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Characterisation of commercial and prototype power ultrasonic devices used in bone surgery

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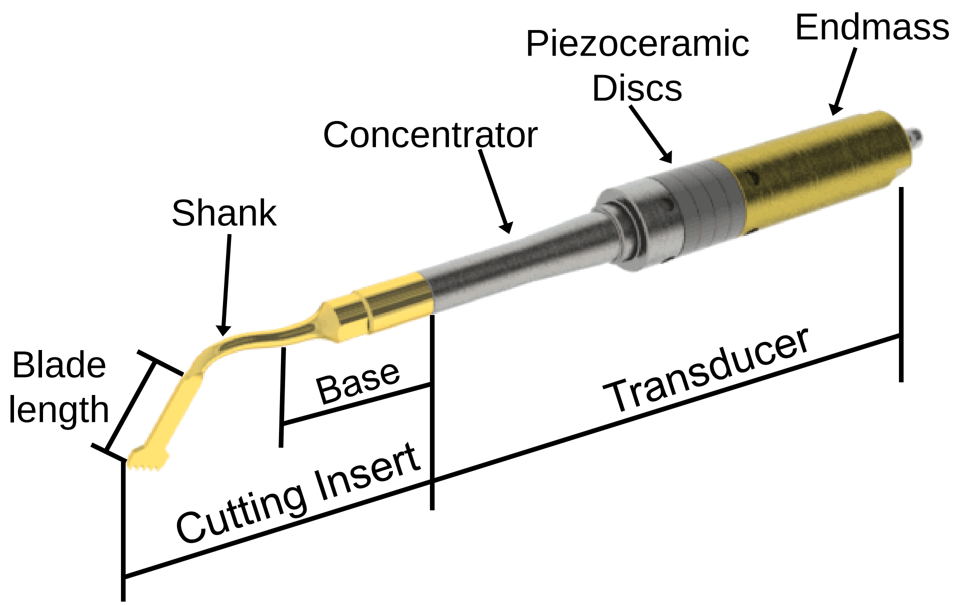
Piezosurgery® Device

Image courtesy of Mectron S.p.A



Developed and manufactured by Mectron S.p.A

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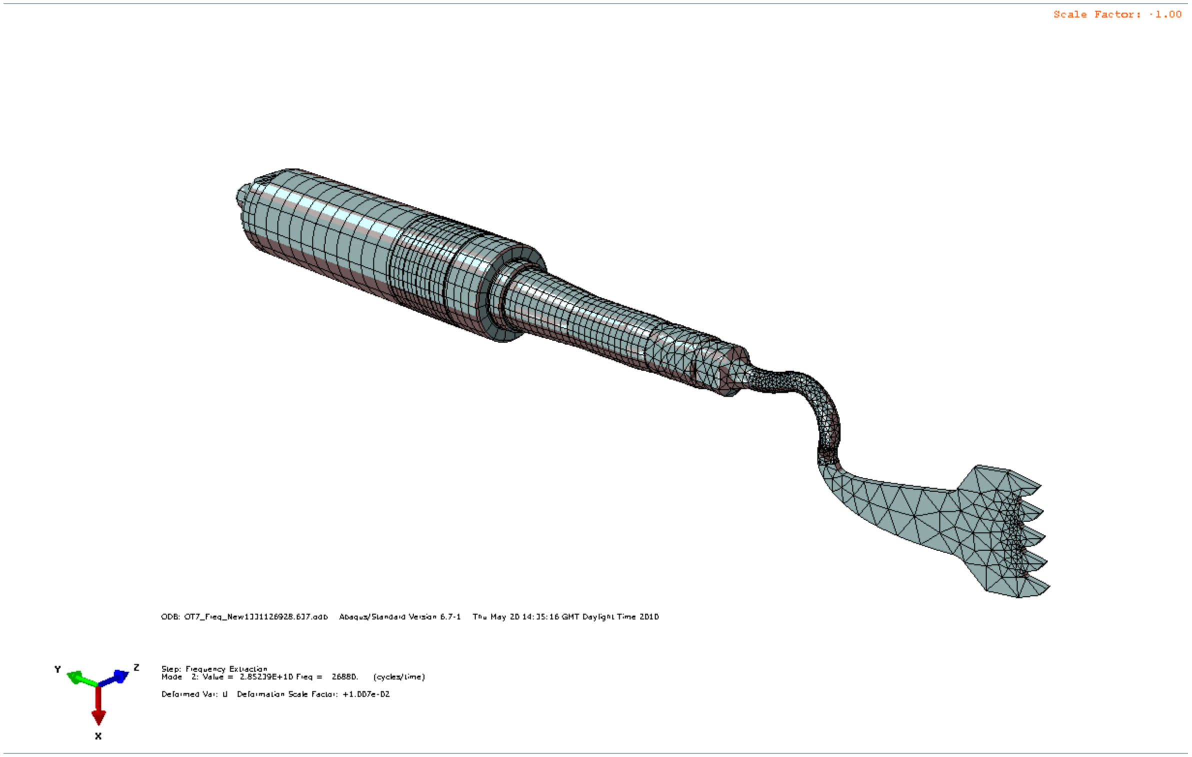
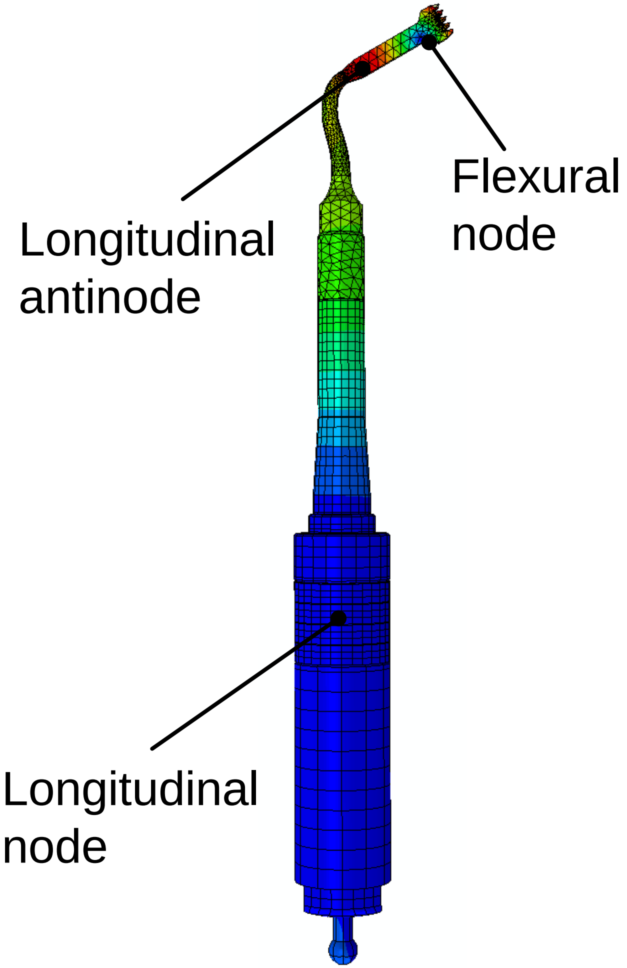
Piezosurgery® Device: Vibrational behaviour





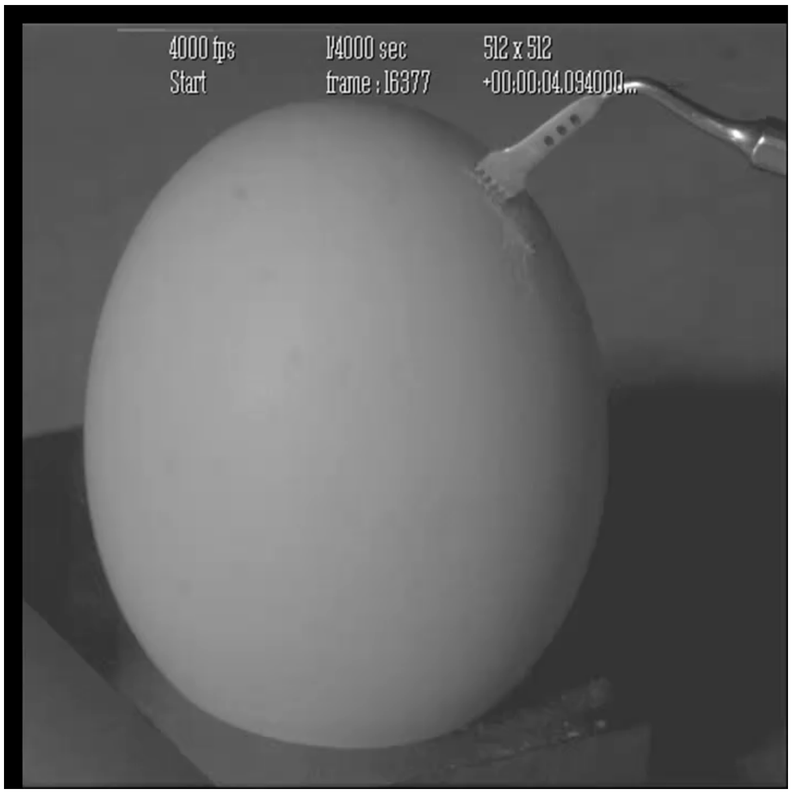
Mectron dental transducer with OT7 insert

Ultrasonic bone cutting: Benefits

- Reduced applied loads
- Reduced debris formation
- Increased accuracy
- Low threat to delicate soft tissue; nerve, brain & spine

- Requires 20-30% of force compared to traditional cutting devices
- Fine debris compared to burs and saws
- Enhanced healing time
- Less likely to damage tissue which could lead to halting the procedure

