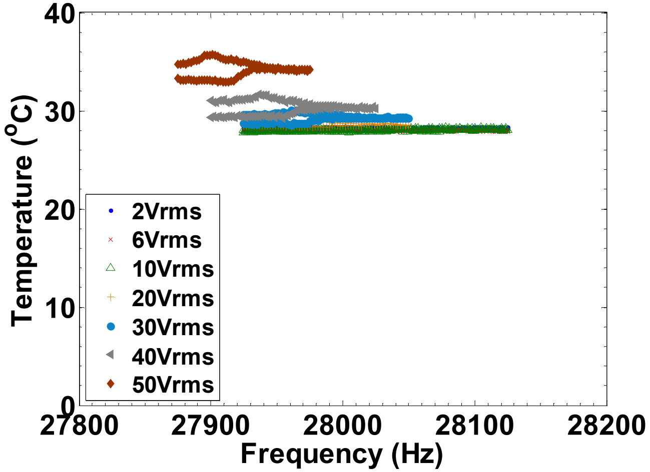




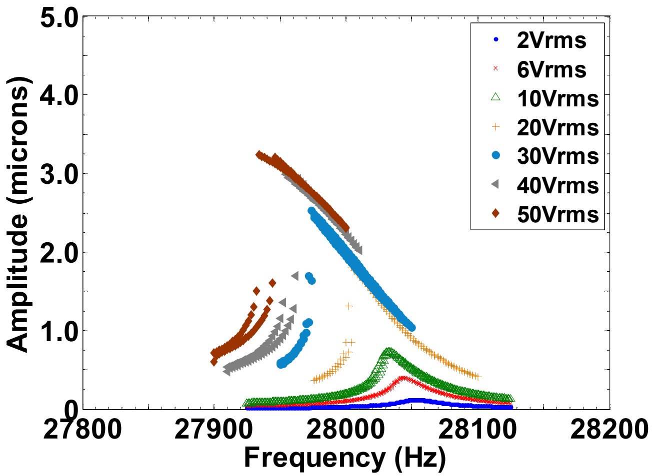
Identifying the delay time between successive bursts

