



NONLINEAR VIBRATION PROBLEMS IN POWER ULTRASONIC SYSTEMS: POSSIBLE CAUSES, DETECTION, AND SOME PRACTICAL REMEDIES

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OUTLINE:



- **POWER ULTRASONIC TRANSDUCERS WITH EXTENSIVE RADIATORS**
- **VIBRATION BEHAVIOUR OF TRANSDUCERS – IDENTIFICATION OF THE CAUSES OF THE MAIN OPERATIONAL PROBLEMS – HOW TO CONTROL THE DYNAMIC CHARACTERISTICS OF POWER TRANSDUCERS?**
 - Nonlinear response characteristics of piezoelectric power transducers
 - Modal interactions:
 - 1) Modal coupling between high and low frequency modes
 - 2) Modal coupling between close modes
- **CONCLUSIONS**



INTRODUCTION



ULTRASONIC PLATE TRANSDUCERS:

Designed for applications in gases and multiphase fluid media

- Good impedance matching
- Large amplitude of vibration
- High efficiency (up to 80%)
- High directional or focused

Vibration behaviour issues which may hamper applicability to industry

- Multimodal responses
- Combination of resonances
- Modal couplings between close modes
- Hysteretic responses

Method:

In this work strategies for the mitigation of ultrasonic system nonlinear behaviour and modal couplings towards a better control of tuned devices are provided through a combination of FEM and experimental work.



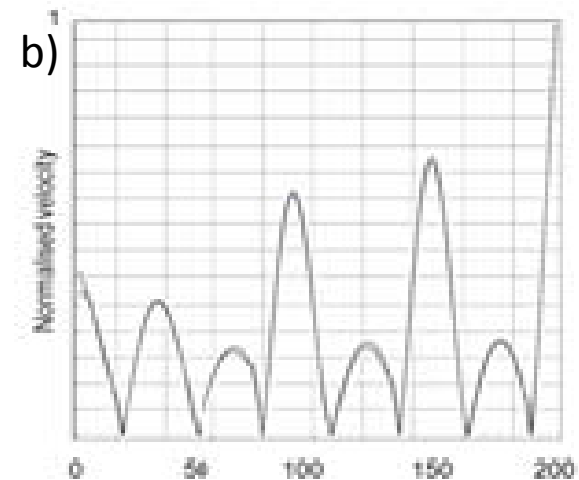
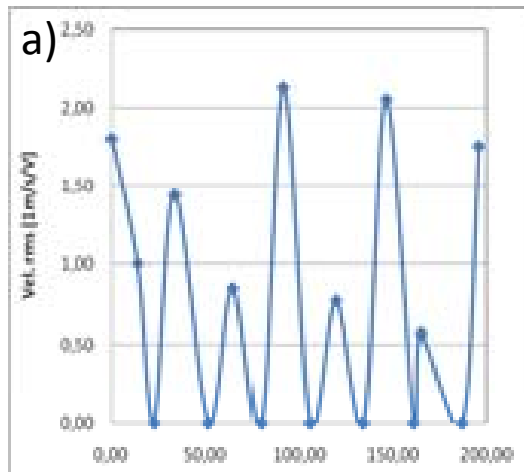
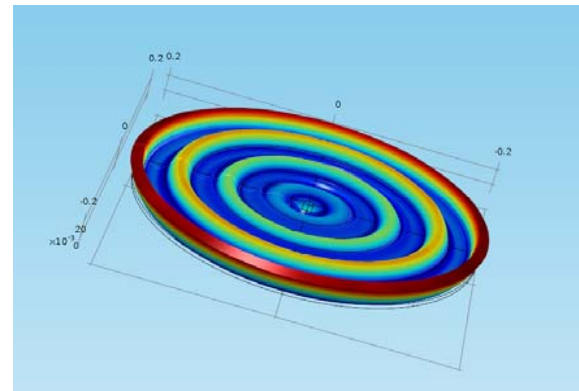
POWER PIEZOELECTRIC TRANSDUCERS WITH EXTENSIVE RADIATORS