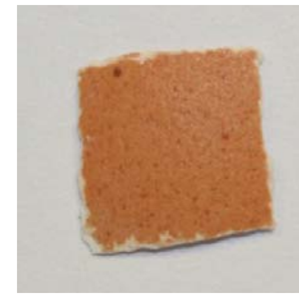
Device precision

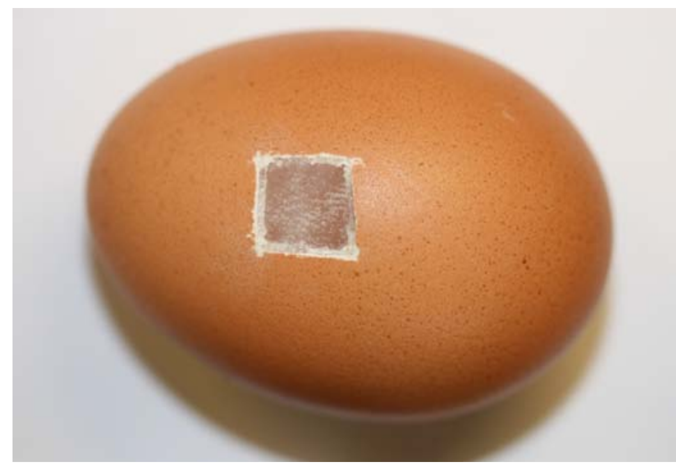


Photron fastcam ultima APX

Recording: Frame rate: 4000fps Resolution: 512x512
Video: Frame rate 1000fps

Window cut in egg





Mectron transducer with OT7 cutting insert

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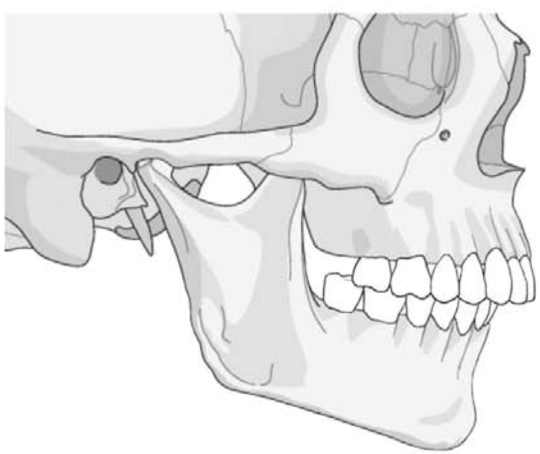
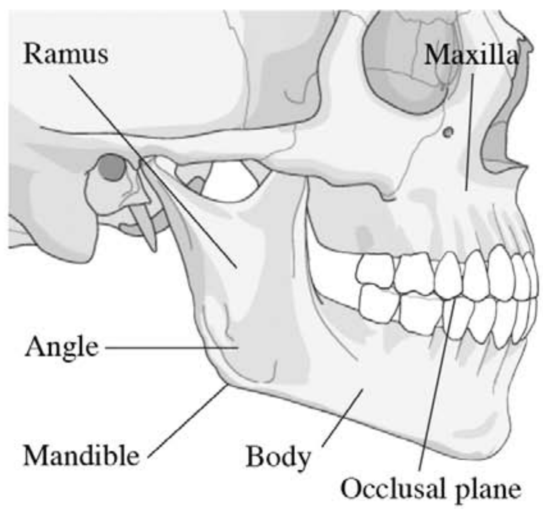
Clinical procedure: Bilateral sagittal split

<u>Osteotomy of the mandibular</u>

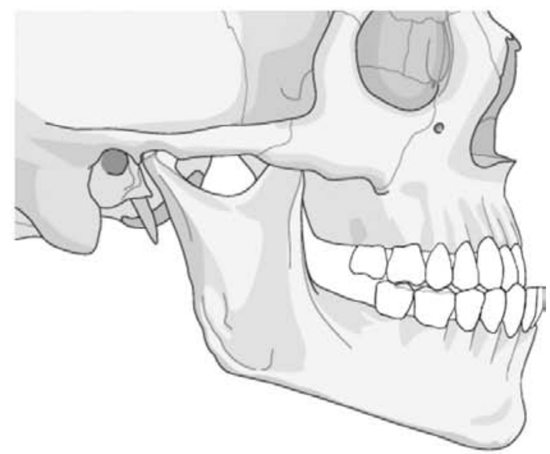
Shortens or lengthening of the lower jaw to correct dentalfacial deformities caused by congenital abnormal skeletal development as well as trauma sequelea.



<u>Mandible exhibiting prognathism</u>



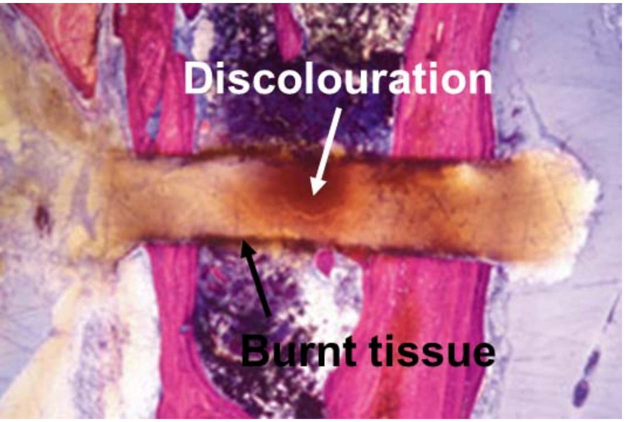
<u>Normal mandible position</u>

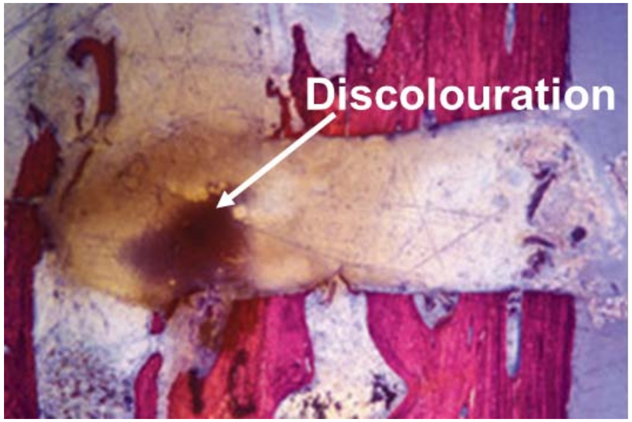


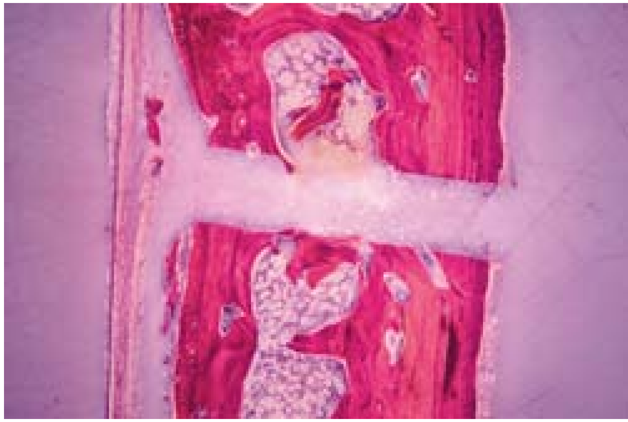
<u>Mandible exhibiting retrognathism</u>

Clinical procedures: Osteotomy

Comparison with traditional cutting methods







Images courtesy of Mectron S.p.A

Bone saw

Bone bur

Ultrasonic device
(Piezosurgery® Device)

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

However, power ultrasonic devices can exhibit behaviour that reduces their performance and which can subsequently lead to premature device failure.

Aim of Research

To create design criteria for stable power ultrasonic systems through understanding sources and causes of nonlinear behaviour

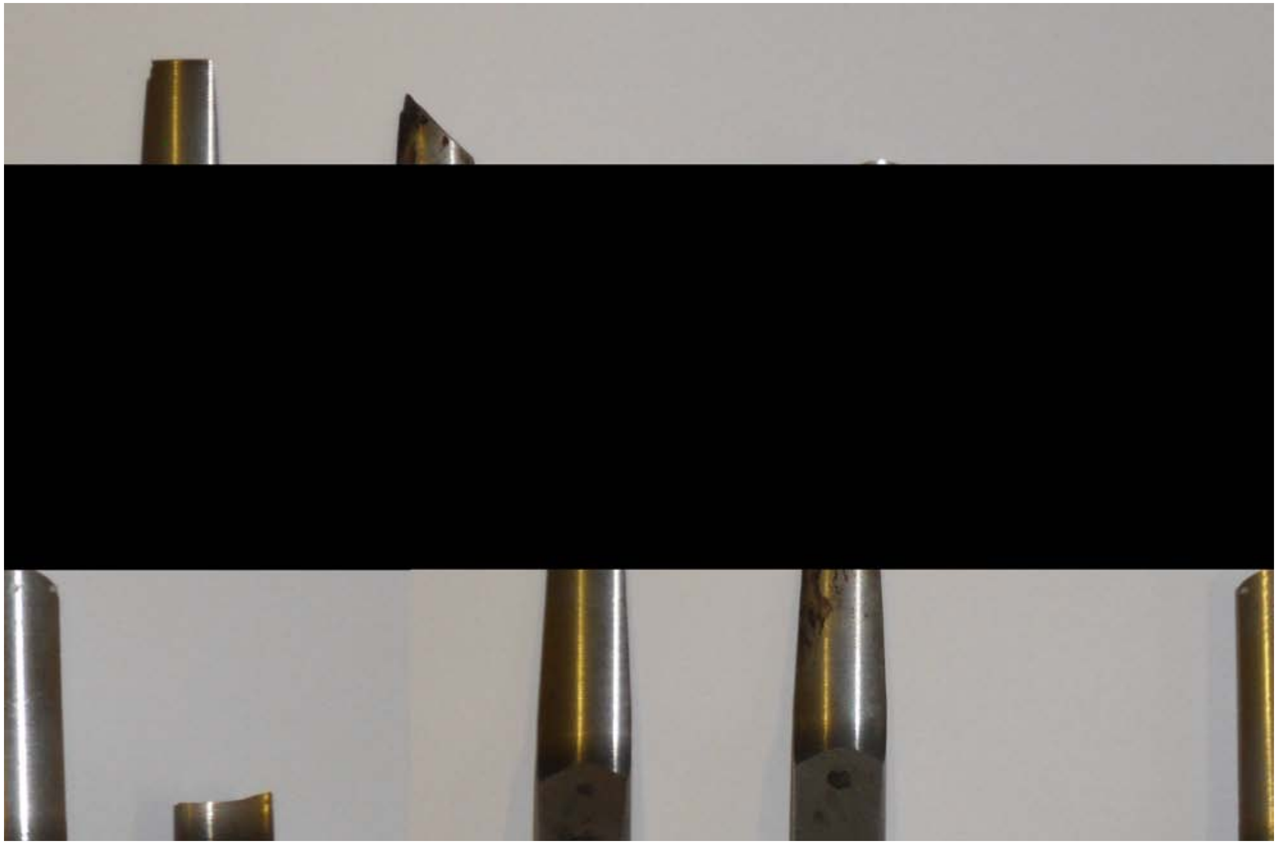
Poor performance in power ultrasonic devices

Poor performance and reliability can stem from a number of sources, such as;

- Sub-optimised / poor design
- Modal coupling
- Modal interaction
- Presence of Duffing-like behaviour

Outcome of poor reliability and performance

Failure of cutting blades



Linear response of ultrasonic devices

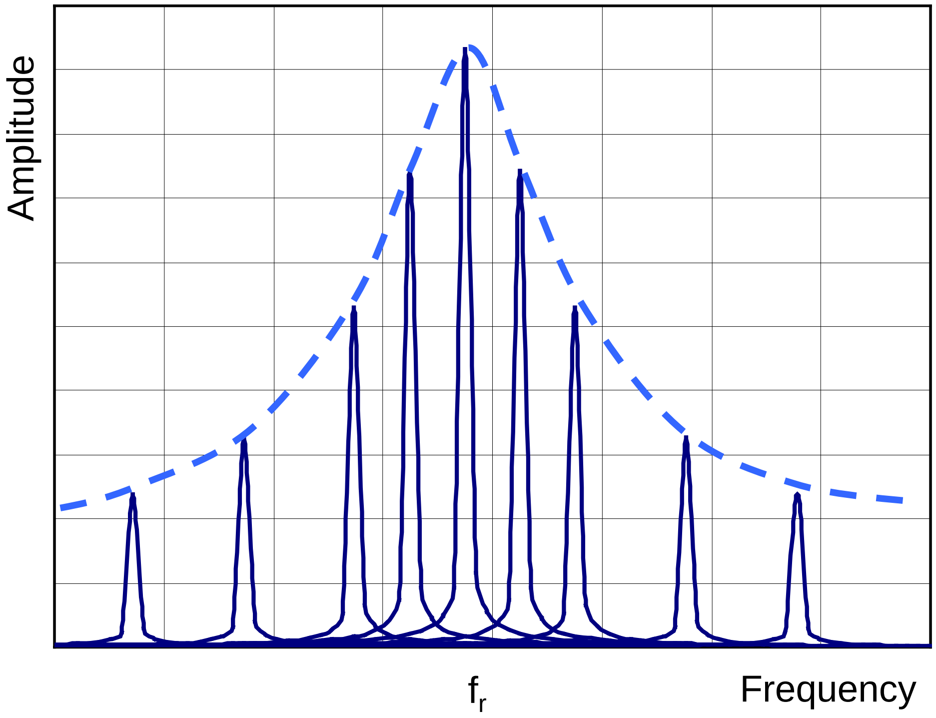
Amplitude of vibration is proportional to input excitation.

