University of Glasgow | School of Engineering

Ultrasonic Industrial Association 2011 Symposium

Characterisation of Langevin transducers

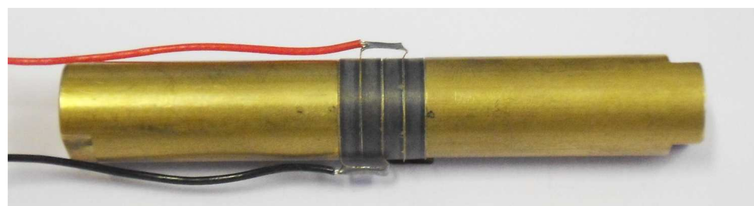
Andrew Mathieson[1], Andrea Cardoni[2], Niccolò Cerisola[3]
[1]Systems, Power & Energy research division, School of Engineering, University of Glasgow
[2]PUSONICS SL, Spain
[3] Mectron Medical Technology, Italy

Overview

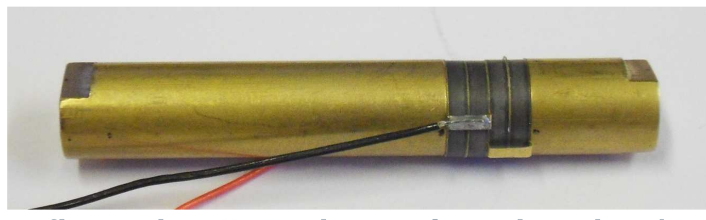
Langevin transducers, also commonly known as sandwich or stack transducers, at their most basic, are generally constructed from four fundamental components; front mass, back mass, piezoceramic stack and are held together under a compressive pre-load with a stud or bolt. It is traditionally proposed that the piezoceramic stack is positioned at or close to the vibrational nodal point of the longitudinal mode, however, this also corresponds with the position of highest dynamic stress. Ultrasonic devices are inherently nonlinear when driven at high excitation levels, and it is well documented in literature that piezoceramics, partly due to their low linear stress threshold, are a source of nonlinear behaviour. Therefore, this study investigates whether locating the piezoceramic stack away from a position of intrinsic high stress will reduce or alter the nonlinear behaviour of the device.

Transducers

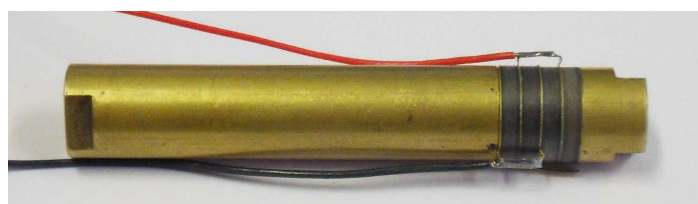
Half wavelength transducers with brass endmasses and three different stack locations.



Configuration I: Endmass length ratio 1:1



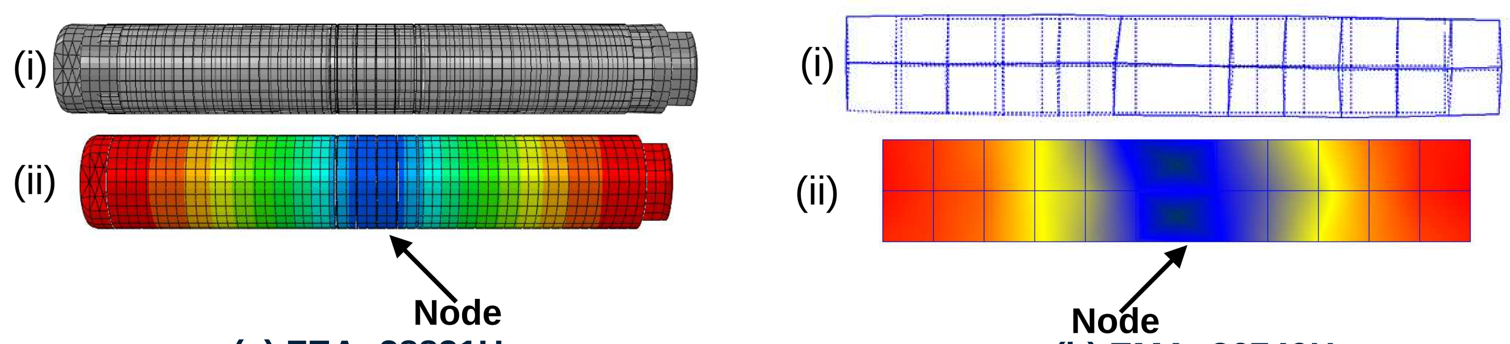
Configuration II: Endmass length ratio 1/4:3/4