a) Ultrasonic plate-transducer



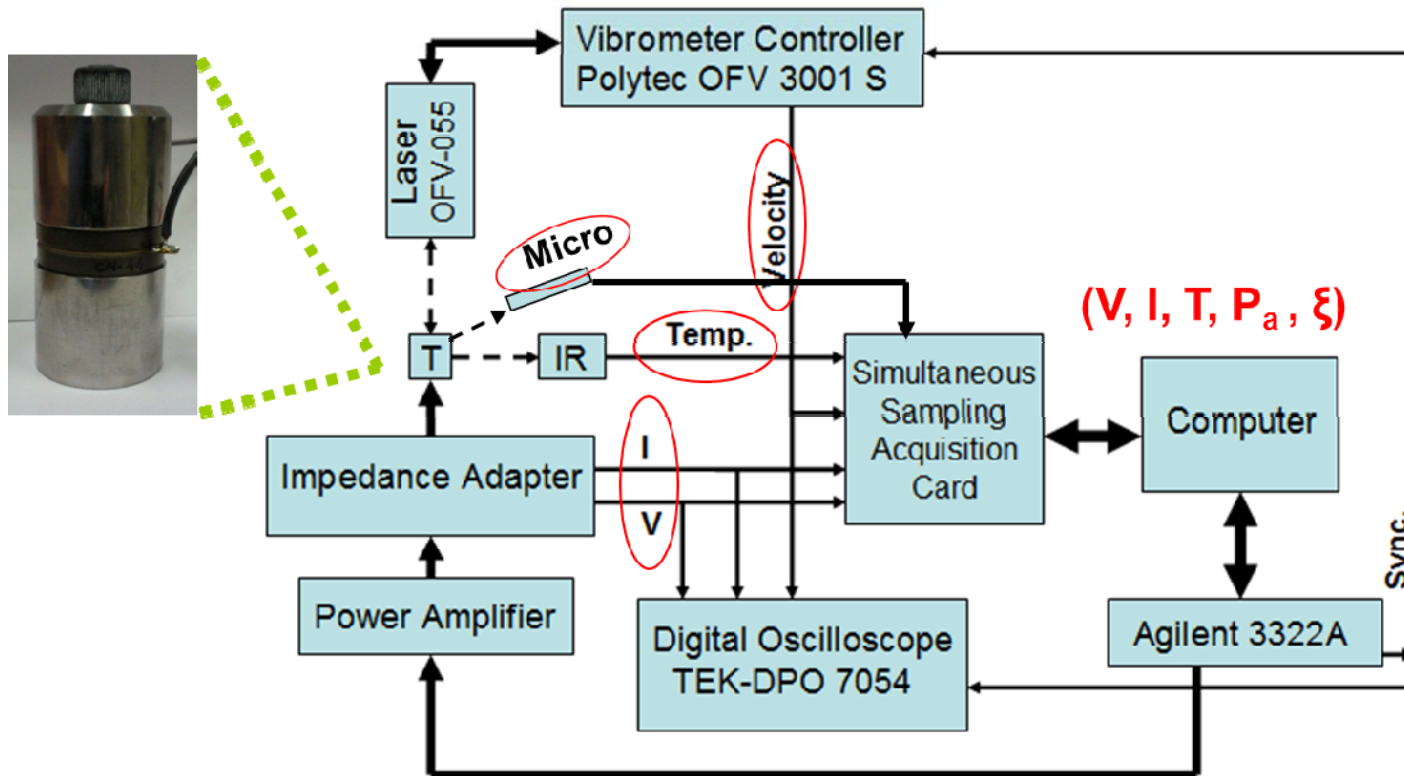
3D FE plate model resonating in the tuned mode



Displacement distributions: (a) by laser vibrometer measurements, b) by FEM

CHARACTERISATION OF THE BEHAVIOUR OF ULTRASONIC SYSTEMS AT HIGH POWER

Schematic of experimental rig for transducers' response characterization



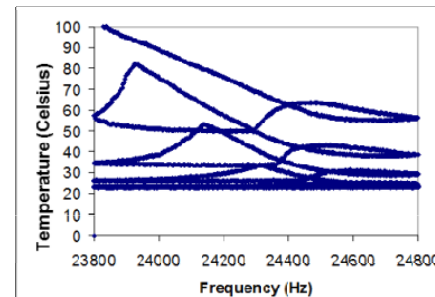
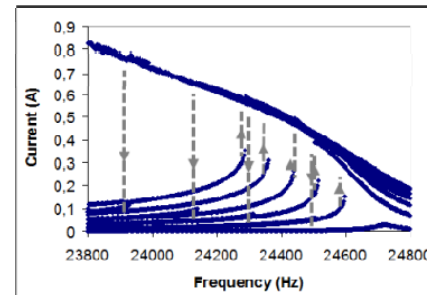


Nonlinear response characteristics of piezoelectric power transducers (I)



Experimental and theoretical studies have shown that “softening” response characteristics of ultrasonic devices are mainly due to the **nonlinear behaviour of the PZT stacks**. Piezoelectric, dielectric and elastic losses of piezoceramics have shown being responsible **for modal frequency shifts and temperature increases** at high power.