<u>Measurements</u>

Excitation at individual frequencies

Continuous / burst swept sine wave

Low excitation levels



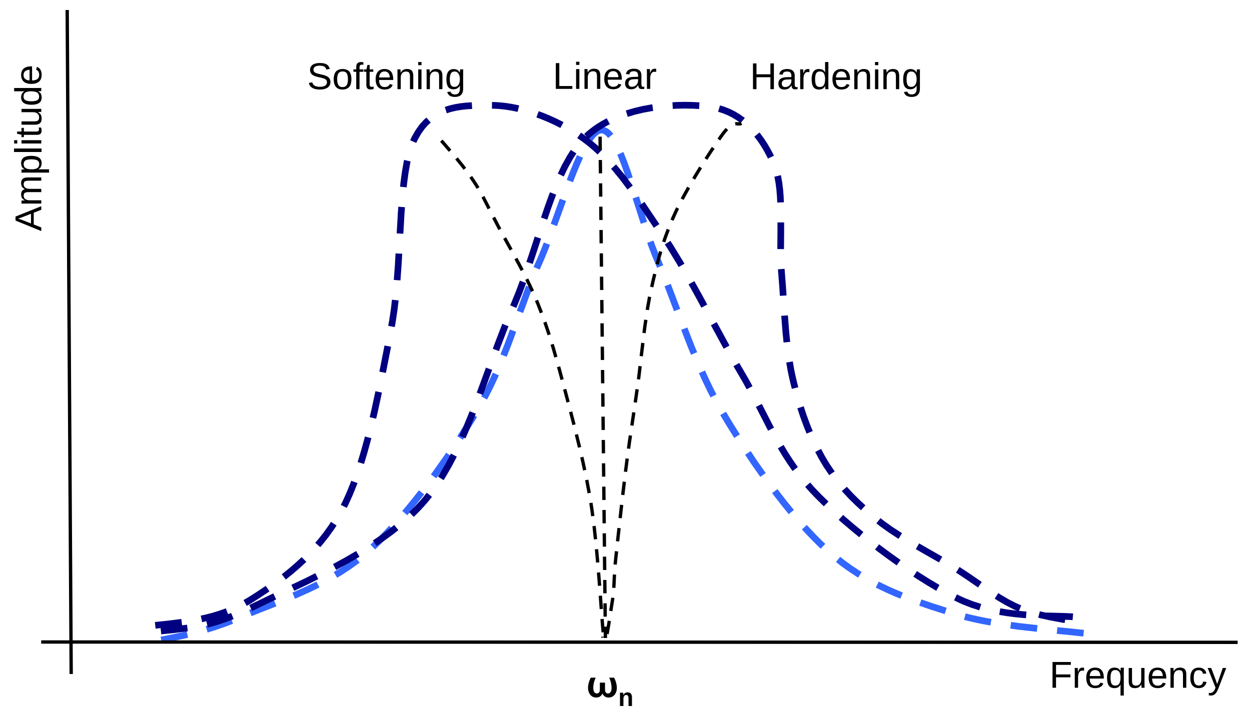
Nonlinear responses of ultrasonic devices

Can significantly influence driving stability as well as hindering power ultrasonic system development

Nonlinear behaviour

Frequency Shifts

Softening / Hardening effect



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Nonlinear responses of ultrasonic devices

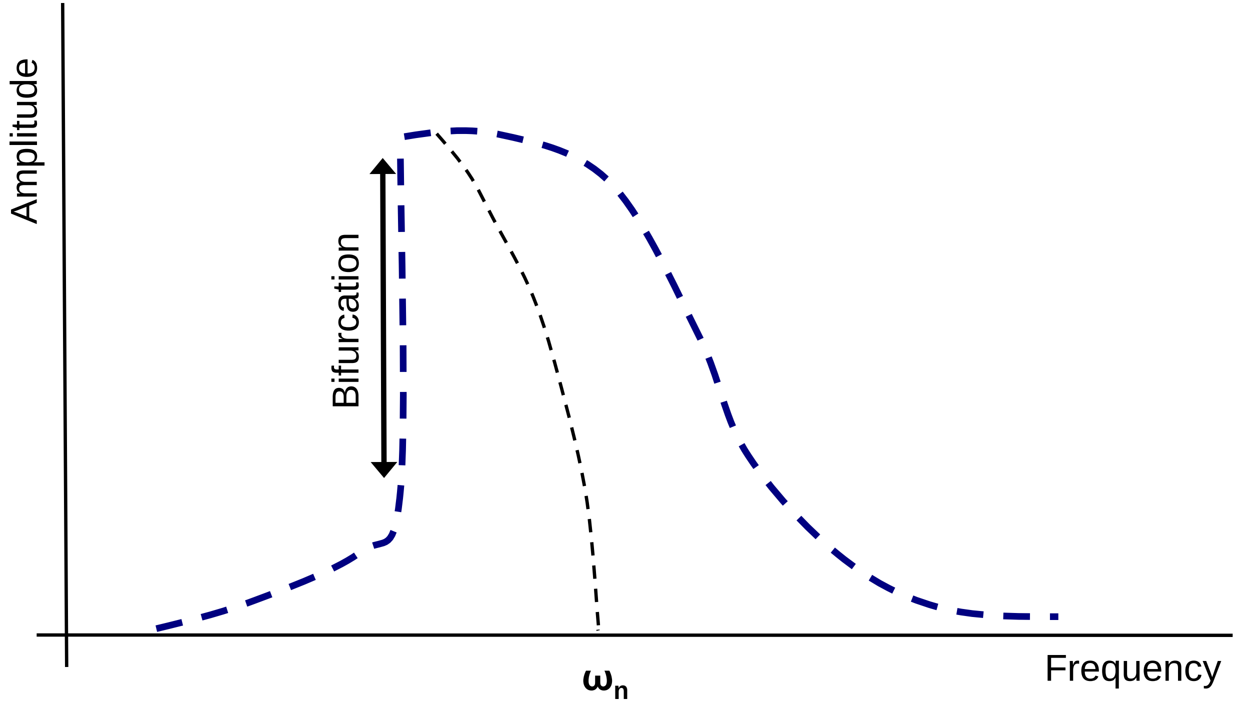
Can significantly influence driving stability as well as hindering power ultrasonic system development

Nonlinear behaviour

Frequency Shifts

Softening / Hardening effect

Bifurcations



Nonlinear responses of ultrasonic devices

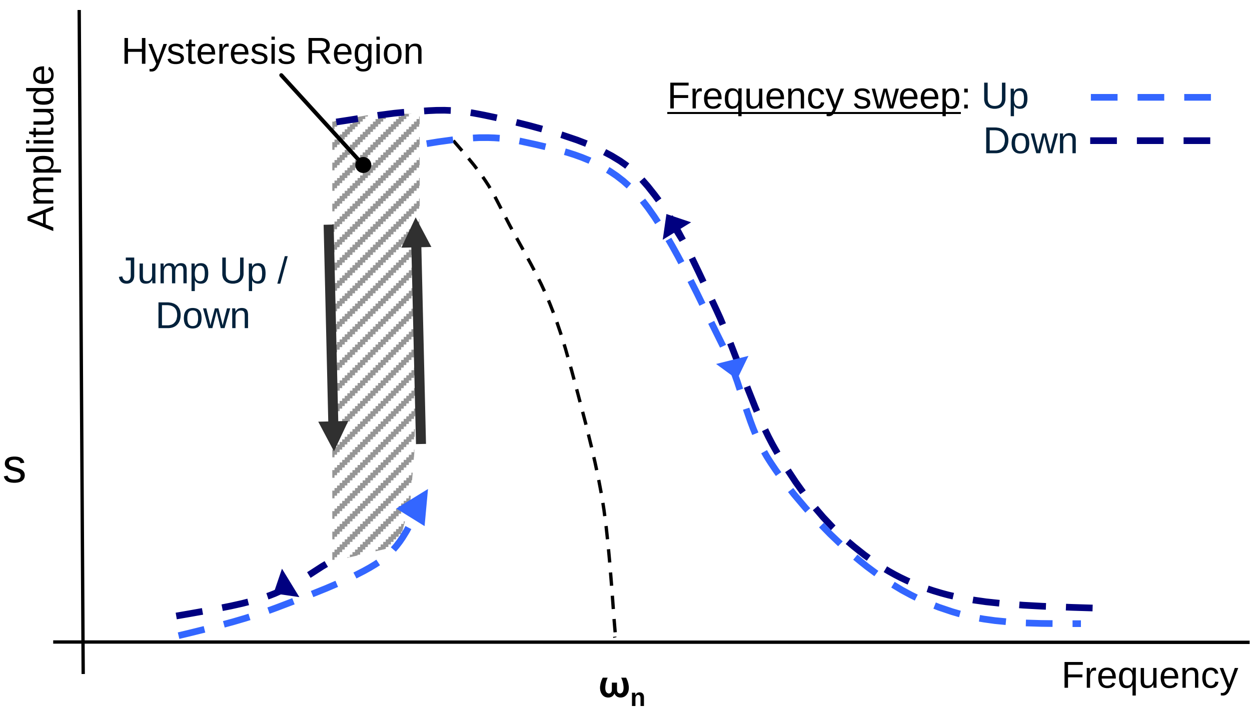
Can significantly influence driving stability as well as hindering power ultrasonic system development

Nonlinear behaviour

Frequency Shifts
Softening / Hardening effect

Bifurcations

Jump-resonance hysteresis



Nonlinear responses of ultrasonic devices

Nonlinear behaviour in piezoceramics is influenced by:

Application of high stresses

- High vibration amplitudes

Dielectric, mechanical and piezoelectric losses within piezoceramics

- Temperature increases
- High electric field

Ultrasonic tools:

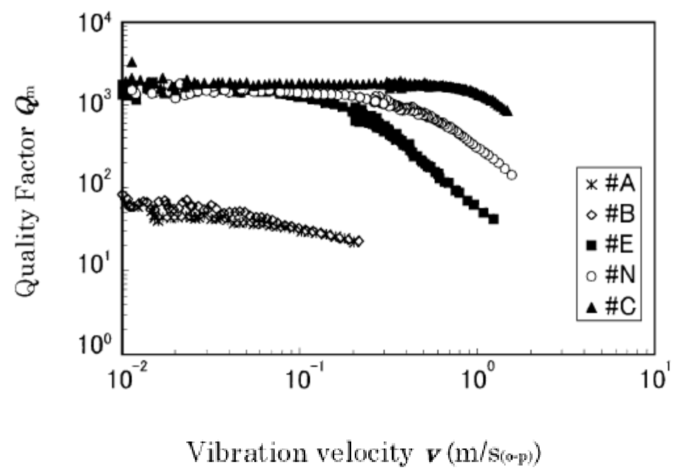
Application of high stresses

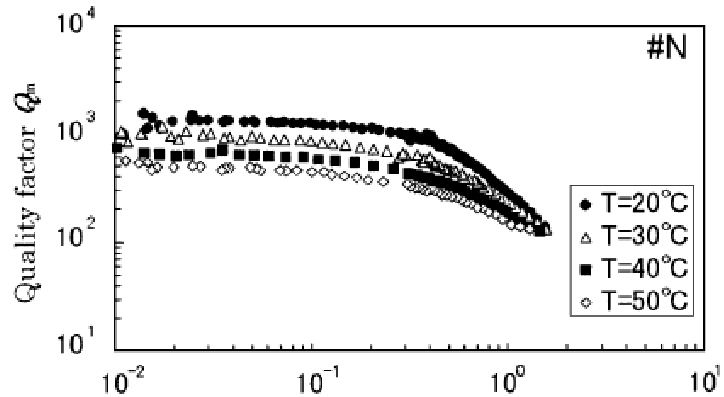
- High vibration amplitudes

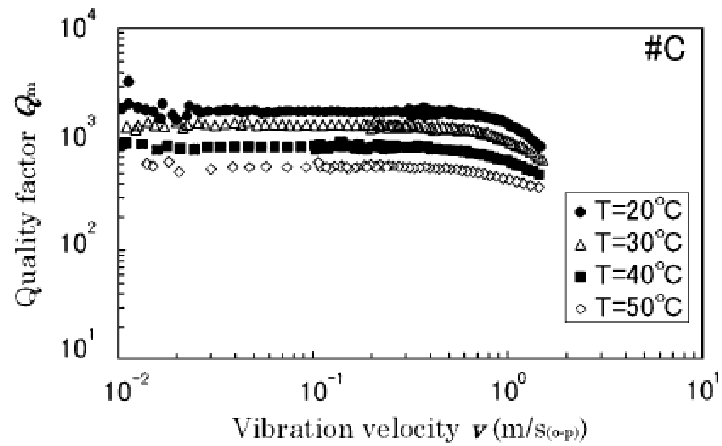
Device architecture

Material selection

Influence of temperature and ε on piezoceramics





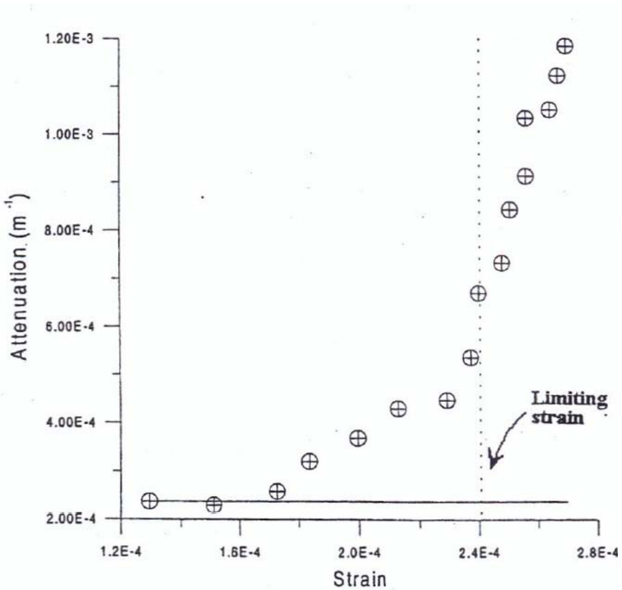


Piezoceramic samples;

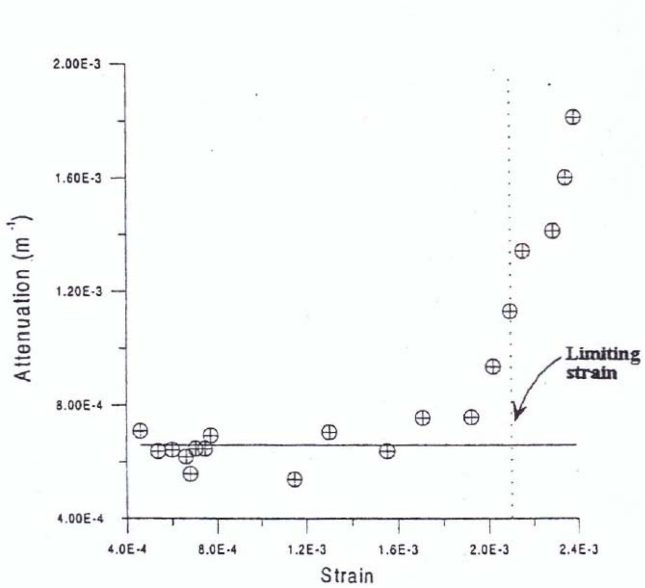
Q_m values:
#A: 60.7, #B: 85.2
#E: 1554, #N: 1292, #C: 2053

Umeda *et al*,1999.

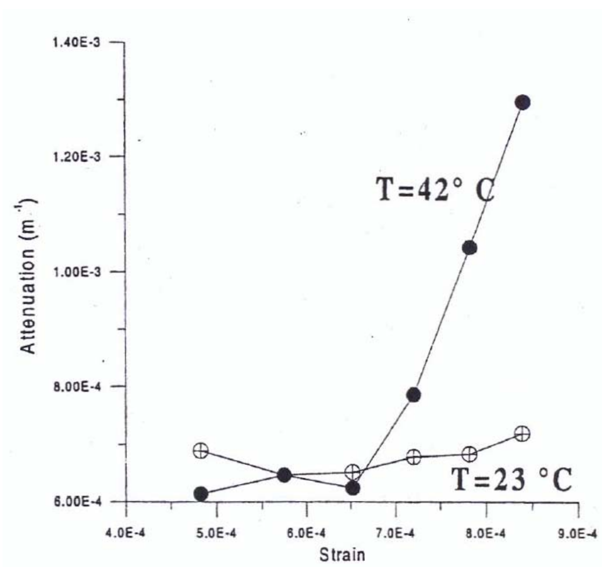
Influence of temp and ε on acoustic efficient metals



Duraluminium



Titanium



Titanium

Attenuation with respect to strain

	Limiting strain	Max Stress w/o fatigue
Duraluminium:	2.4×10^{-4}	30MPa
Titanium:	2.2×10^{-3}	200MPa

Campos-Pozuelo & Gallego-Juárez, 1996.

Characterisation of ultrasonic devices

Experimental modal analysis

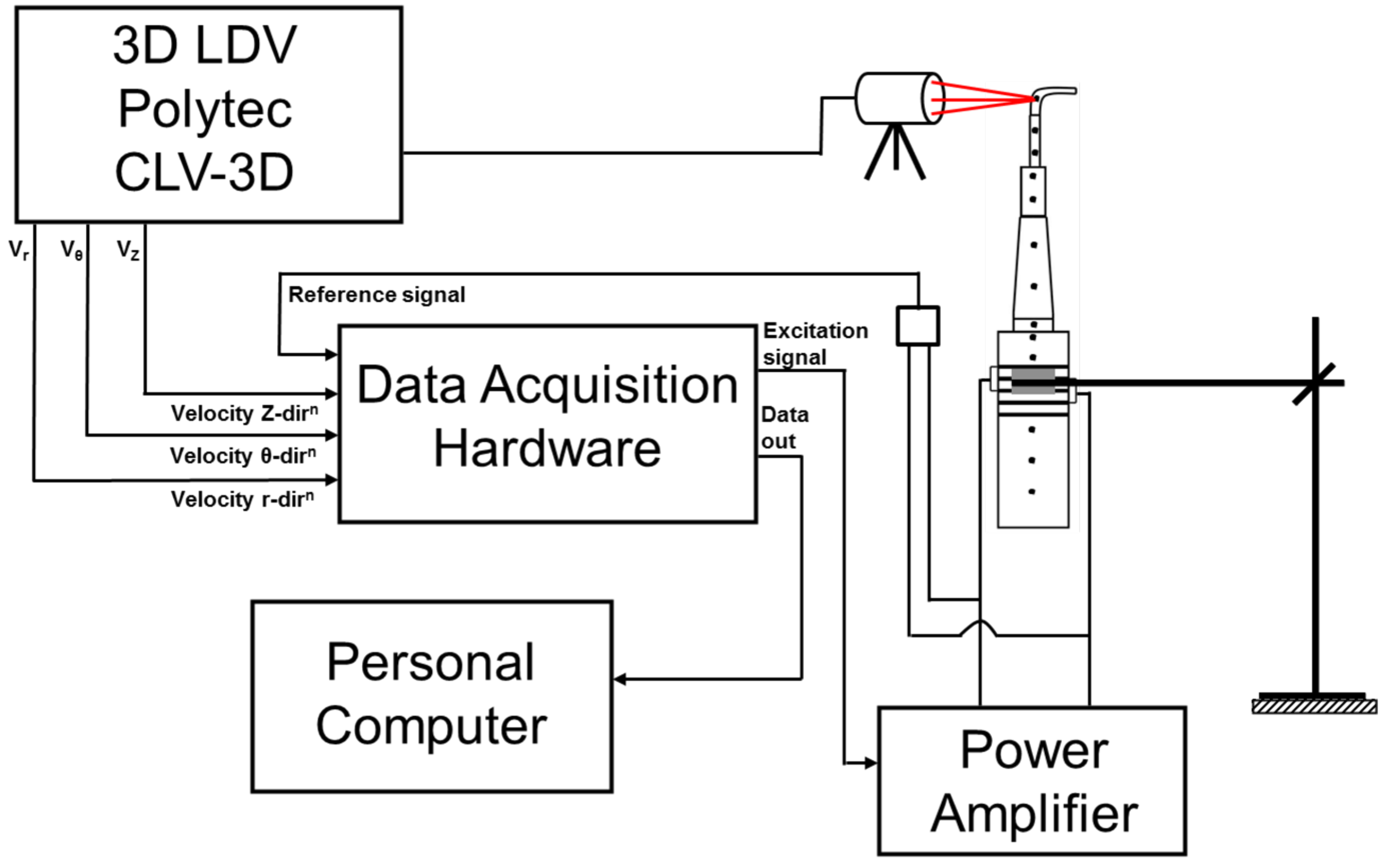
- Low power excitation: linear region of vibration
- Resonant frequencies and mode shapes extracted