Configuration III: Endmass length ratio 1/8:7/8

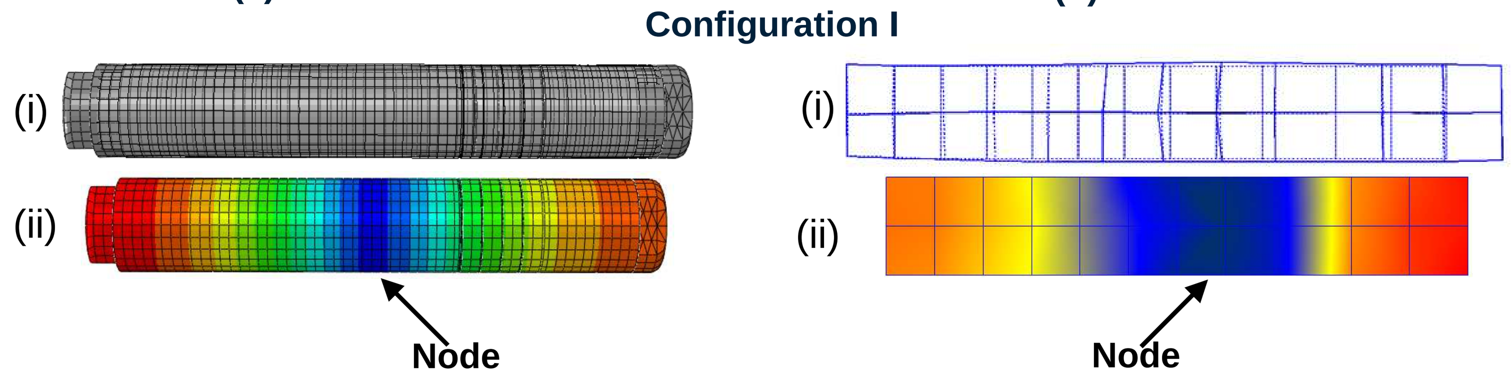
Resonant frequency and mode shape extraction

The transducers initially designed through finite element analysis (FEA) and were tuned to vibrate at the 1st longitudinal mode at approximately 28kHz. The predicted resonant frequencies and mode shapes were validated through experimental modal analysis (EMA).