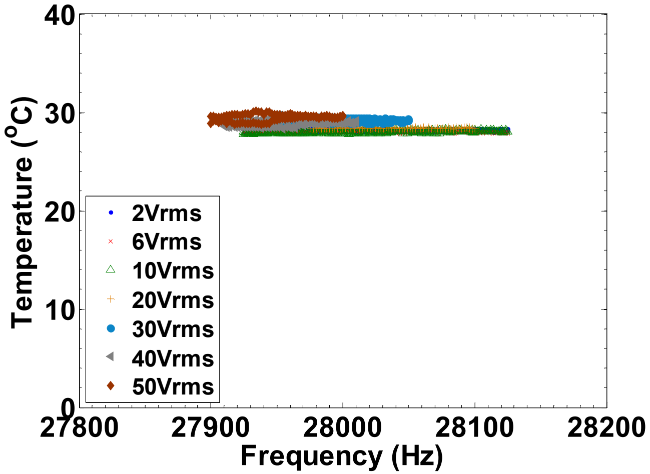
Time delay: 1sec



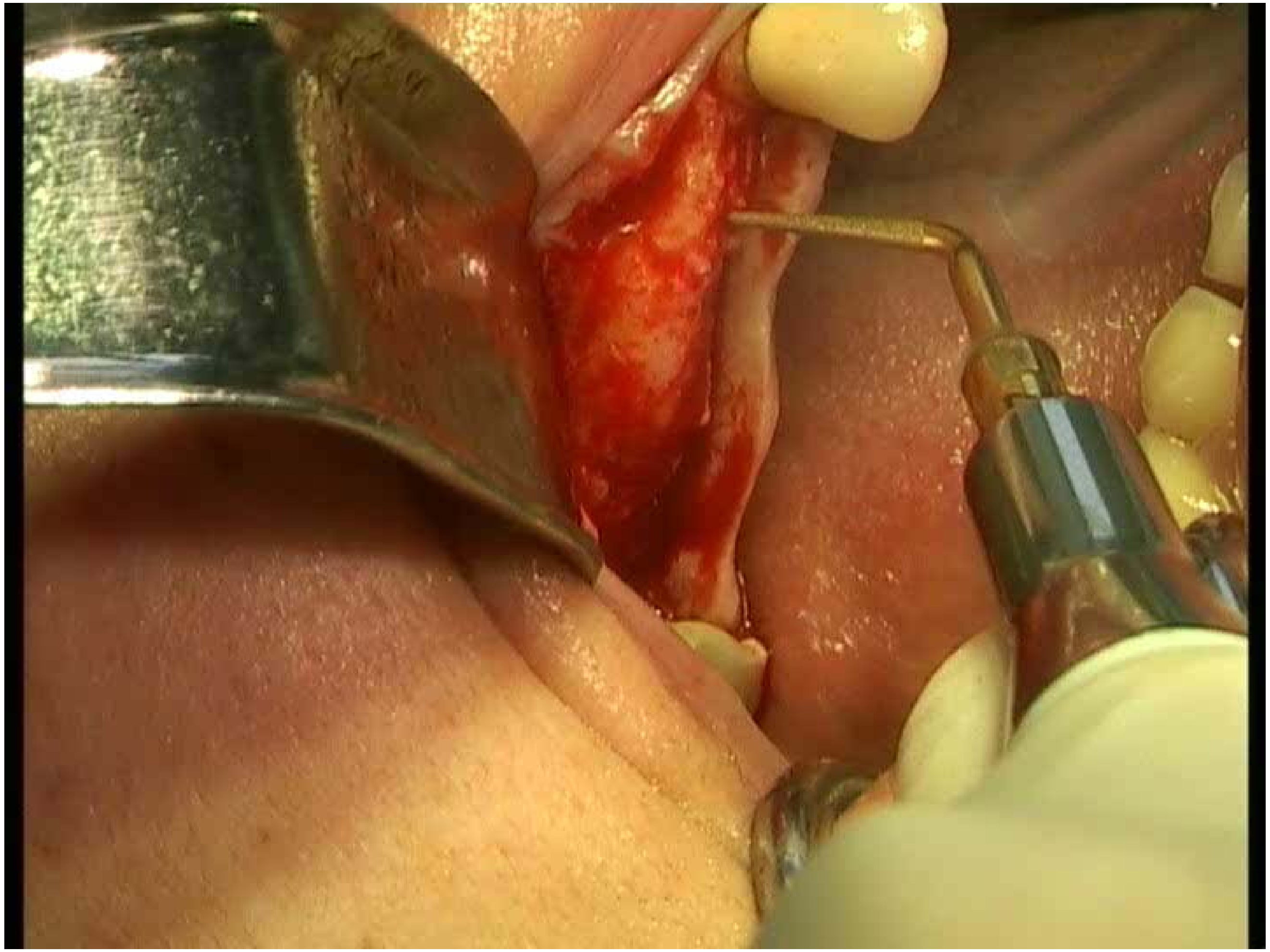


Time delay: 10sec





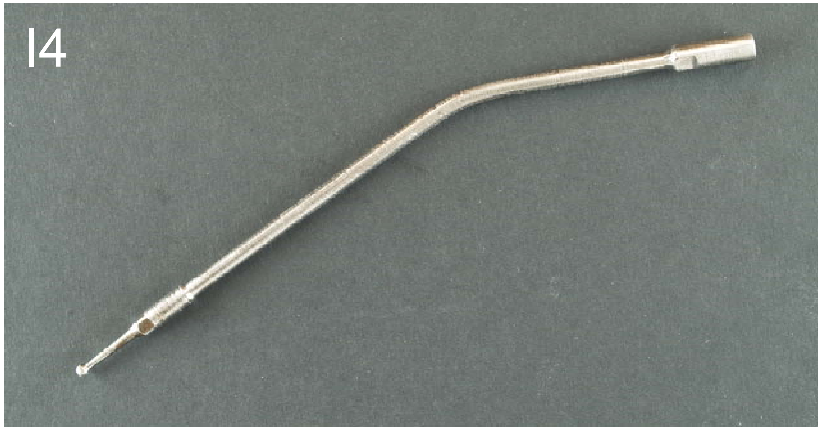
Ultrasonic Implant Surgery



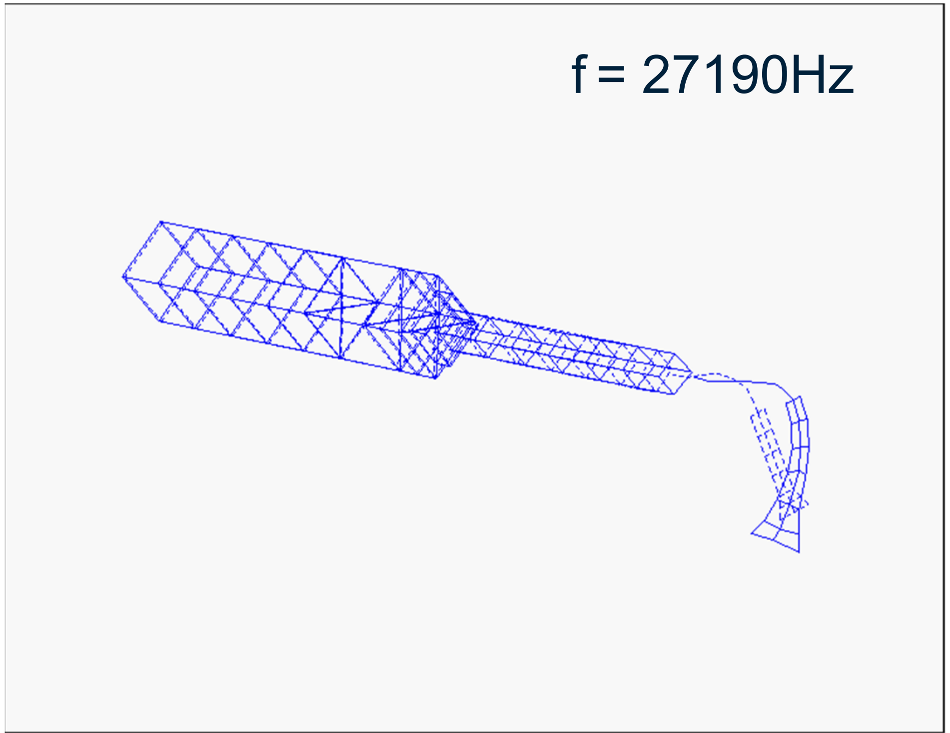
Reaching deeper structures with longer devices

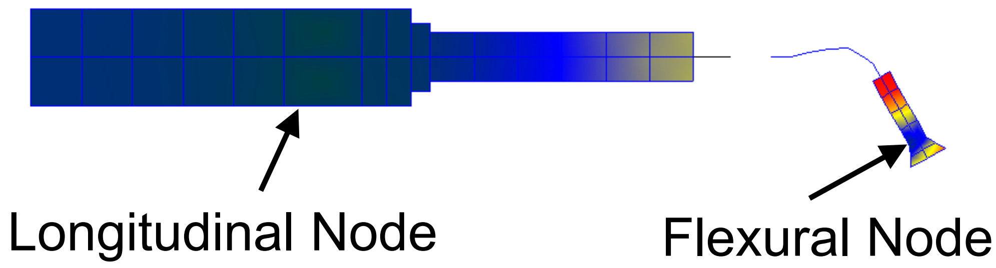
OT7 is a half-wavelength cutting device

I1 – I4 are multiple-wavelength cutting tips for minimally invasive surgeries

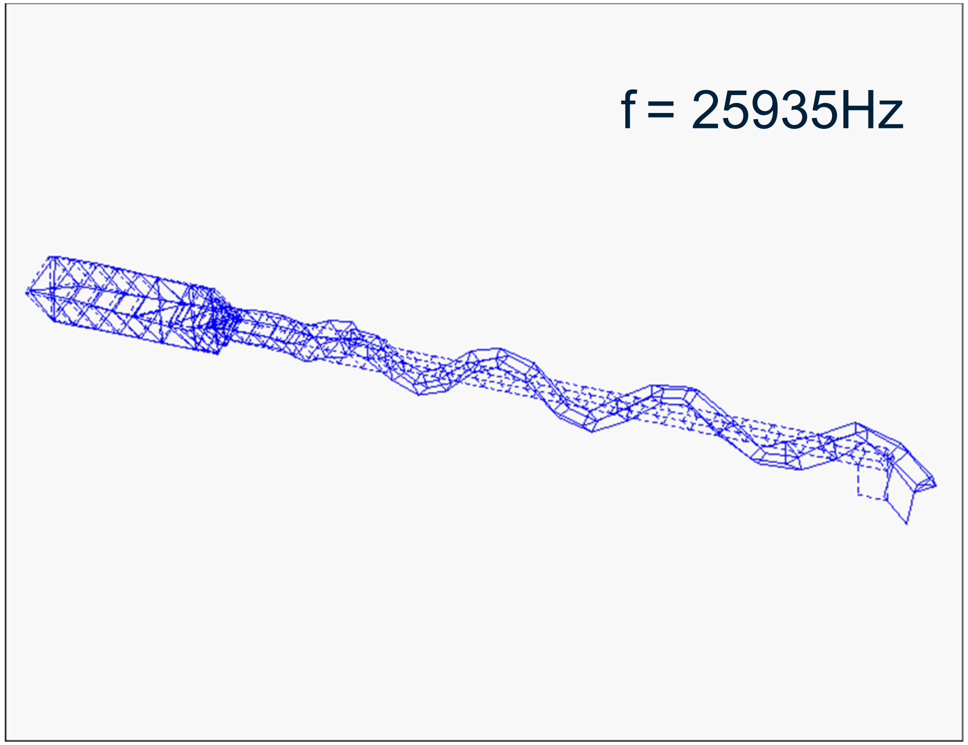


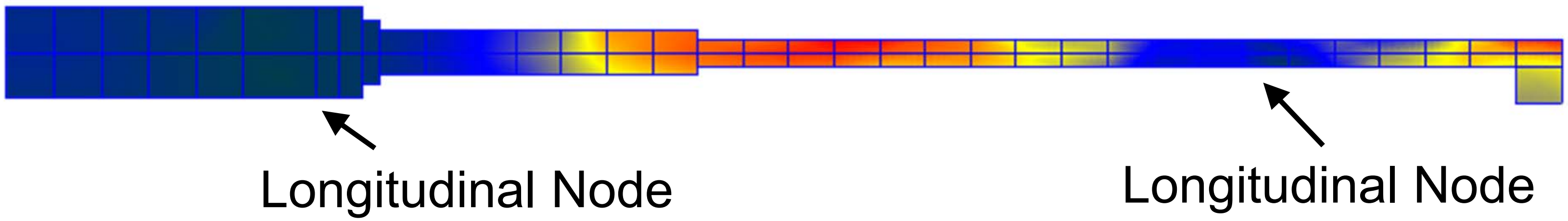
EMA: Half wavelength devices



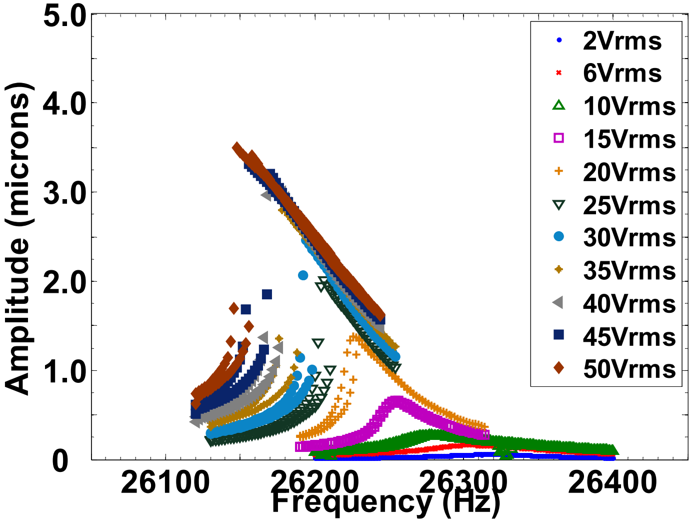


EMA: Full wavelength devices

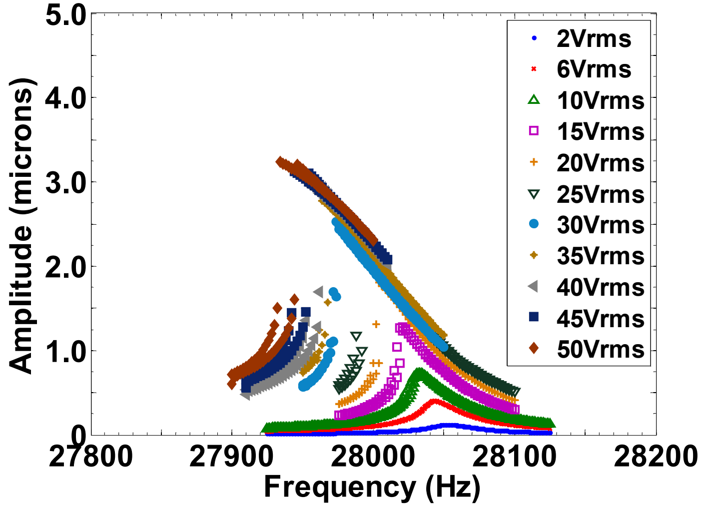




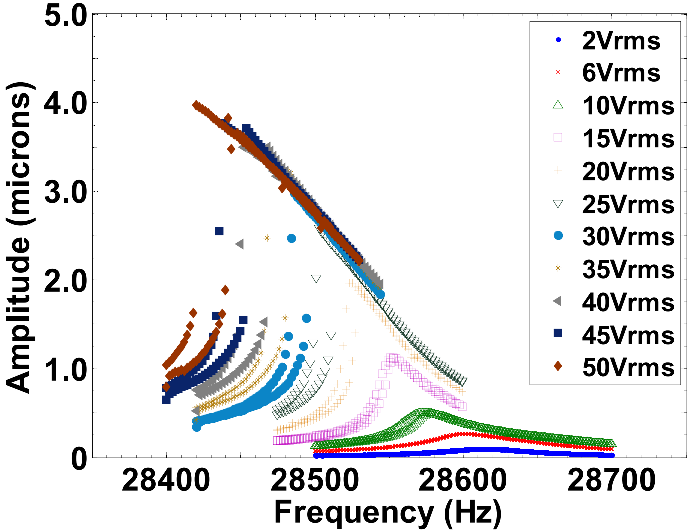
Harmonic characterisation of long devices