Ultrasonic Piezoelectric Transducer – Langevin Type



Frequency sweeps of sinusoidal excitation: Continuous signal

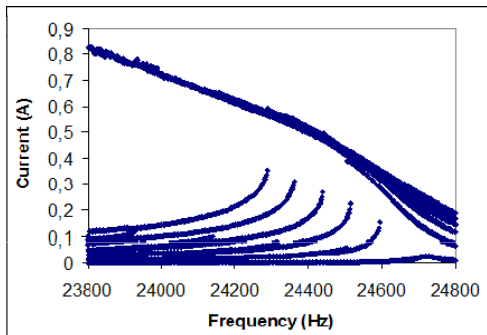


Nonlinear response characteristics of piezoelectric power transducers (II)

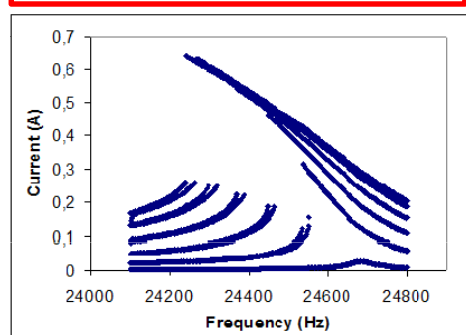


Continuous Excitation Vs Burst Excitation on transducer vibration response

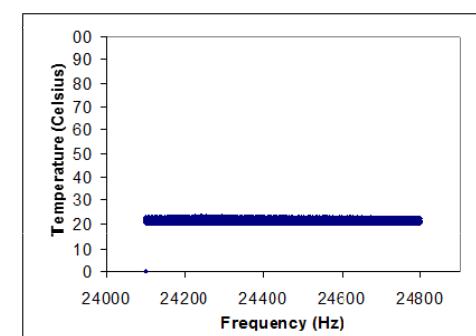
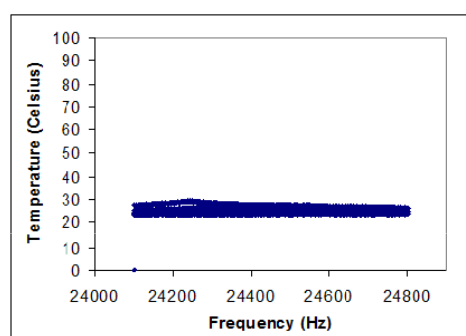
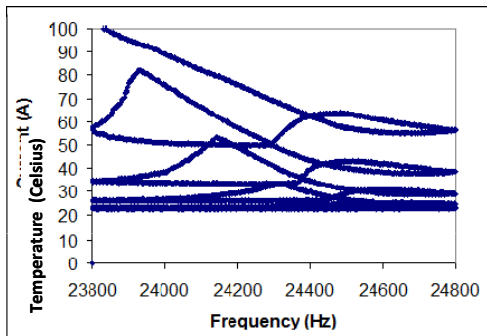
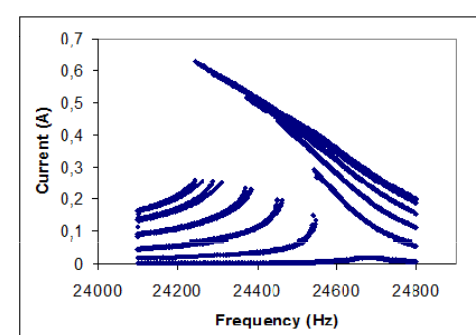
Continuous excitation



Burst excitation 0,5 sec between frequency incr.

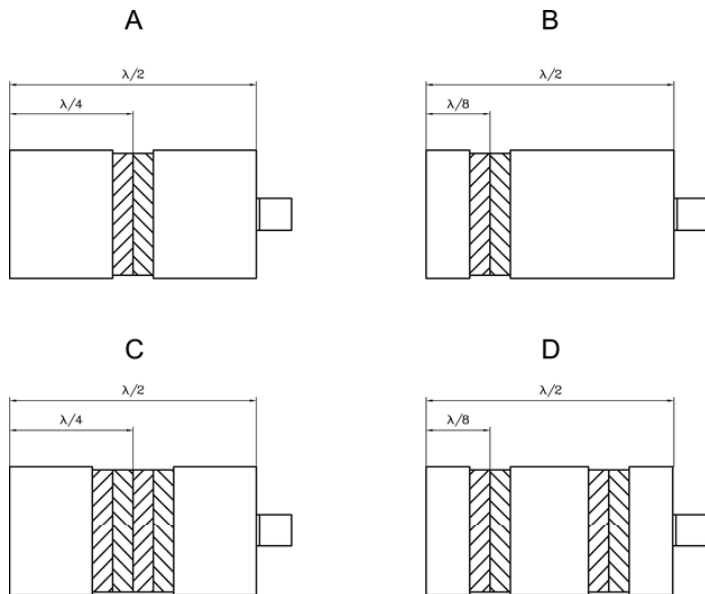


Burst excitation 5 sec between frequency incr.