Harmonic excitation

- Both low and high power excitation: linear and nonlinear regions
- Excitation via a bidirectional sweep
- To understand nonlinear characteristics of the ultrasonic device it is necessary to remove thermal contributions from the piezoceramics

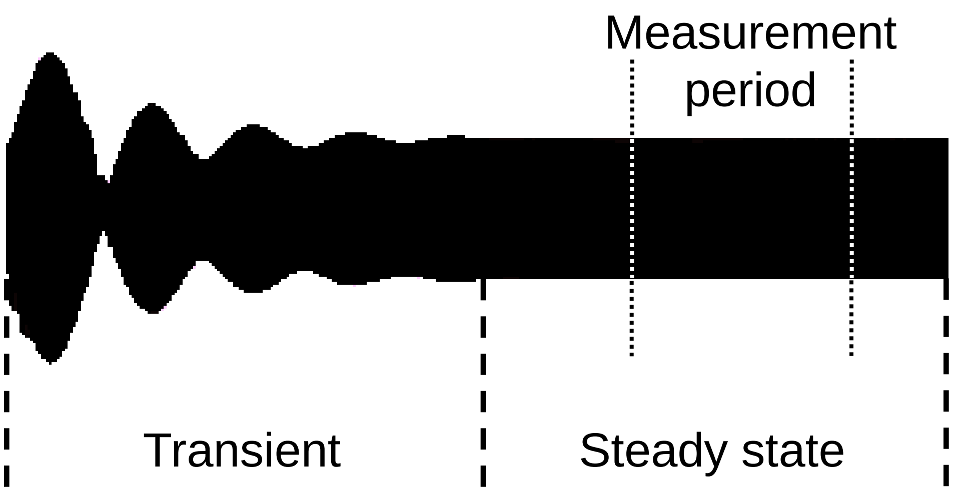
Characterising of power ultrasonic devices

Experimental modal analysis (EMA)



Harmonic excitation

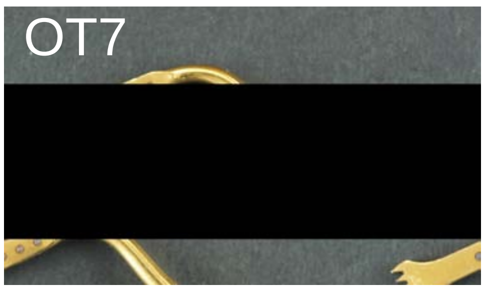
Bidirectional burst sine sweep technique



Burst

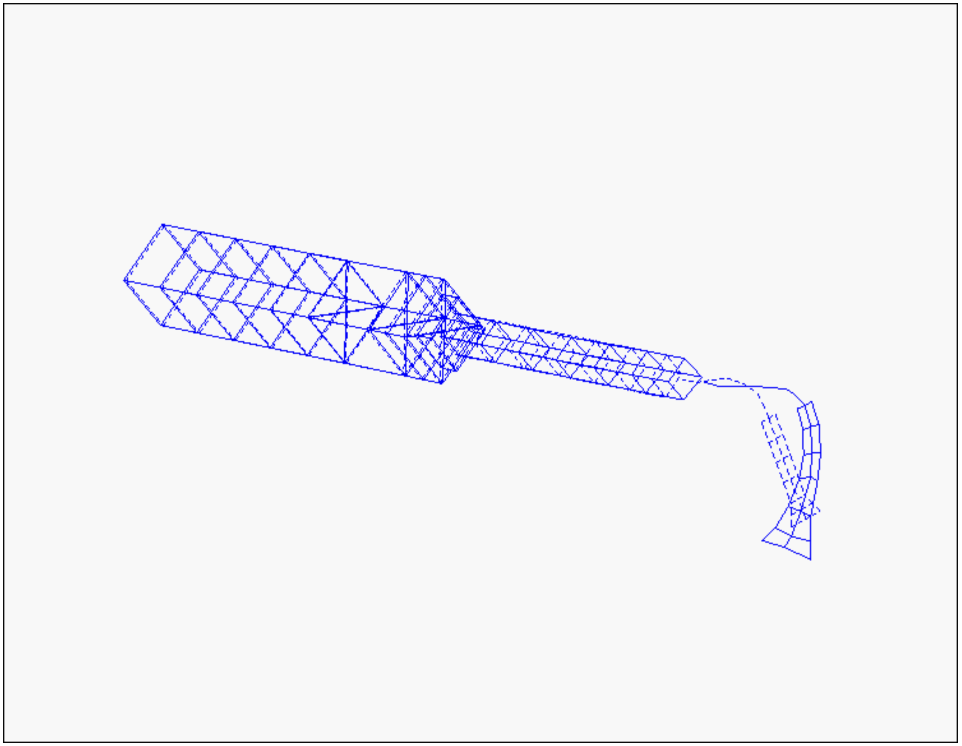
- 6000 cycles
- At 28kHz; 0.286 sec
- Time delay; 1-10 sec