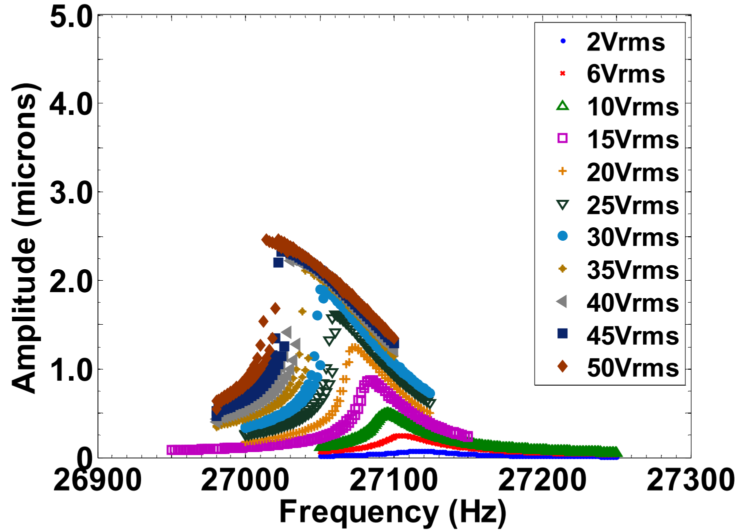
I1



I3

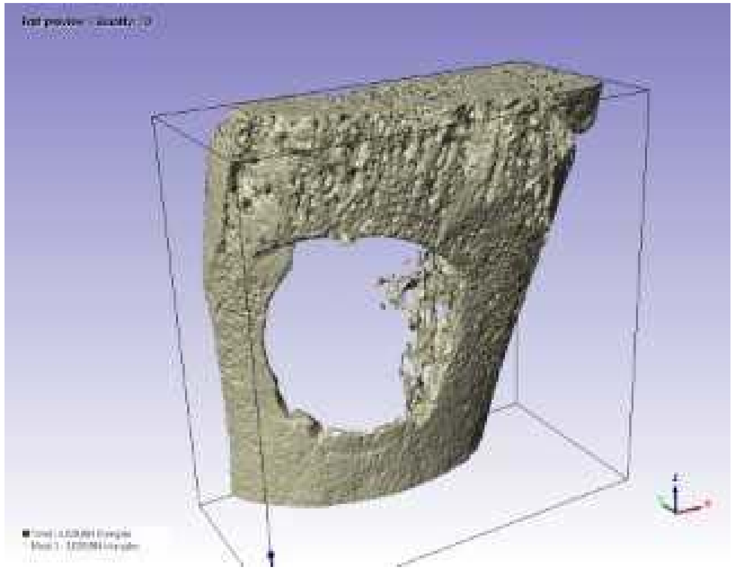


I2

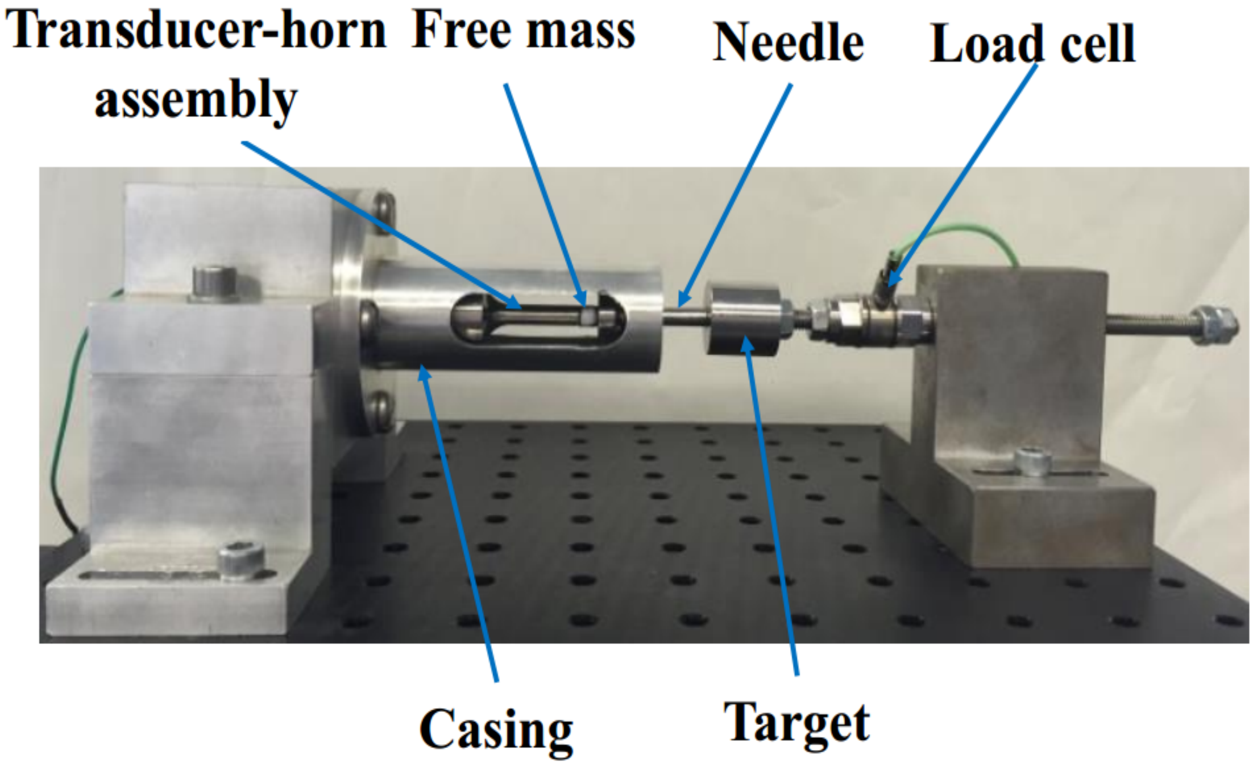


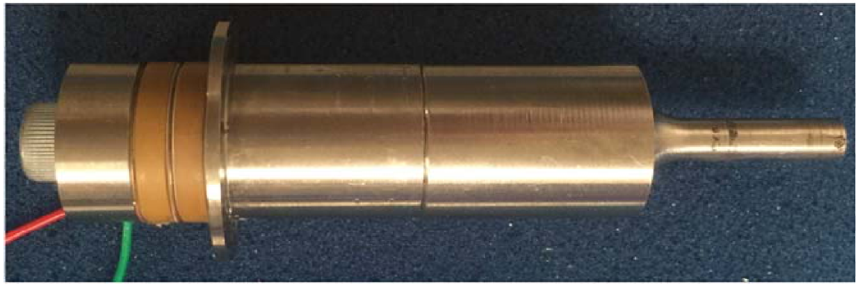
I4

An ultrasonic-sonic device for bone biopsy, 28 kHz



An alternative ultrasonic-sonic device for bone biopsy



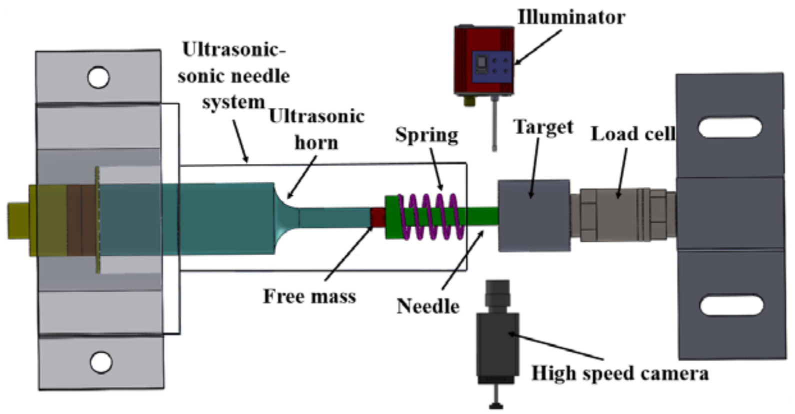


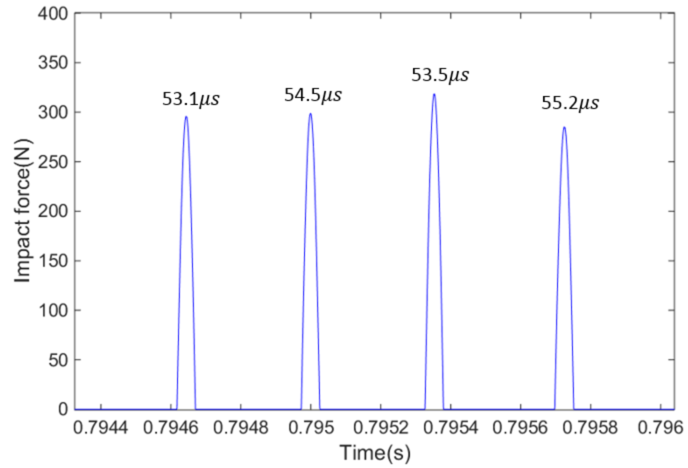
The ultrasonic transducer-horn operates at 50 kHz