Nonlinear response characteristics of piezoelectric power transducers (III)

Effect of the positioning of piezoceramics in a Langevin transducer



(a)

A) 24.7 kHz



(b)

B) 26.9kHz



(c)

C) 22.5 kHz

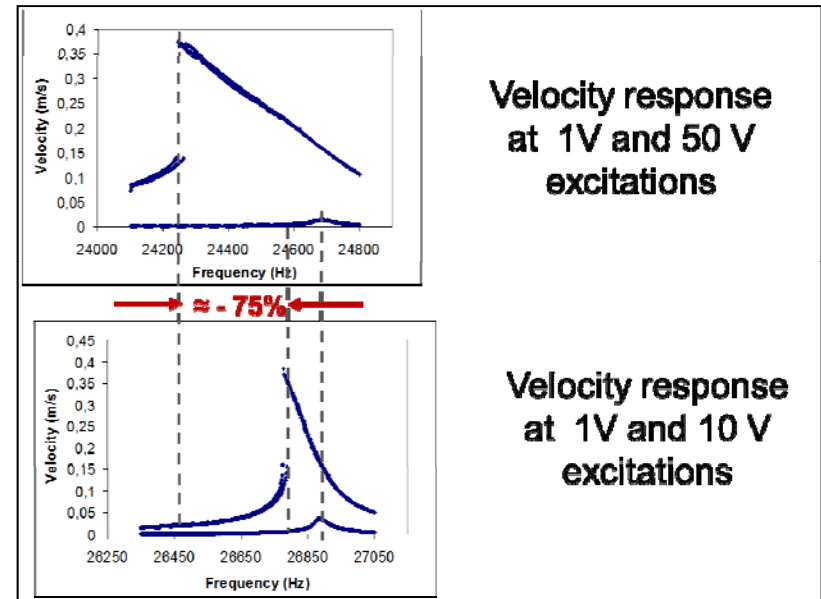
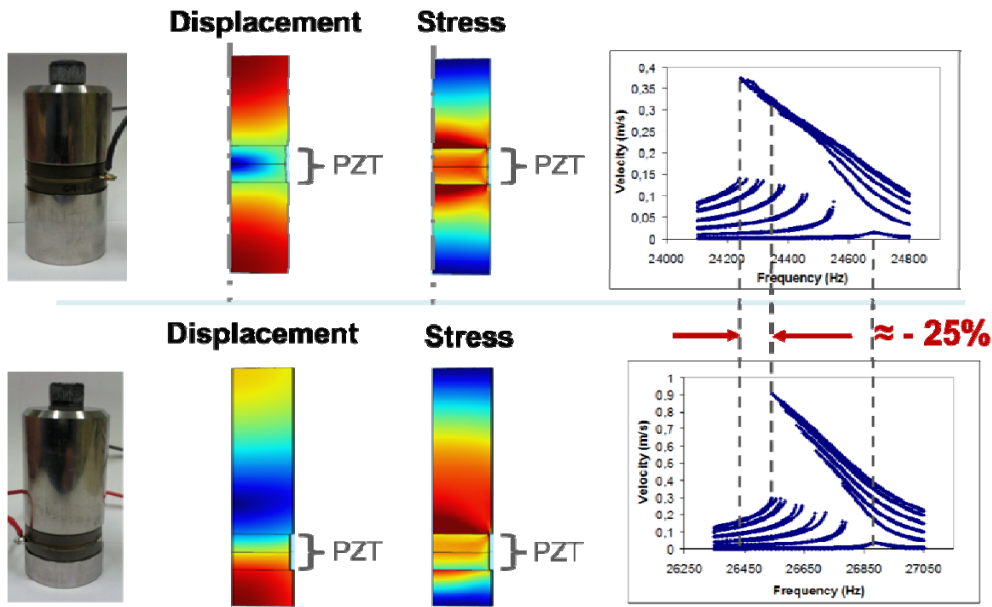


(d)

D) 24.7kHz



Effect of PZT position on transducer response with two-ceramic stack. Mitigation of nonlinear response