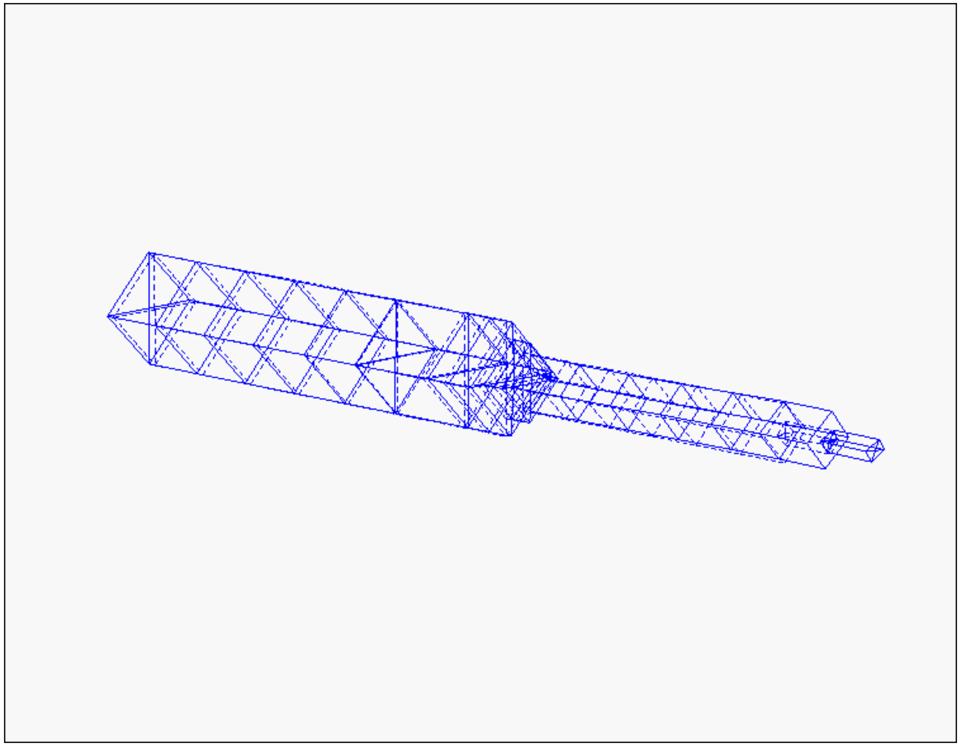
Investigated Devices



Mectron Transducer

EMA: Half wavelength devices

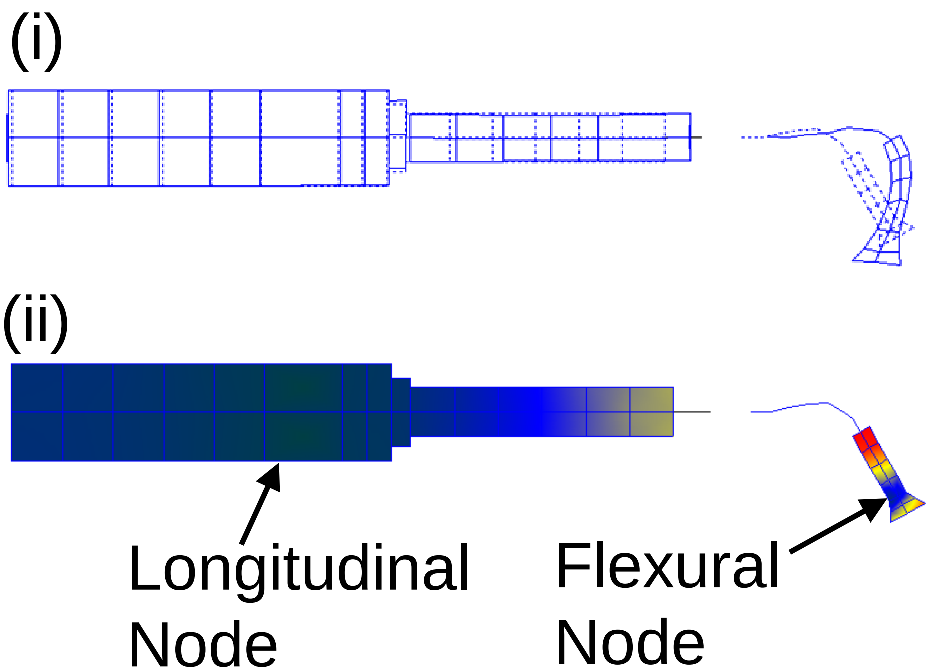


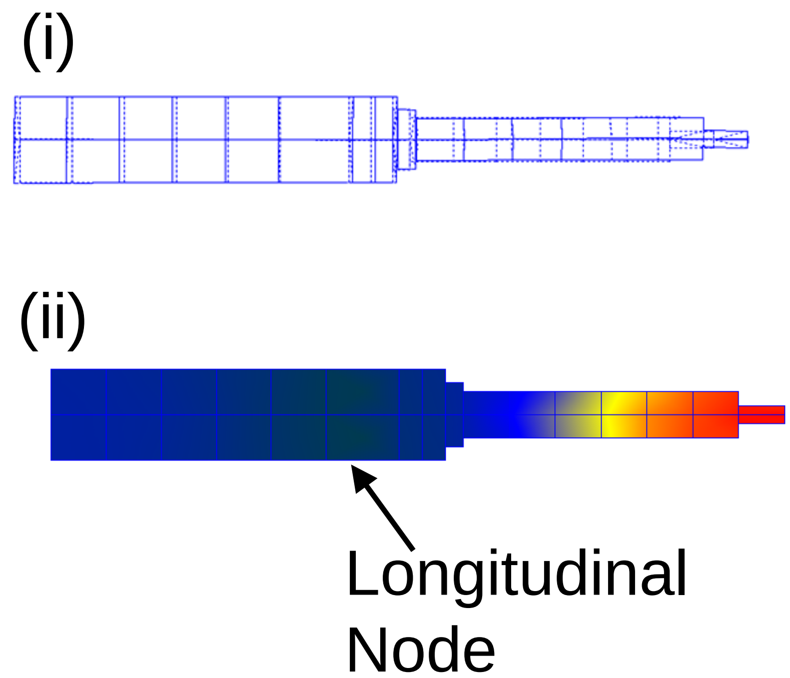


OT7: f = 27190Hz

BI: f = 28761Hz

EMA: Half wavelength devices

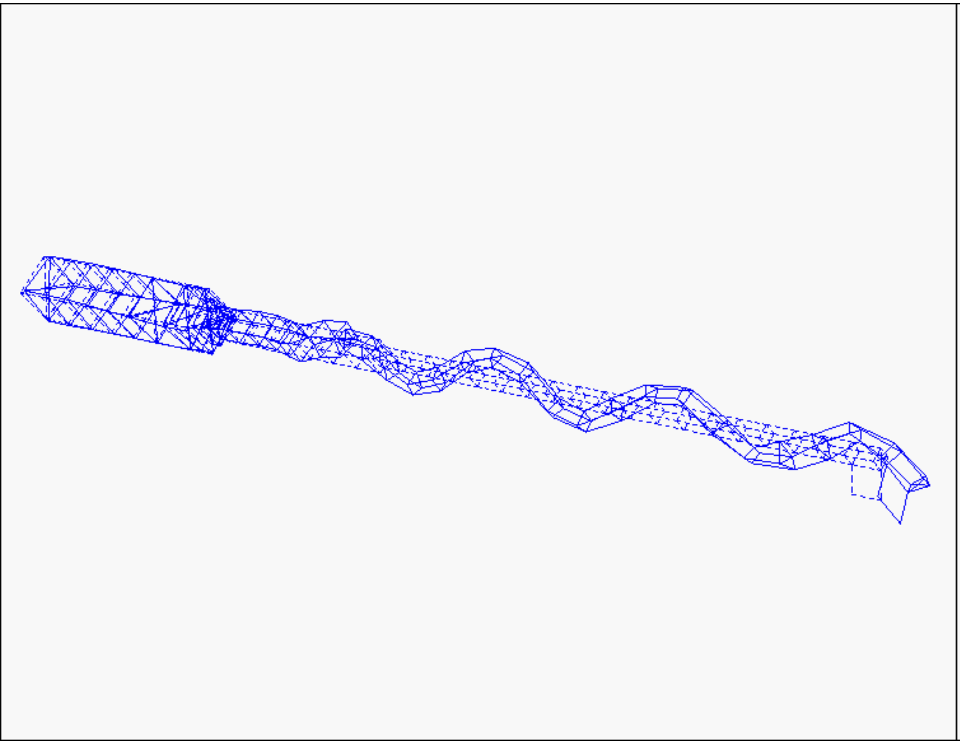


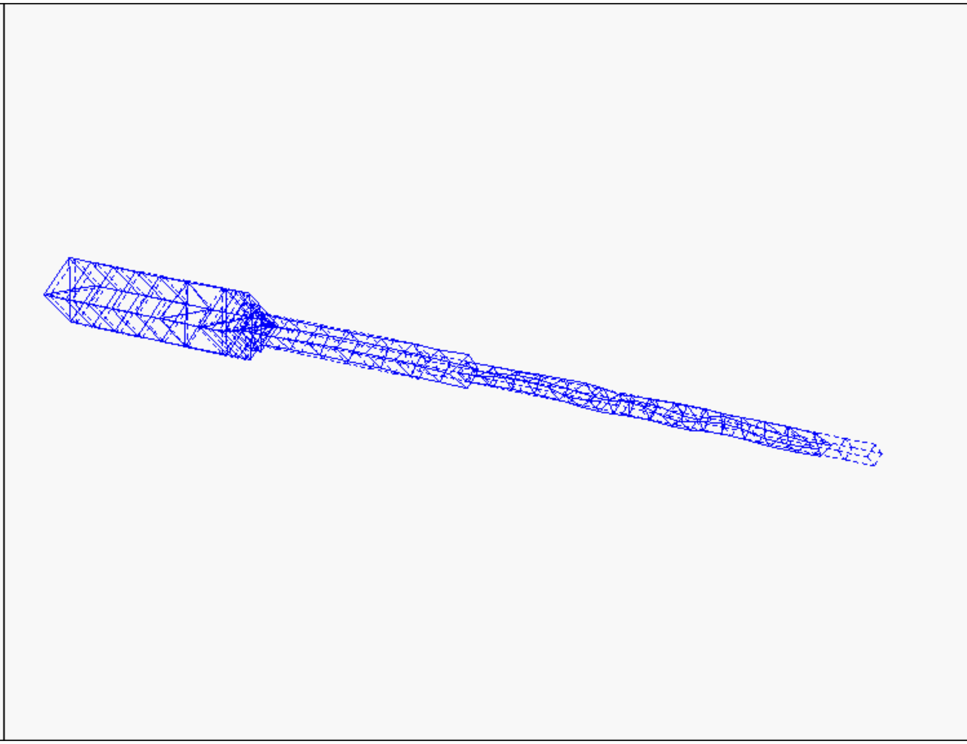


OT7: f = 27190Hz

BI: f = 28761Hz

EMA: Full wavelength devices



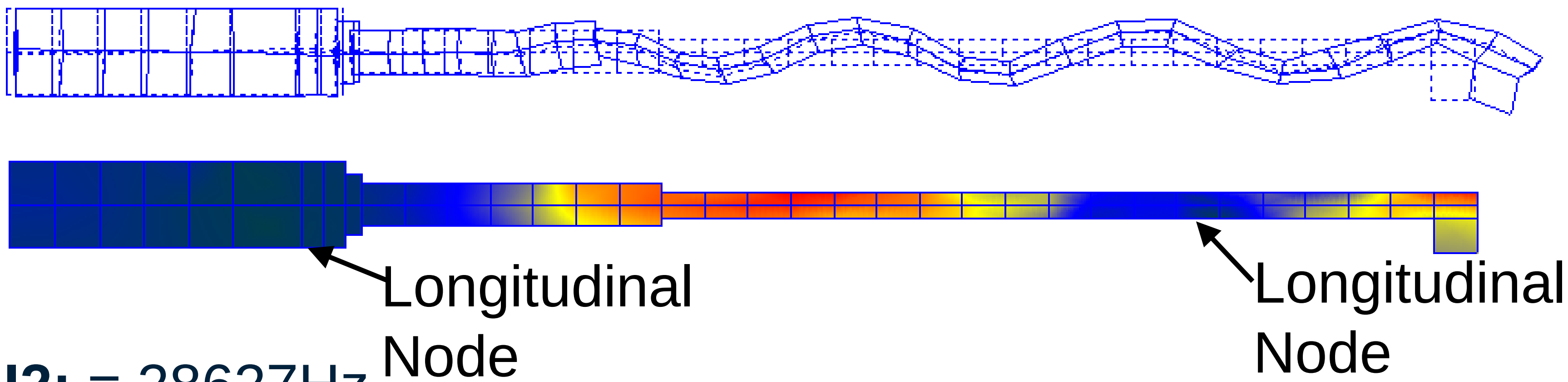


I1: f = 25935Hz

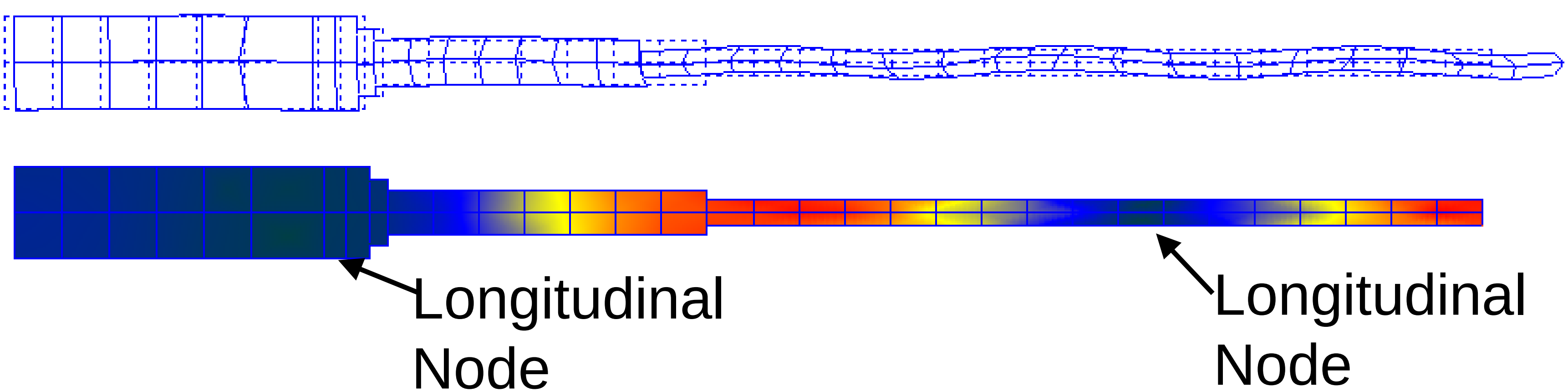
I2: = 28627Hz

EMA: Full wavelength devices

I1: f = 25935Hz



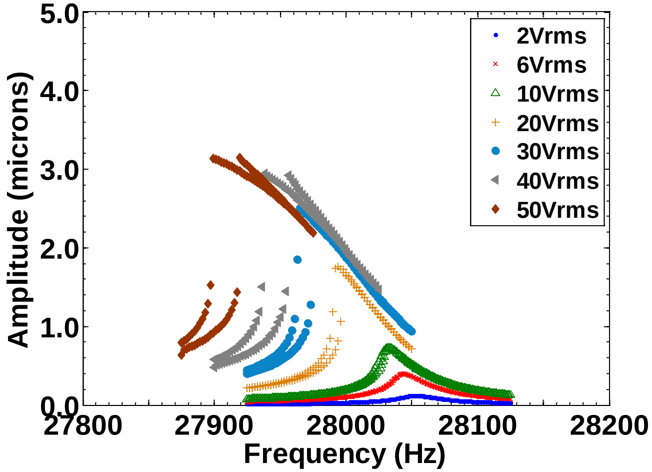
I2: = 28627Hz