The ultrasonic horn impacts with a cylindrical free-mass and the free-mass impacts with the needle

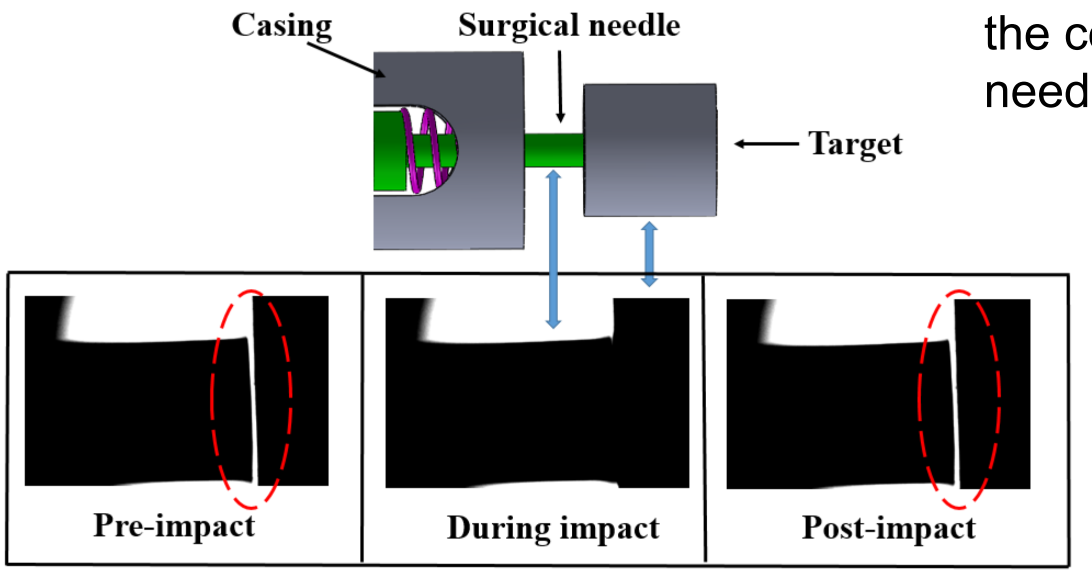
10000 fps

Calculating the contact stiffness k_5 from ultra-high speed camera measurements



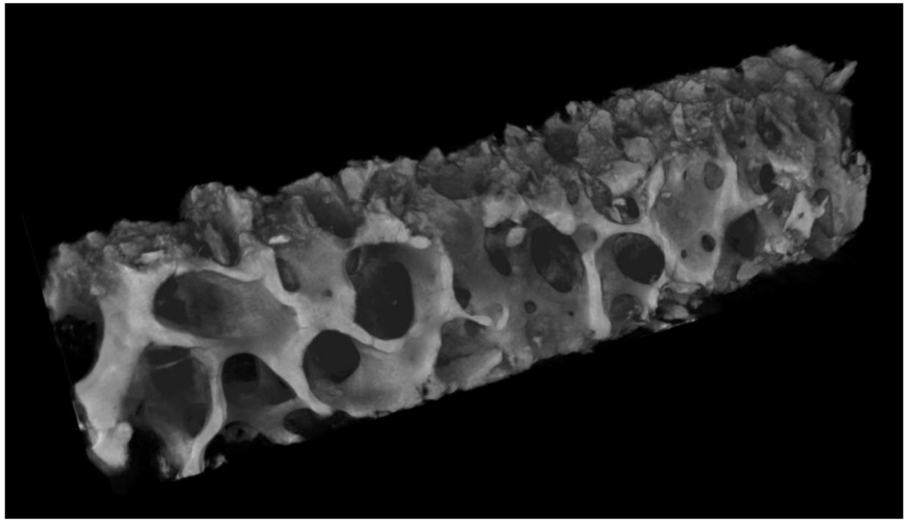


Simulated impact force used to show the contact time between the surgical needle and target

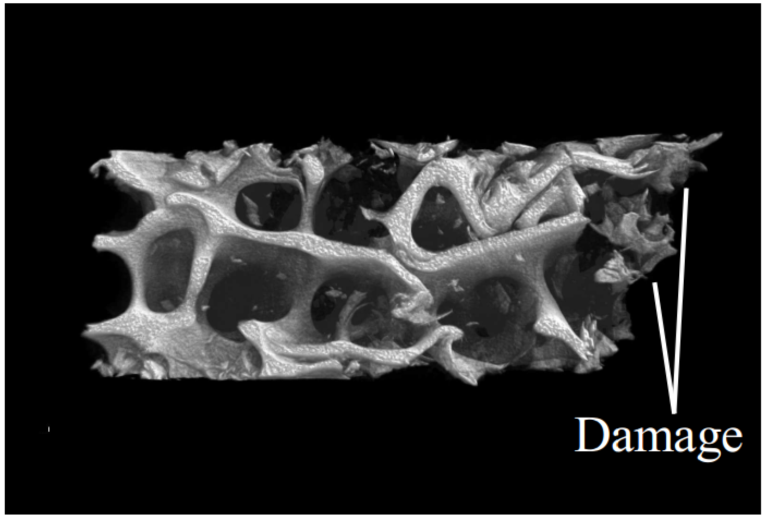


The average contact time for 30 impact events is used in a numerical model to estimate the contact stiffness.

3D micro-CT reconstruction of bone biopsy samples



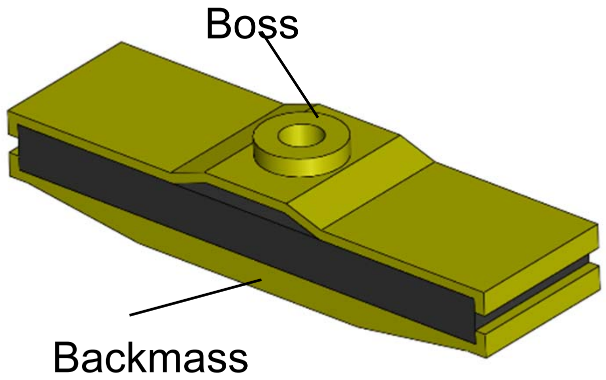
(a) Ultrasonic resonant needle

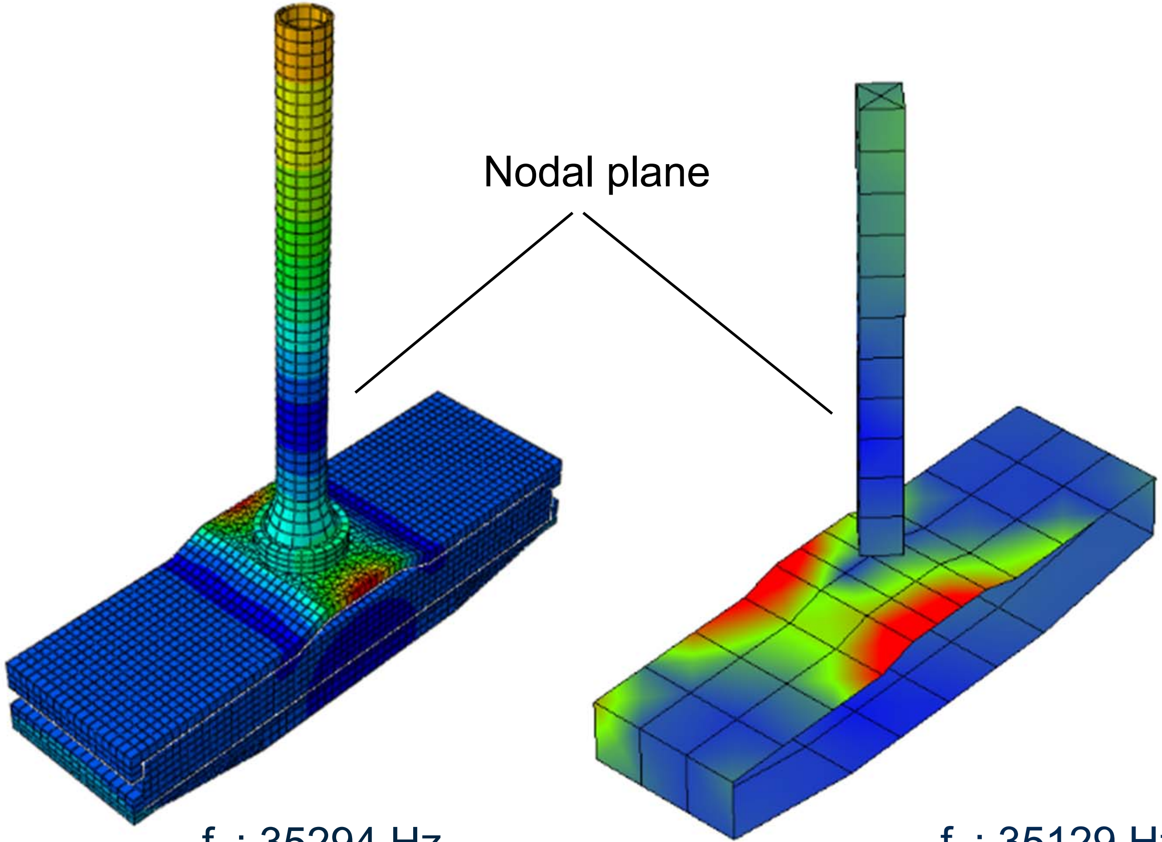


(b) Ultrasonic-sonic needle

The needles extracted intact and viable biopsy samples where the majority of micro-architecture remained intact