Voltage levels = 10 V, 20 V, 30 V, 40 V, 50 V

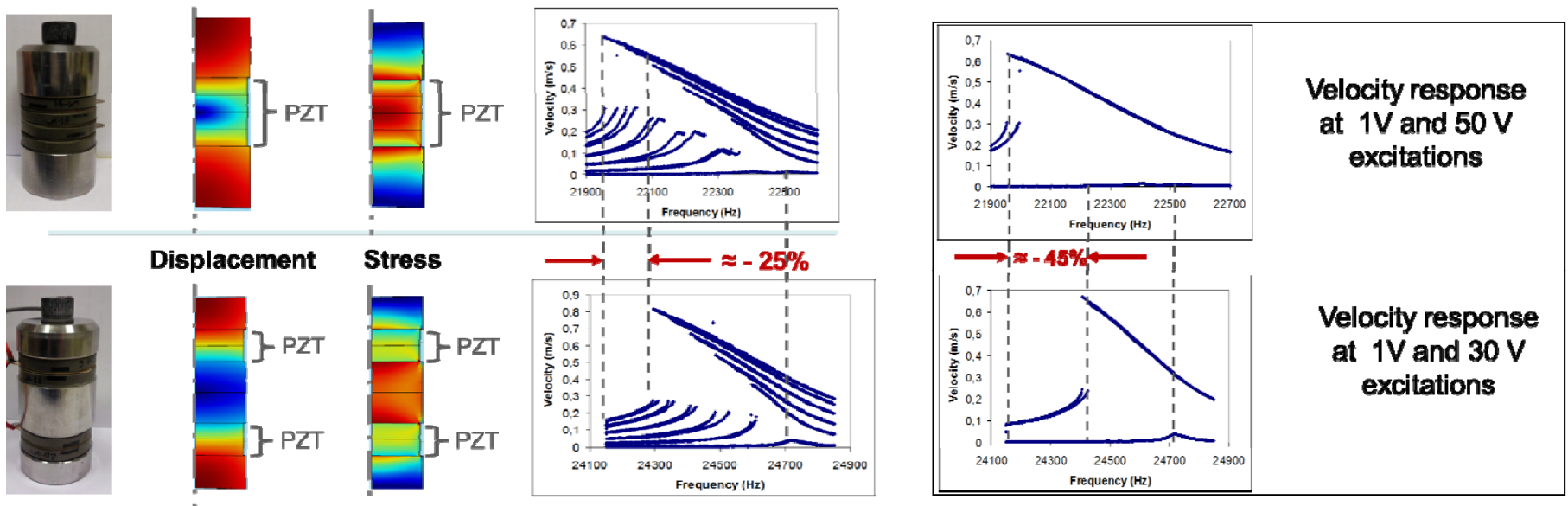
Time delays = 0.5 sec to avoid thermal increases in the PZT

Modal response characteristics were measured around the tuned frequency by pointing the laser vibrometer at the transducer output face

For a fixed vibration velocity value a **reduction** of the frequency shift of **75%** could be achieved



Effect of PZT position on transducer response with four-ceramic stack. Mitigation of nonlinear response



Voltage levels = 10 V, 20 V, 30 V, 40 V, 50 V

Time delays = 0.5 sec to avoid thermal increases in the PZT

Modal response characteristics were measured around the tuned frequency by pointing the laser vibrometer at the transducer output face.