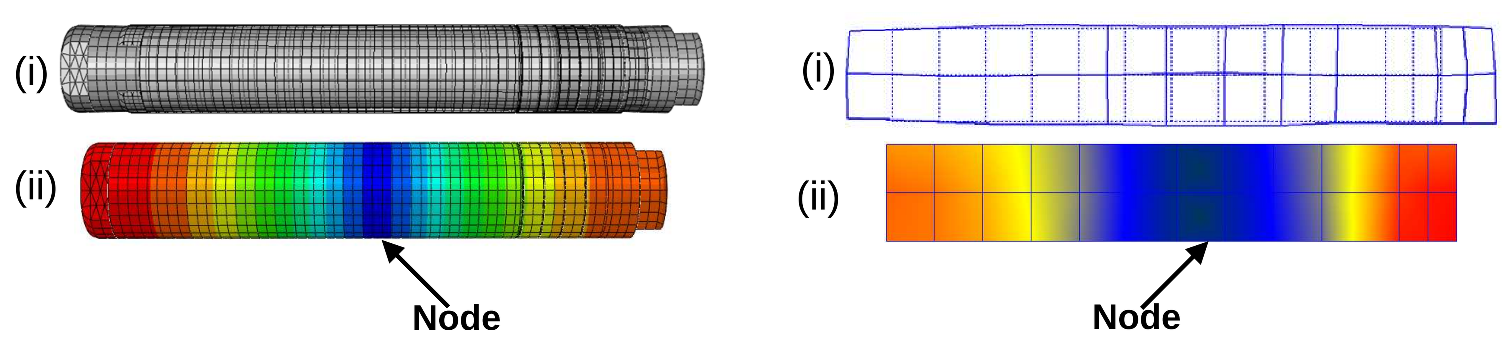
(a) FEA: 28831Hz **(b) EMA: 26740Hz**

Configuration I



(a) FEA: 28770Hz **(b) EMA: 28135Hz**

Configuration II



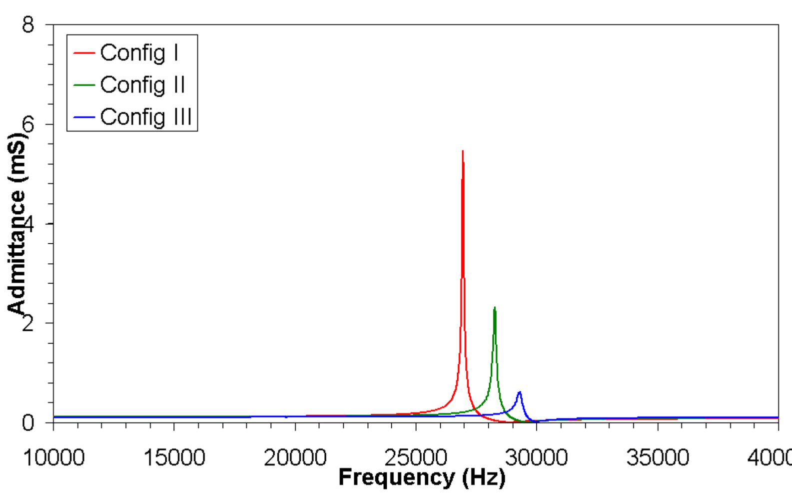
(a) FEA: 28582Hz **(b) EMA: 29161Hz**

Configuration III

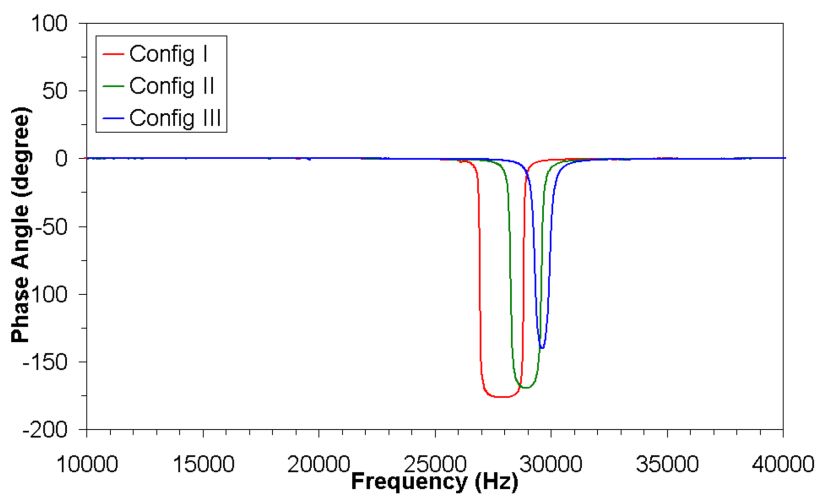
1st longitudinal mode shape and resonant frequency:
(i) Deformed/Undeformed (ii) Undeformed normalised displacement gradient

Good correlation was found to exist between resonant frequencies and mode shapes of the 1st longitudinal mode predicted by FEA and experimentally through EMA; the percentage difference being 7.25%, 2.10% & 2.03% for configurations I, II and III.