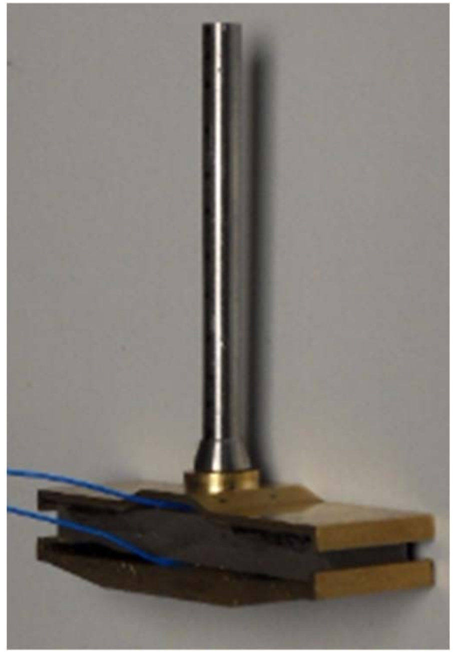
Flextensional transducers – an alternative for bone biopsy



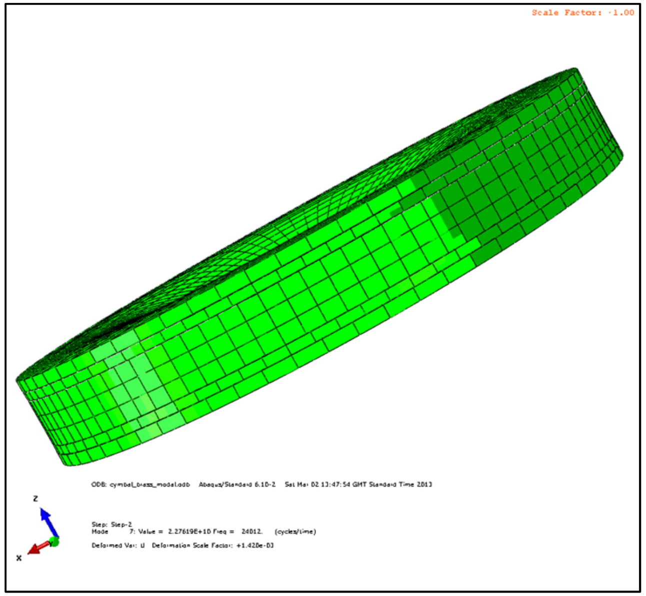


f_r : 35294 Hz
Finite element analysis

f_r : 35129 Hz
Experimental modal analysis



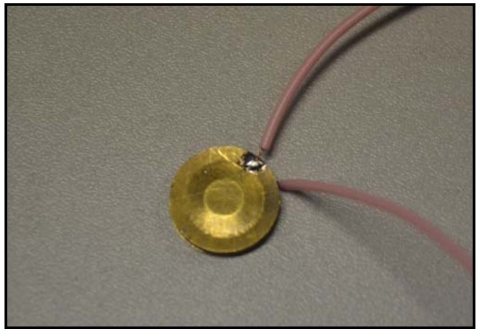
Flextensional transducers – cymbal



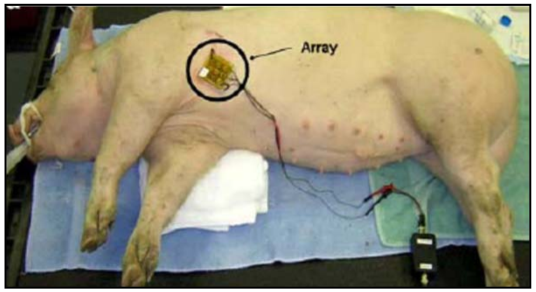
Benefits for ultrasonic orthopaedic devices:

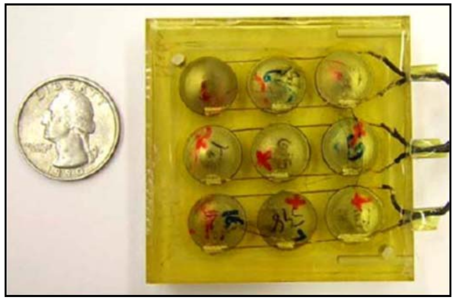
- Potential for high vibrational displacement at low ultrasonic frequencies
- Simple fabrication
- Tailoring of behaviour by choice of end-cap material and dimensions

But previously used in **low power applications**: hydrophone, accelerometer, sensors, actuators, motors.



[2]

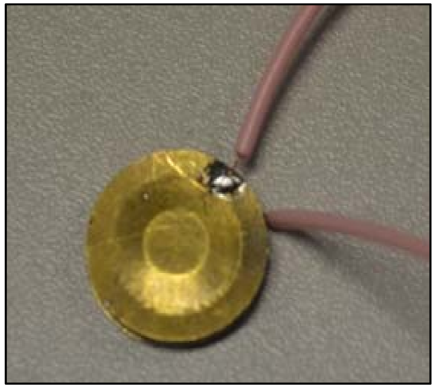


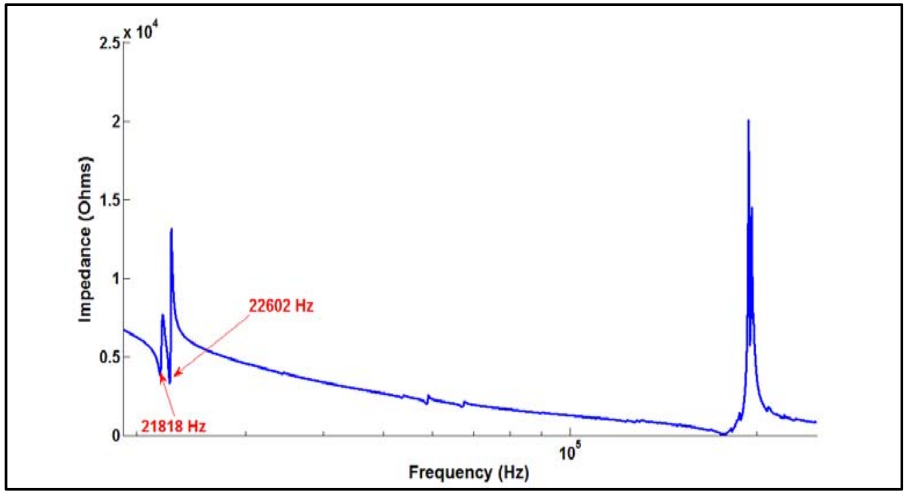


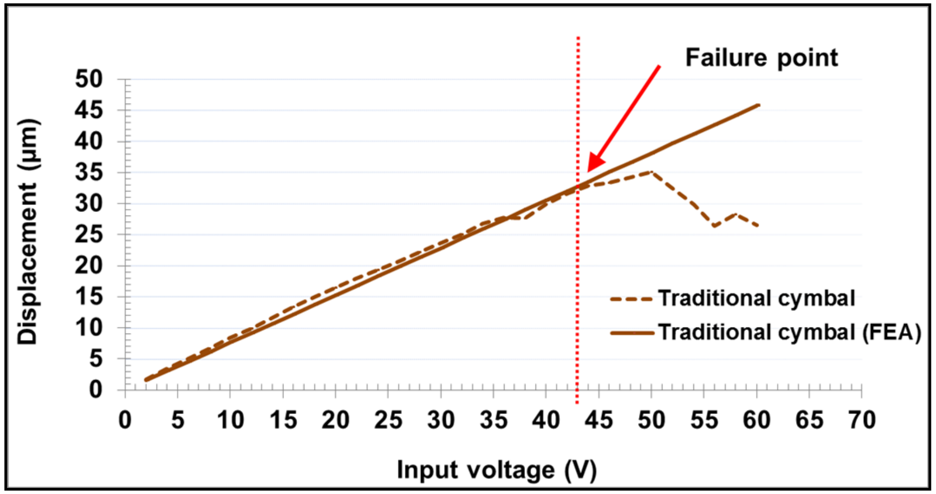
[2] E.J. Park et al, Ultrasound Mediated Transdermal Insulin Delivery in Pigs Using a Lightweight Transducer, Pharm Res 24(7), 2007