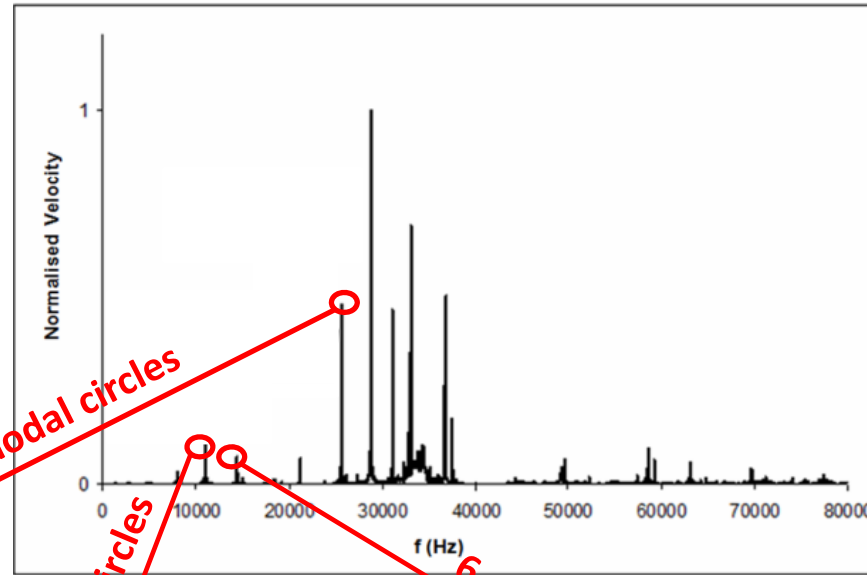
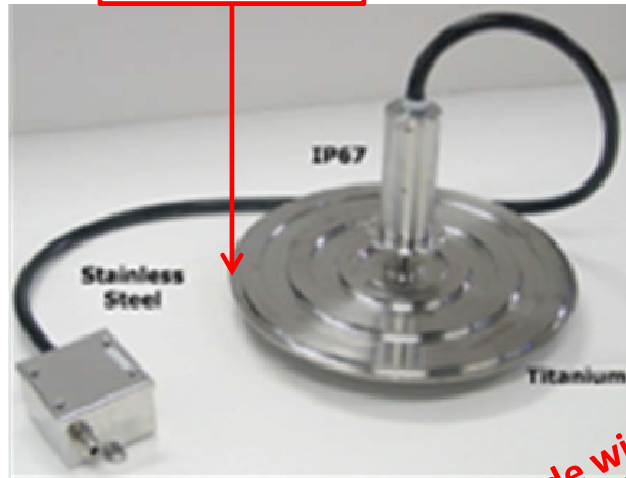
For a fixed vibration velocity value a **reduction** of the frequency shift of **45%** could be achieved .



Modal interactions in plate-transducers (I)



Vibrometer

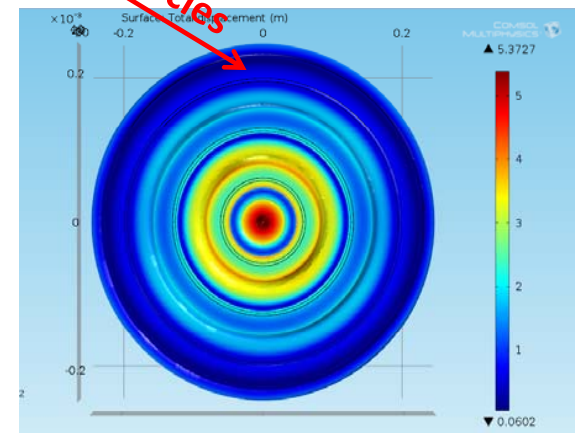
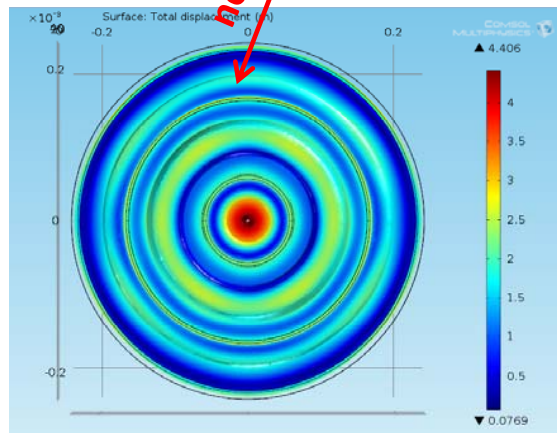
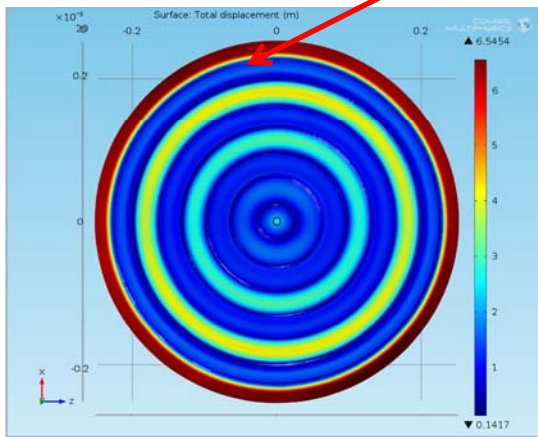