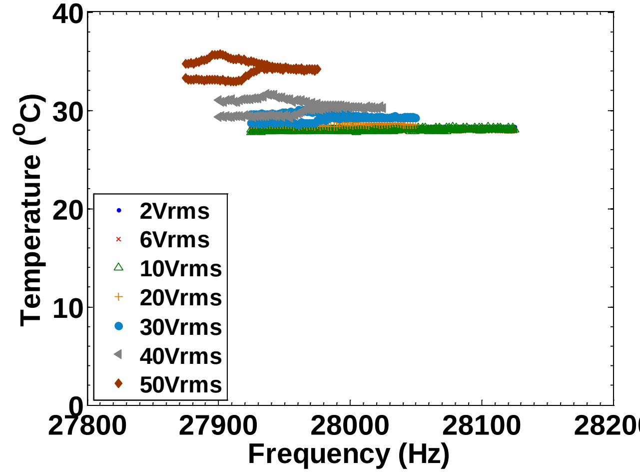


Influence of elevated piezoceramic temperature

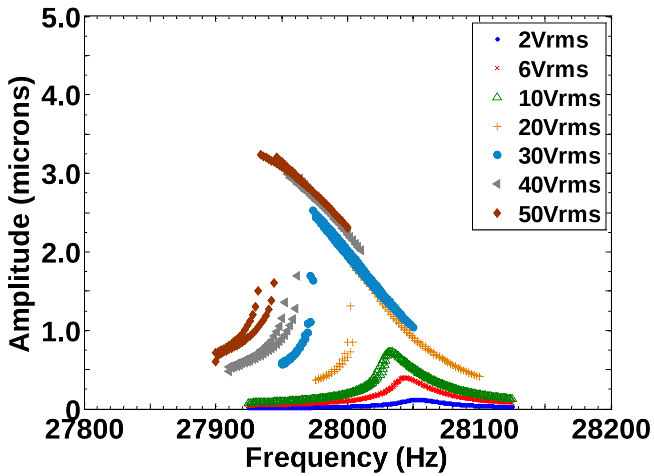
I3 insert

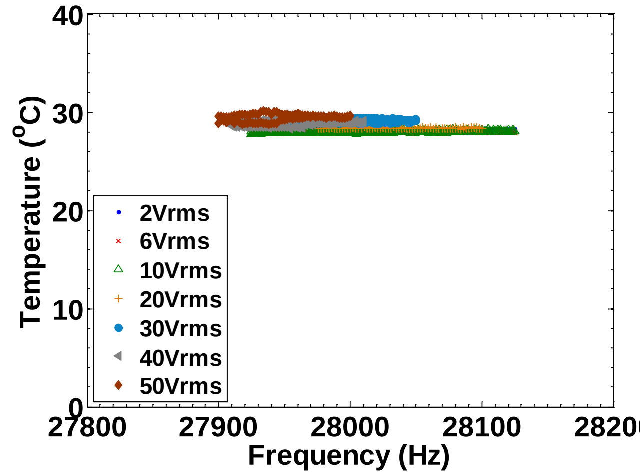
Time delay: 1sec





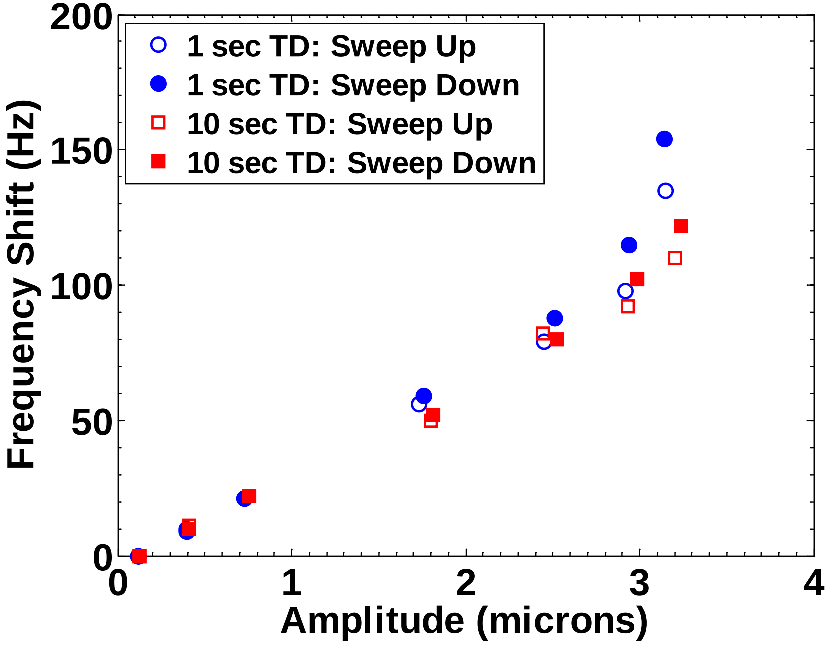
Time delay: 10sec

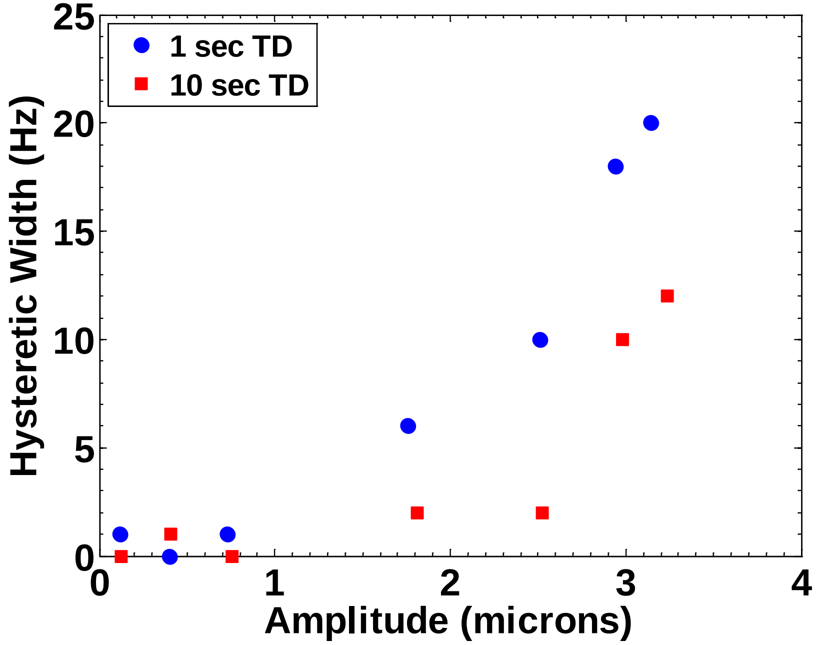




Influence of elevated piezoceramic temperature

Duffing-like behaviour





Resonant frequency shift

Hysteretic width

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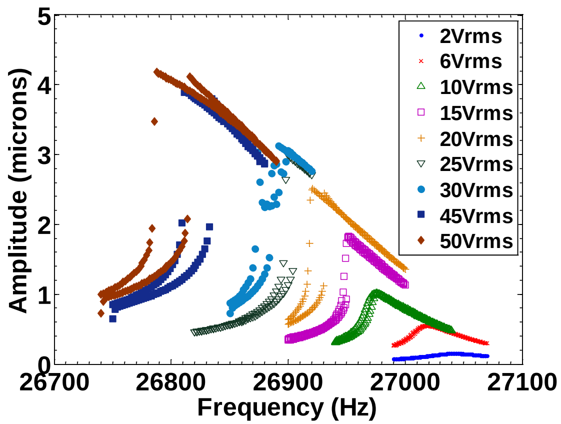
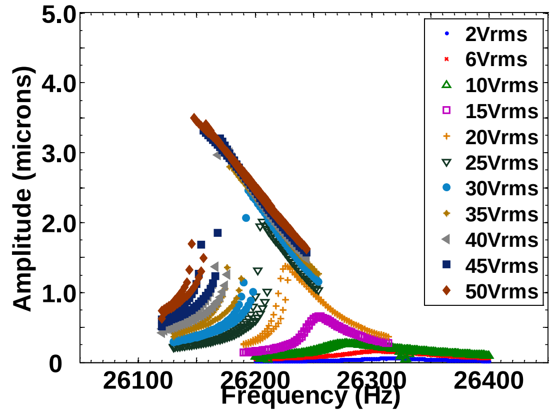
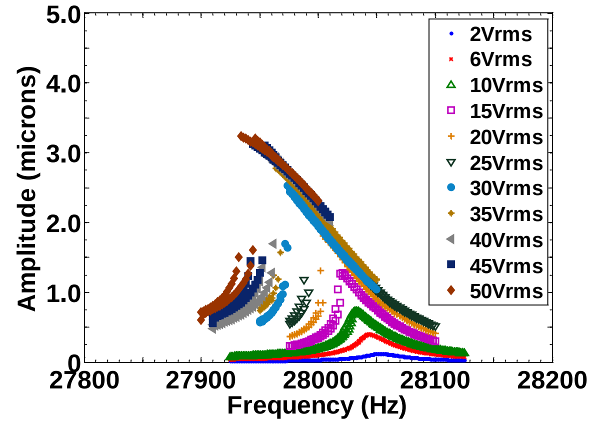
Harmonic characterisation