Cymbal transducer

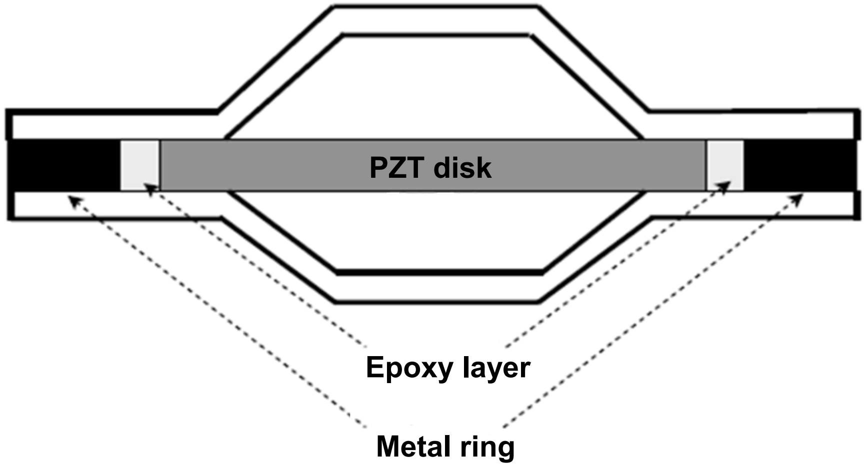
- The geometry of the end-caps greatly affects the frequency response of a cymbal transducer.
- Cymbal transducers exhibit a double peak in the frequency response spectrum, due to even small asymmetries in the epoxy layer or in the end-caps.

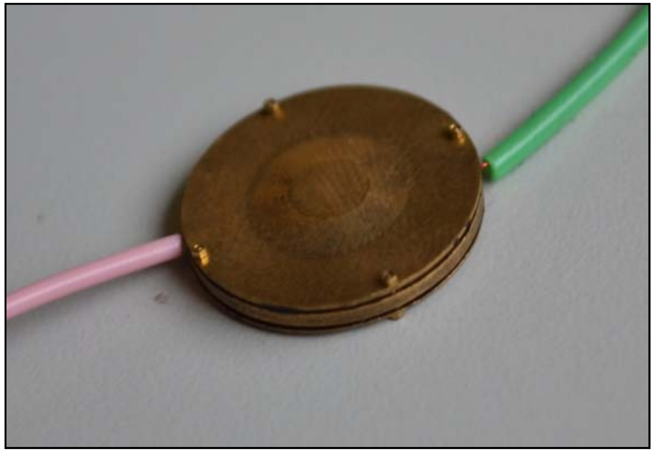






New cymbal for driving an orthopaedic surgical device





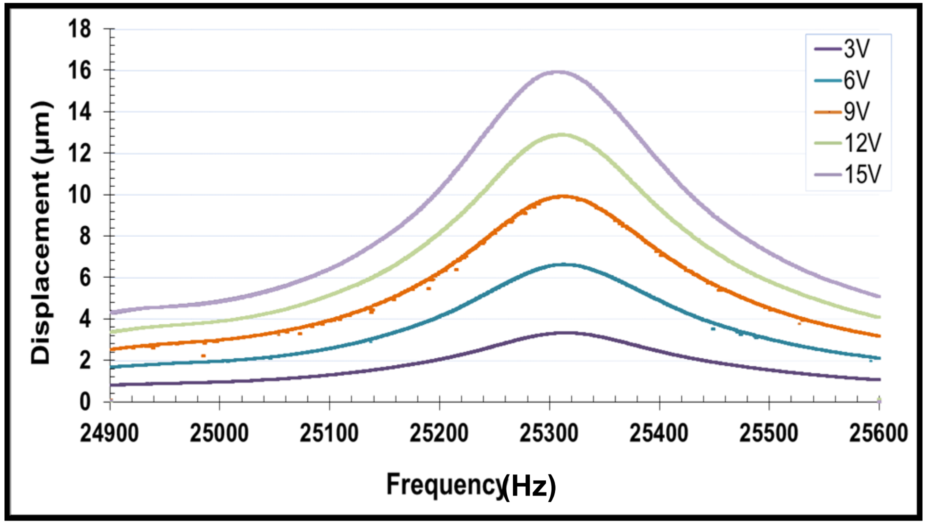
- The piezoceramic disc is coupled, through an epoxy layer, to a metal ring.
- The end-caps are fixed directly to the metal ring via small screws.
- In this configuration, the location of highest stress is no longer in the epoxy layer.

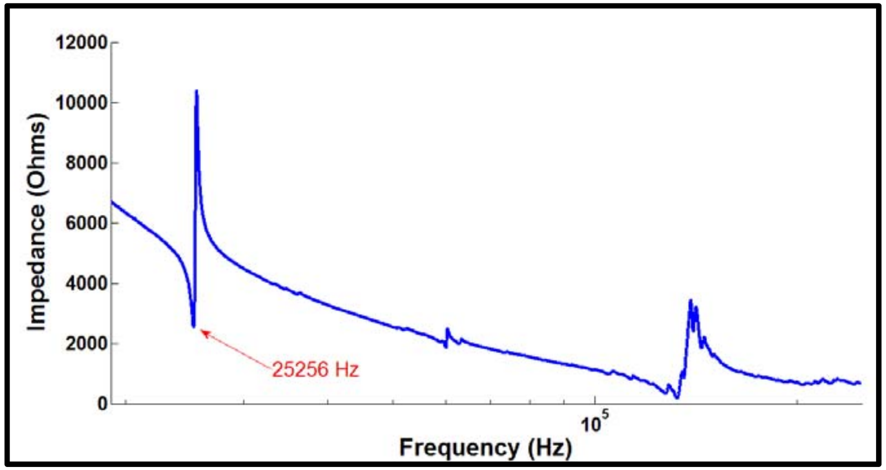
Measurement of new cymbal

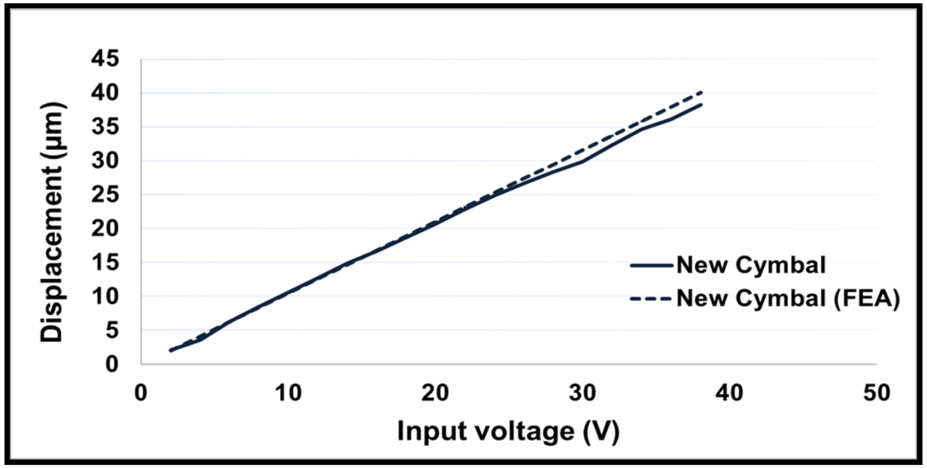
PZT disc: Diameter: 12.7 mm
Thickness: 1 mm

Metal ring: Material: brass
Thickness: 1 mm
Outer diameter: 16.7 mm
Inner diameter: 14.7 mm