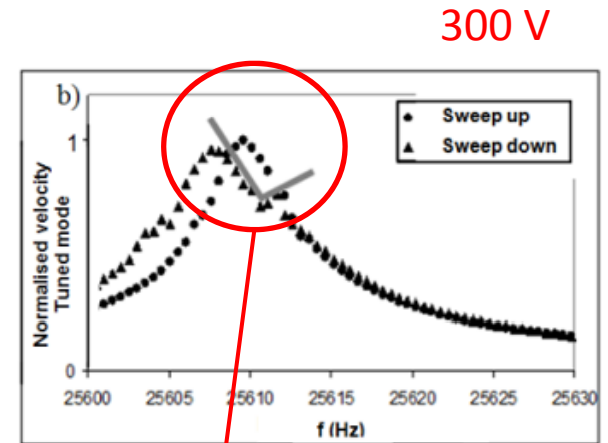
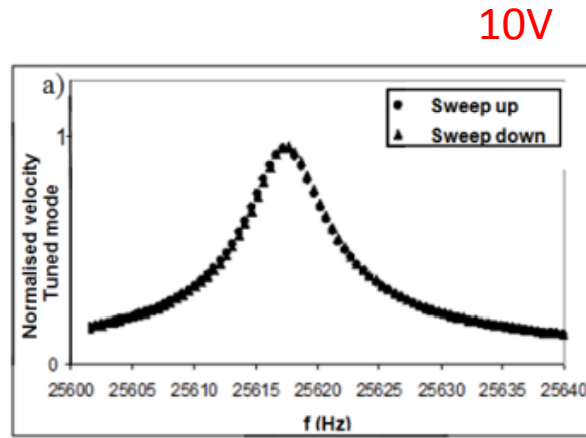
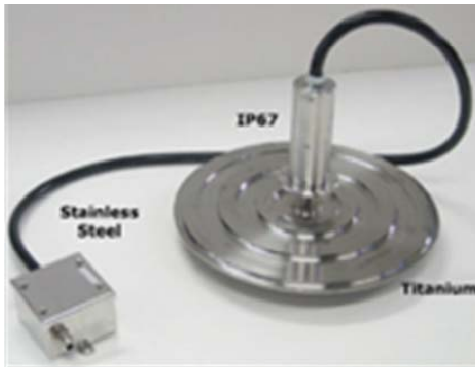
Tuned mode with 7 nodal circles

Focal circles

6 nodal circles

Vibration velocity response measured in the 1-80 kHz range under a 10 V excitation





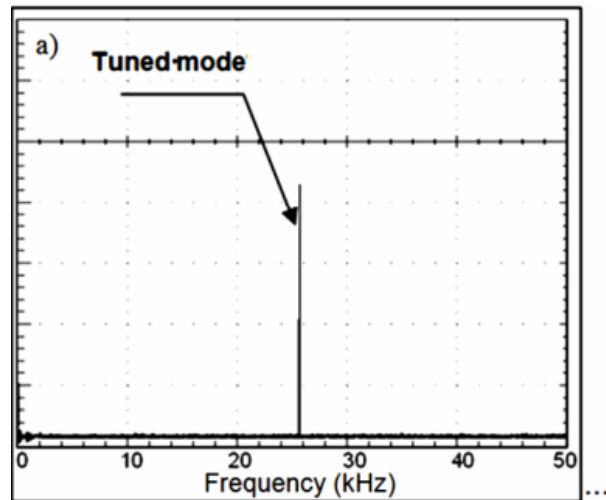
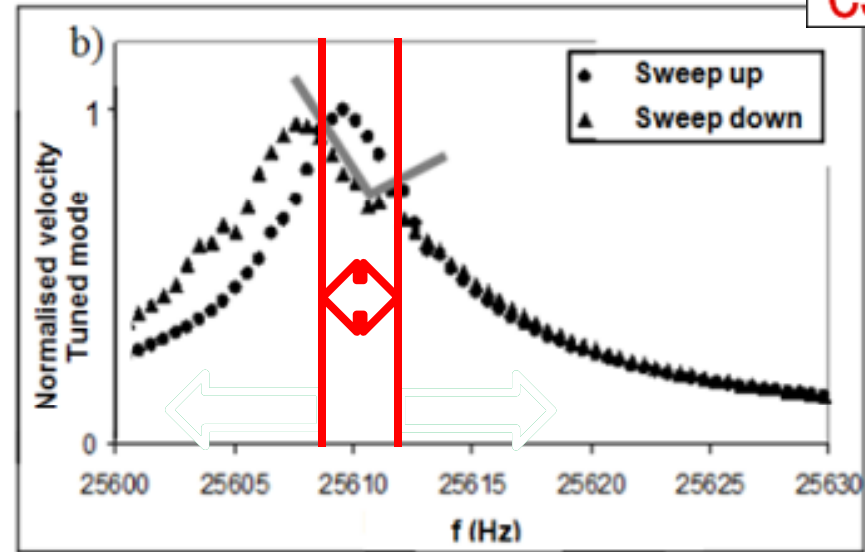
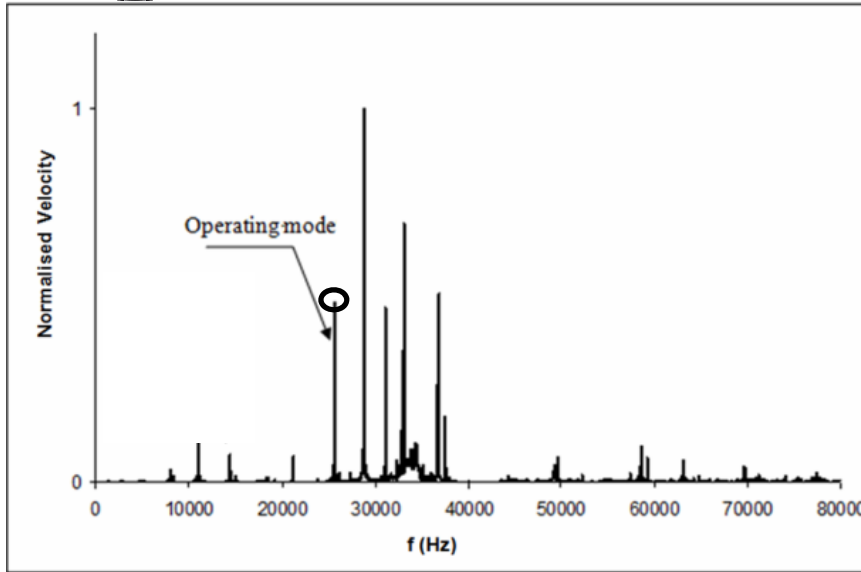
Normalized vibration velocity frequency responses obtained via upward and downward frequency sweeps around the tuned frequency:

- (a) applied voltage, 10 V;
- (b) applied voltage, 300V

V-shaped region



Modal interactions in plate-transducers (III)



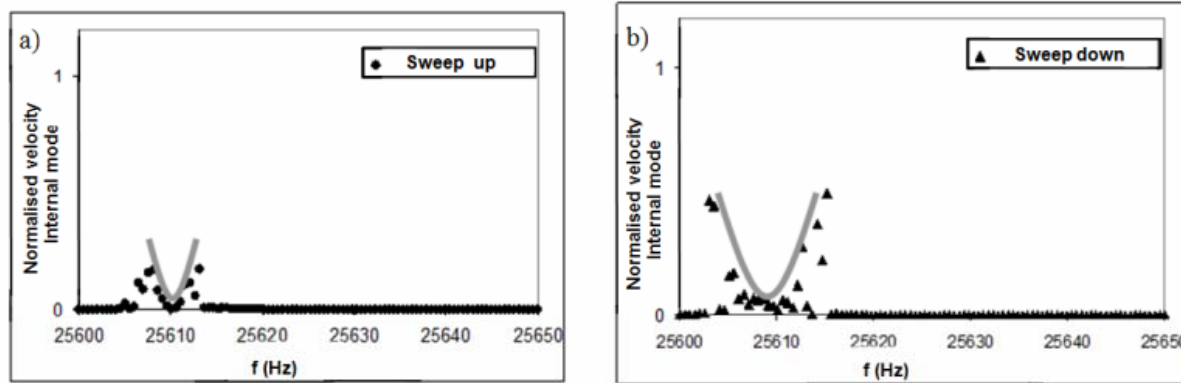
OUTSIDE the V-shaped region. One single mode: 25.5 kHz



Modal interactions in plate-transducers (IV)



25600 – 25650 Hz



Normalized velocity (secondary) response of an internal mode of the plate-transducer excited via frequency sweeps around the tuned frequency under a **300 V** drive: (a) sweep up; (b) sweep down.

To avoid the occurrence of this unwanted modal interaction a modification of the tuned system geometry was carried out to break the frequency relationship between modes. It was decided to (slightly) modify the diameter of the plate by taking off 0.5 mm from it.

Sweep tests of the modified plate-transducer at nominal power did not show evidence of any modal interaction.



CONCLUSIONS

In this presentation a few strategies to control the vibration behavior of power plate transducers have been presented.

- First, the effect of the location of the piezoelectric elements used in the Langevin power transducers was investigated confirming that it is possible to mitigate the high power nonlinear response characteristics by placing PZT away from the most stressed regions.
- Second, geometrical modifications of an airborne plate transducer were carried out to avoid modal interactions between well separated modal frequencies.



ACKNOWLEDGEMENTS:



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