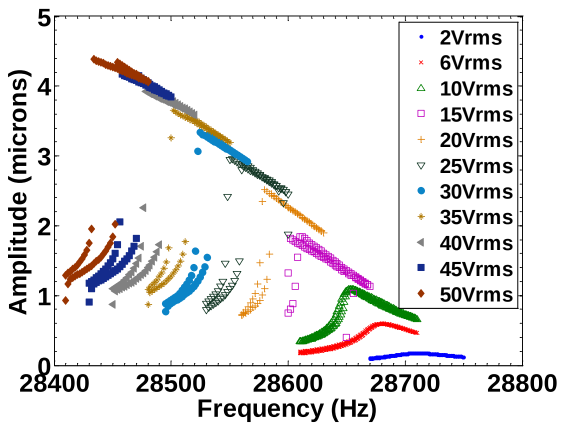
OT7



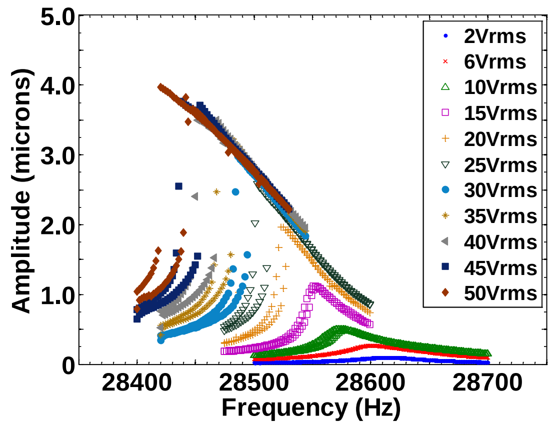
I1



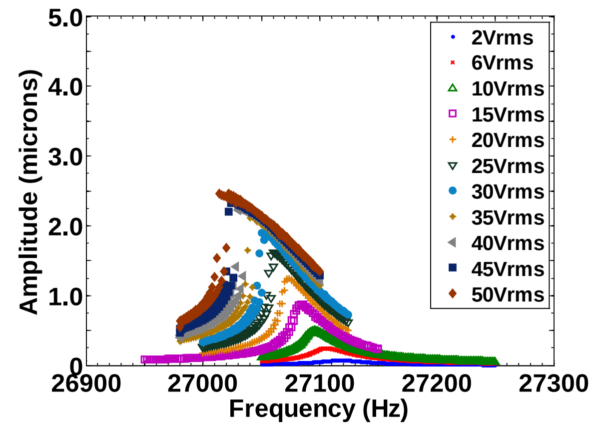
I3



BI



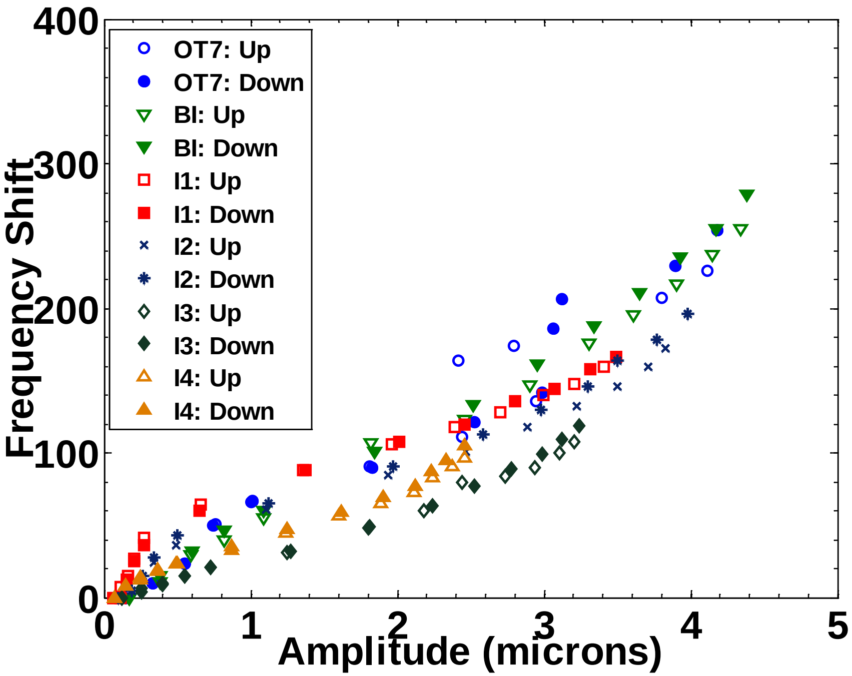
I2



I4

Harmonic characterisation

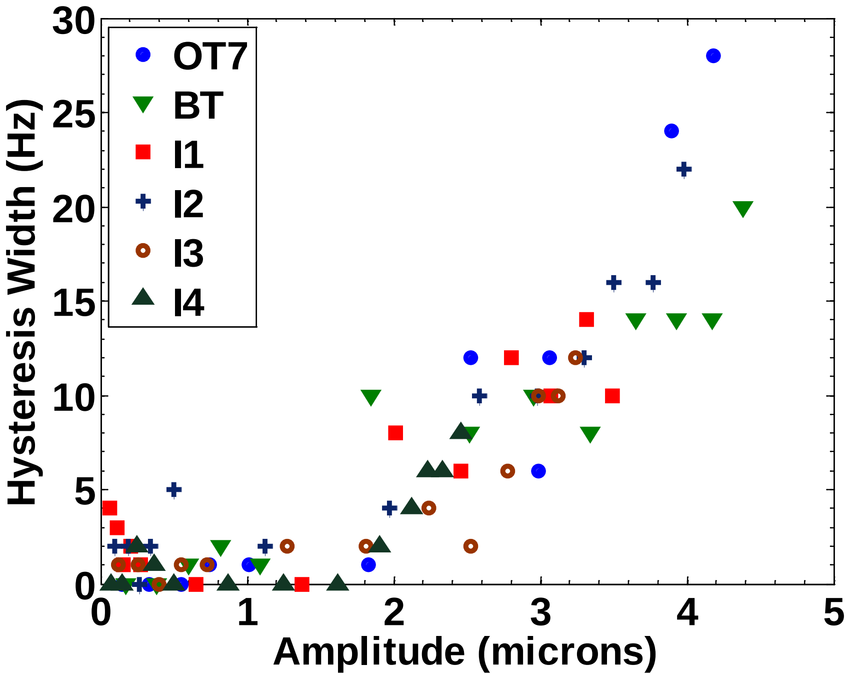
Resonant frequency shift



	Resonant frequency shift at 2.5μm (Hz)	Amplitude jumps	
		Amplitude (μm)	Voltage (V_{rms})
OT7	121	1.81	15
BI	133	1.81	15
I1	120	1.97	25
I2	113	2.47	25
I3	80	1.26	15
I4	105	1.60	25

Harmonic characterisation

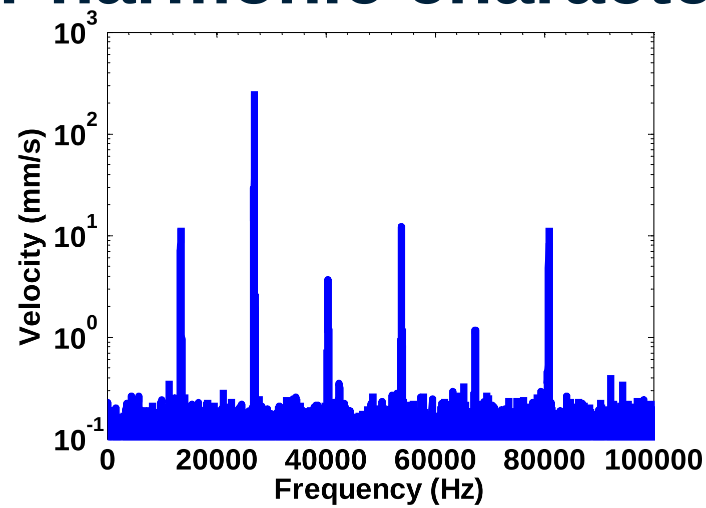
Hysteretic width



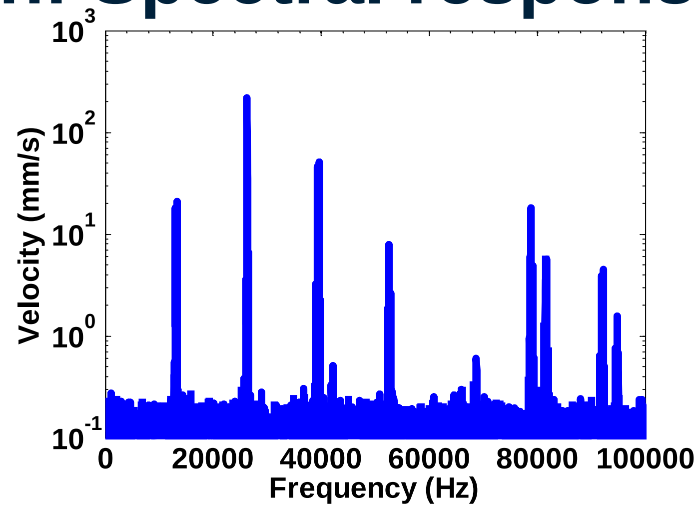
	Hysteretic region at 2.5μm (Hz)
OT7	12
BI	8
I1	6
I2	10
I3	2
I4	8

Power harmonic characterisation: Spectral response

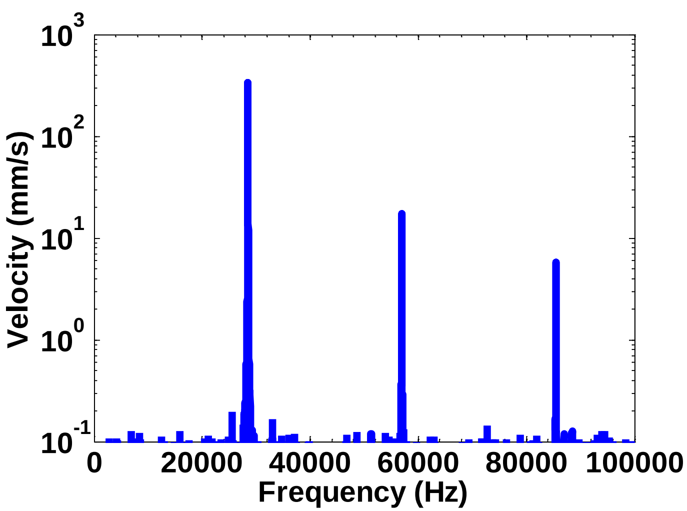
OT7



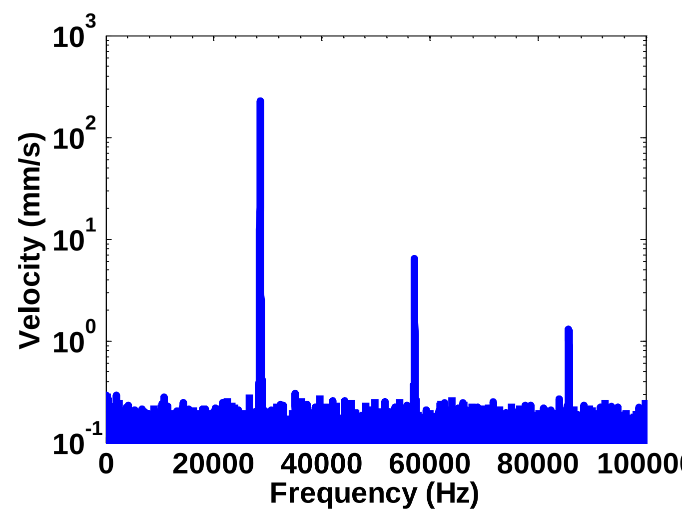
I1



BI



I2



Findings

- Good correlation of resonant frequencies and longitudinal mode shapes between FEA and EMA.
- Devices operating with elevated PZT temperatures exhibited increased levels of nonlinear behaviour;
  - Increase frequency shifts
  - Larger hysteric regions
  - Experimental method of significantly reduced thermal effect
- Devices operating at elevated amplitudes of vibration exhibited increased levels of nonlinear behaviour;
  - Increase frequency shifts found in ½λ devices (lower Q_m & higher strains)
  - Hysteretic regions increase with amplitude of vibration – Geometry appears not to influence this behaviour
- Inserts containing blade tip in both (OT7) ½λ & (I1) full λ assemblies induce flexural motion that increases the spectral response;
  - Possibility of a “route to chaos”

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Lab assistance: High power characterisation

Power Ultrasonic Group, Instituto de Acustica (CSIC), Madrid, Spain

Equipment

Mectron Medical Technology, Carasco, GE, Italy
EPSRC lone pool: High speed camera

Graphics

Peter McKenna: University of Glasgow

Thank you for listening

Questions?

References

www.mectron.com

MacBeath, A. 2006 Ultrasonic bone cutting, PhD thesis, University of Glasgow.

Beziat, J.-L. Bera, J.-C. Lavandier, B. Gleizal, A. 2007 Ultrasonic osteotomy as a new technique in craniomaxillofacial surgery. *Int. J. Oral Maxillofac. Surg*. **36**, 493–500.

O'Daly, B. Morris, E. Gavin, G. O'Byrne, J. McGuinness, G. 2008 High-power low-frequency ultrasound: A review of tissue dissection and ablation in medicine and surgery. *J. Mater. Process. Technol.* **200**, 38-58.

Aurelle, N. Guyomar, D. Richard, C. Gonnard, P. Eyraud, L. 1996 Nonlinear behavior of an ultrasonic transducer. *Ultrasonics, **34**,* 187-191.

Umeda, M. Nakamura, K. Ueha, S. 1999 Effects of Vibration Stress and temperature on the characteristics of piezoelectric ceramics under high vibration amplitude levels measured by electrical transient method. *Japn. J. Appl. Phys*., **38**, 5581-5585.

Albareda, A. Casals, J. Perez, R.Montero de Espinos, F. 2000 Nonlinear measurements of piezocomposite transducers with burst excitation, Application of Ferroelectrics, **2**, 979-982.

Campos-Pozuelo, C. Gallego-Juarez, J. 1996 Limiting strain of metals subjected to high-intensity ultrasound. *Acta Acust,* **82**, 823-828.