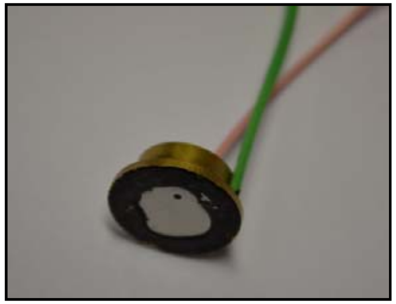
Epoxy: Eccobond 45LV
Thickness: 1 mm

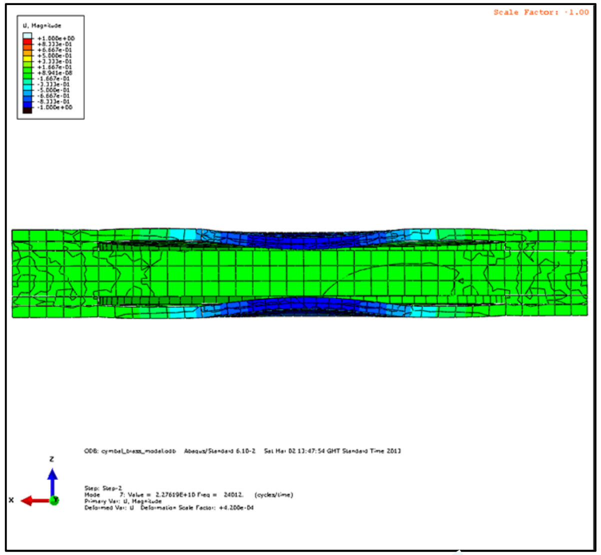


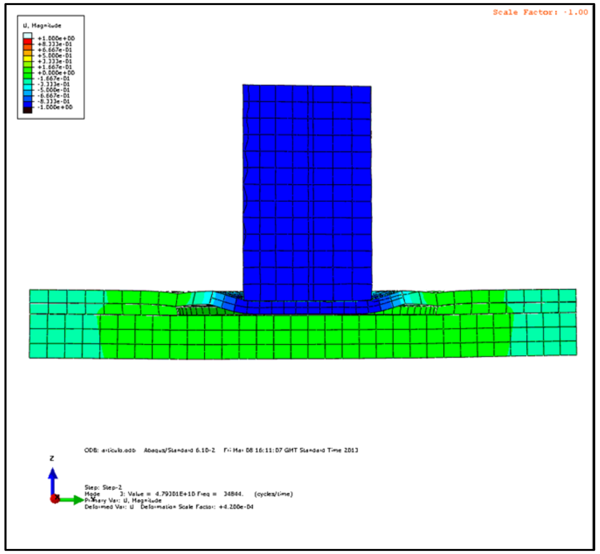


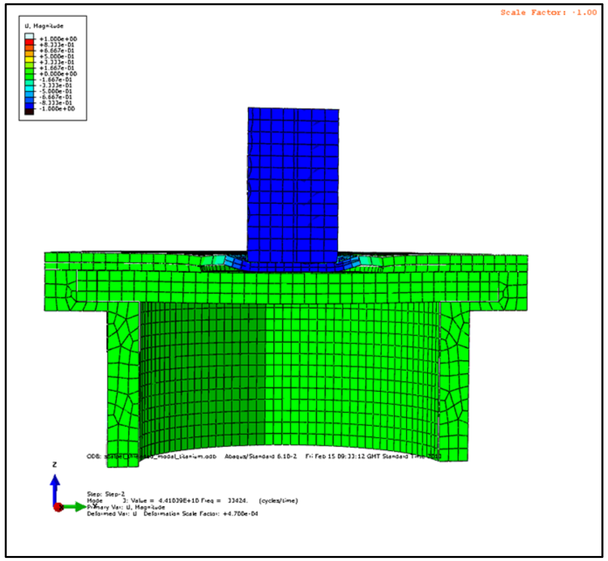


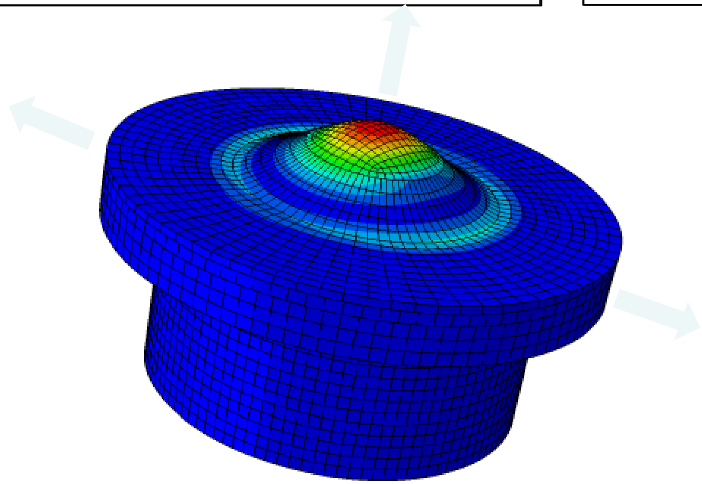
Prototype transducer for cutting device

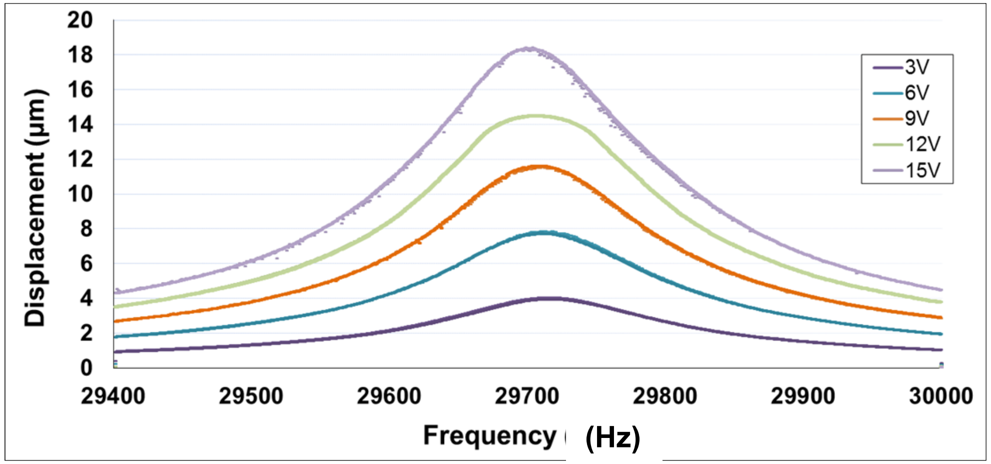




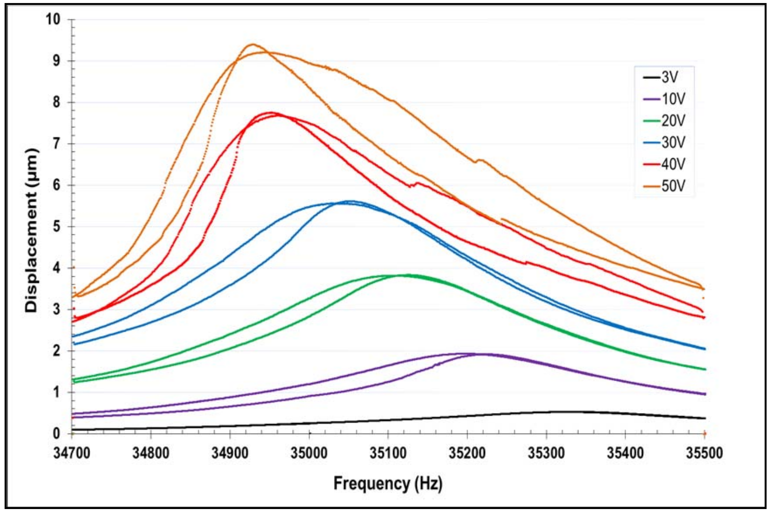


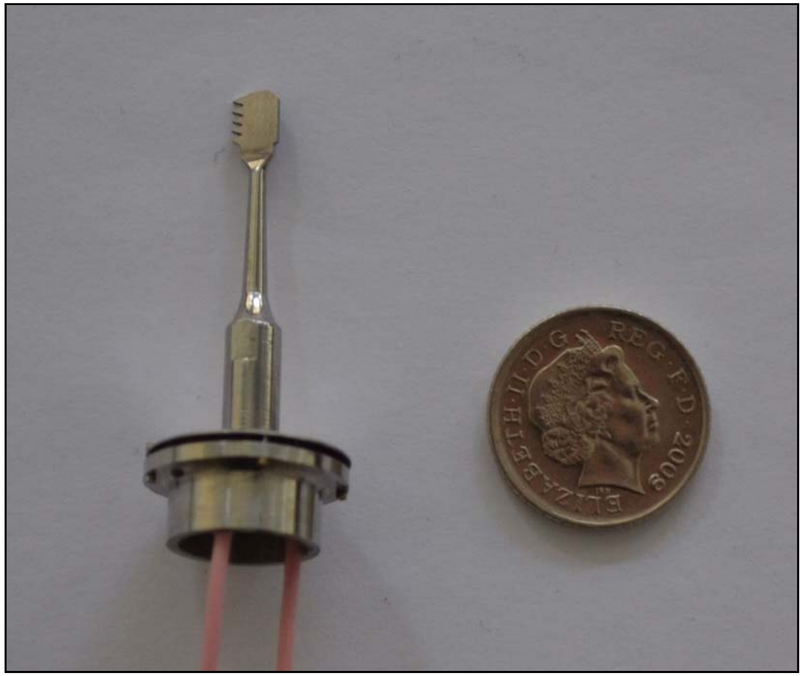


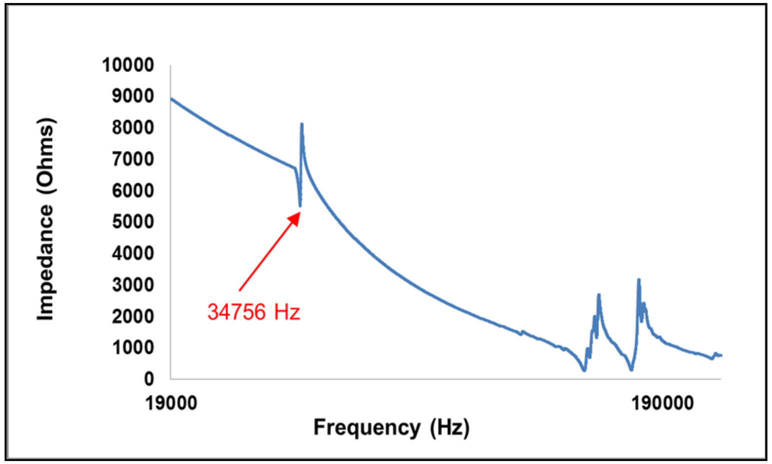




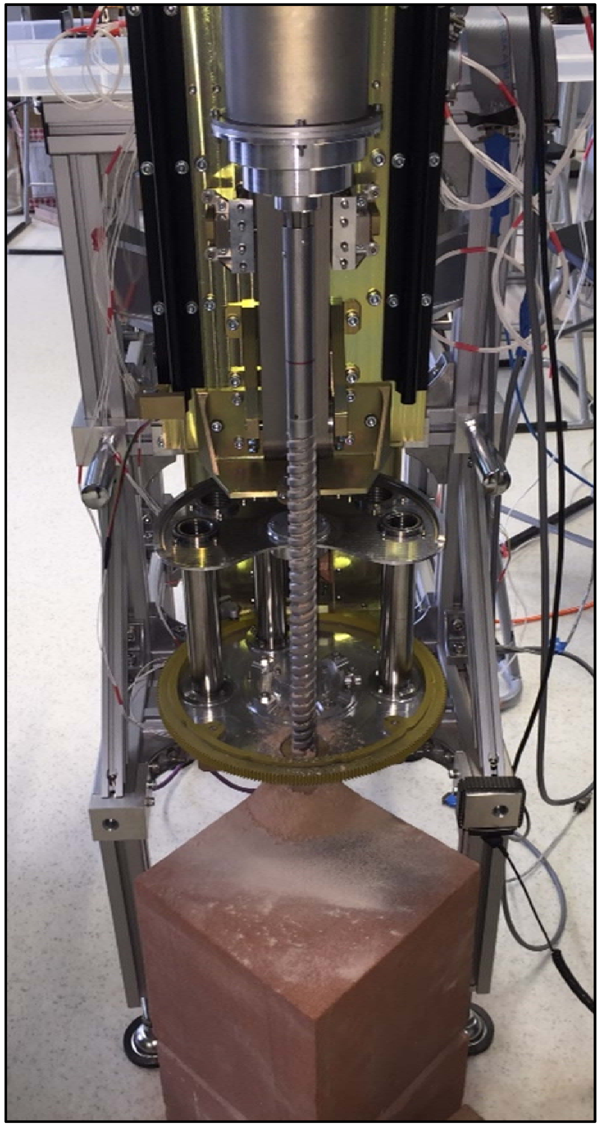
Measurement of a prototype surgical device







Ultrasonic Planetary Core Drill – UPCD



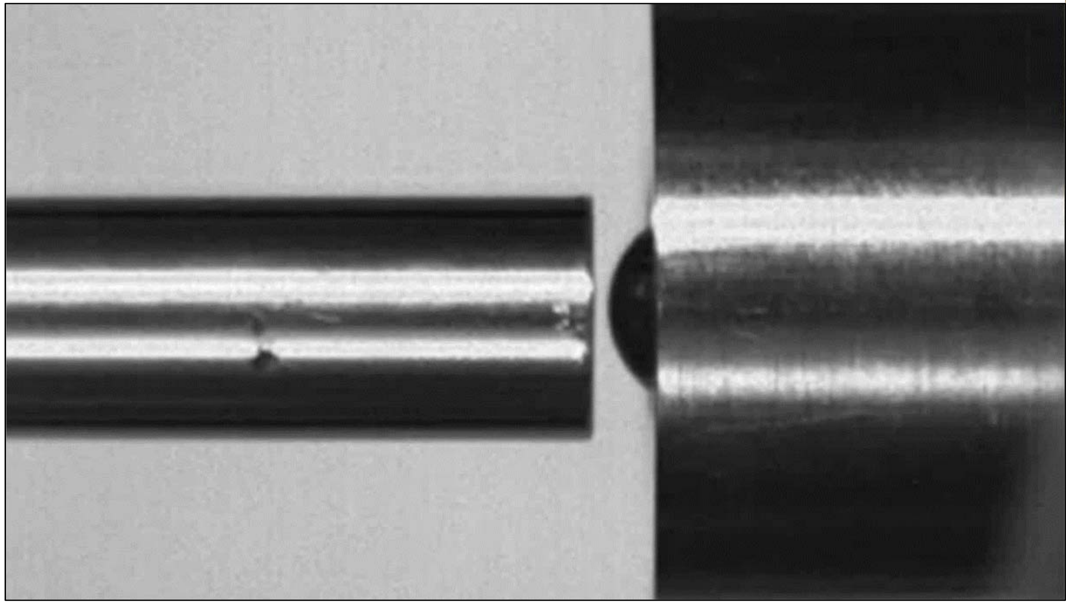
Drilling in sandstone and in frozen sand/ice

Drilling into sandstone in the lab

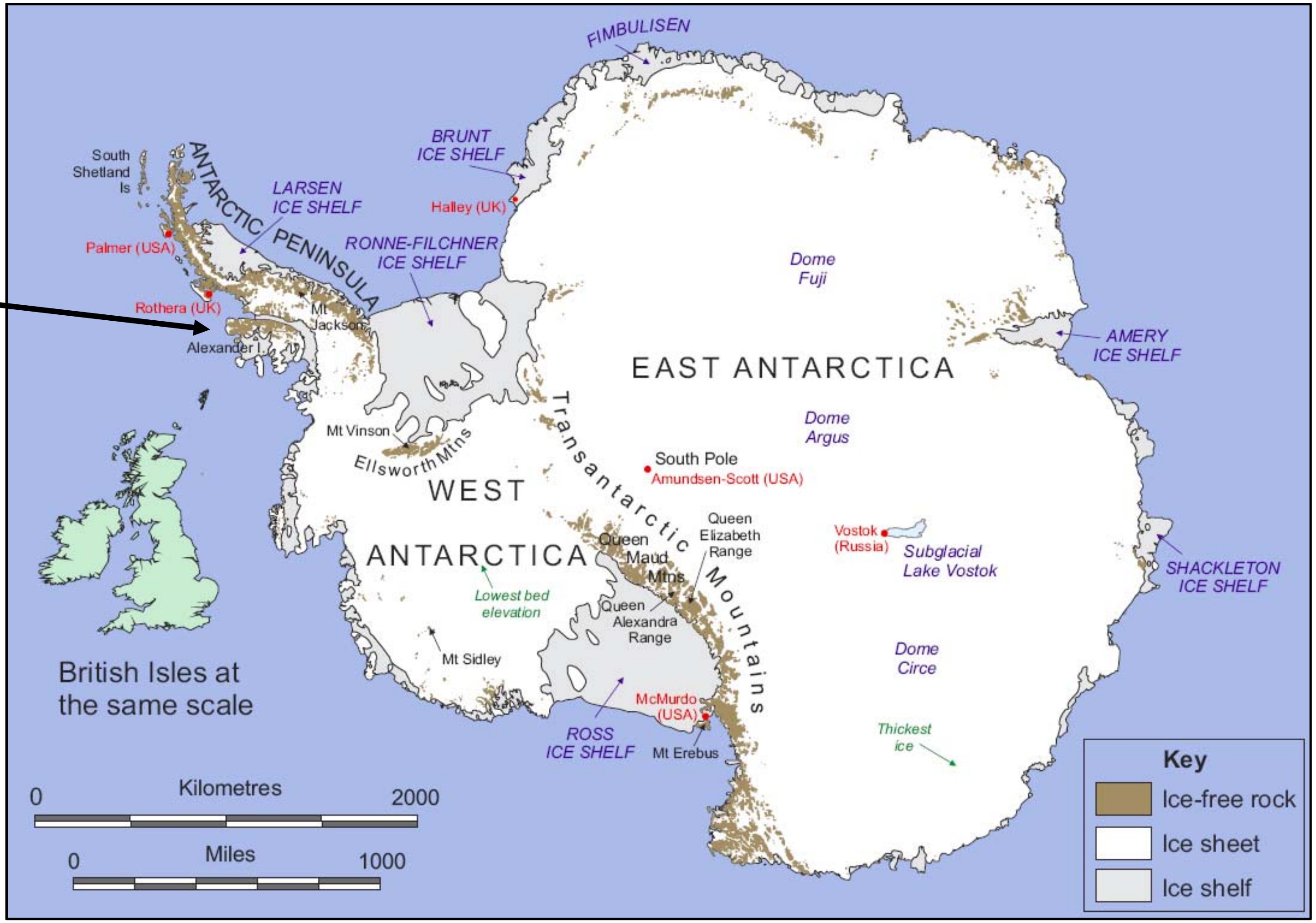
Ultrasonic percussion

Delivers the hammering action by applying ultrasonic vibration to a free-mass, which in turn strikes a splined cutting bit-holder.

Weight-on-bit and power requirements are low.



The Earth analogue site for trials



Test site and living conditions!

Testing the driller/corer and sample containerisation

University of Glasgow


University of Glasgow
School of Engineering
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