Low excitation measurements



Admittance



Phase angle

Admittance and phase angle measurements of transducer configurations at low excitation

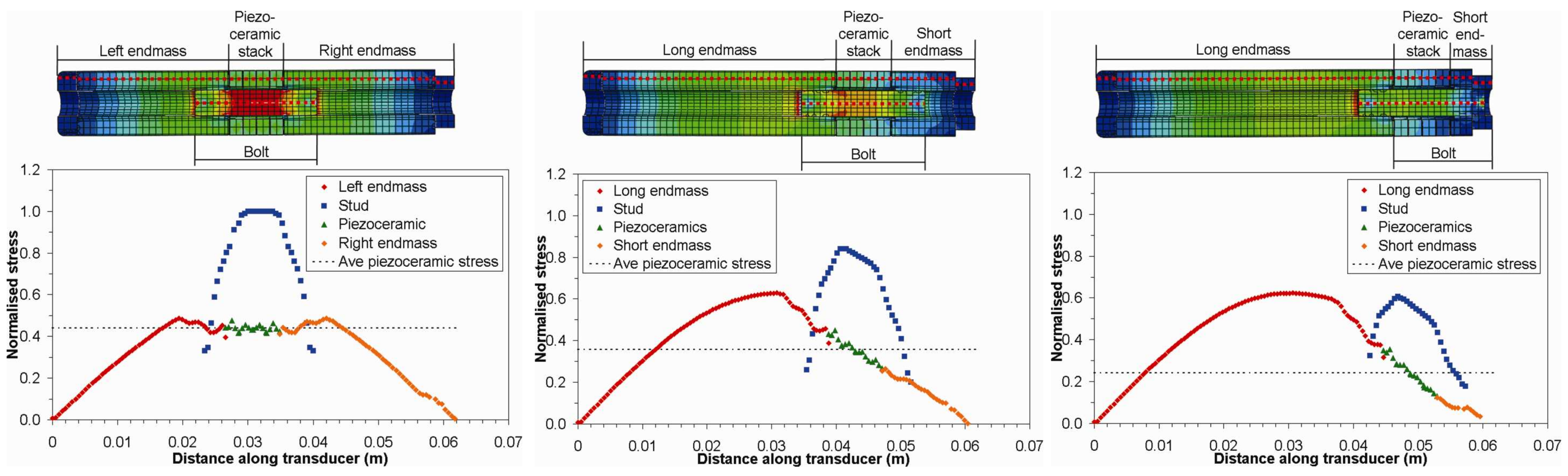
	$f_m \approx f_r$	$f_n \approx f_a$	k_{eff}	Q_e	Q_m
Config I	26748Hz	28568Hz	0.351	393.4	225.1
Config II	28167Hz	29484Hz	0.295	225.3	186.5
Config III	29168Hz	29819Hz	0.207	116.7	111.7

Summary of low excitation properties of transducer configurations

At resonance, f_r, can be assumed to approximately equal the value of highest admittance, f_m, while at anti-resonance, f_a, can assumed to approximately equal the value of minimum admittance, f_n [1].

Stress Analysis

Stress distribution throughout the transducers was investigated through FEA. Each transducer was simulated to oscillate under steady state conditions at a common vibrational amplitude.

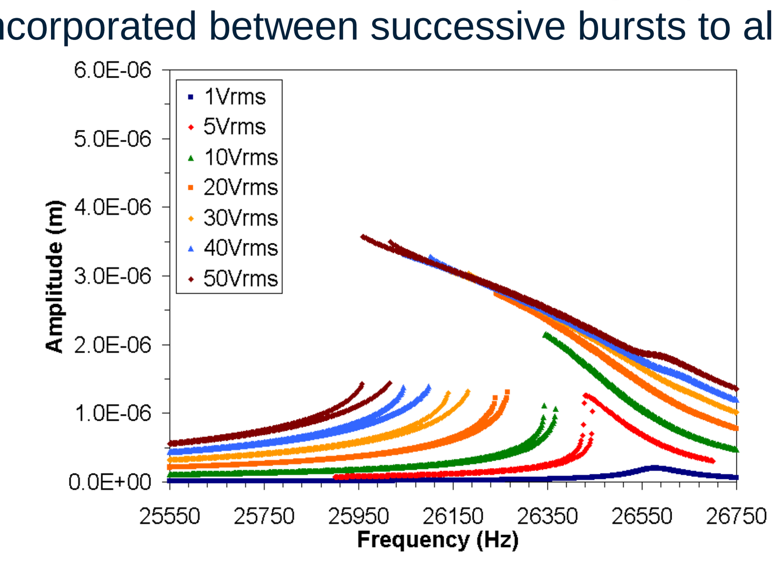


Configuration I **Configuration II** **Configuration III**

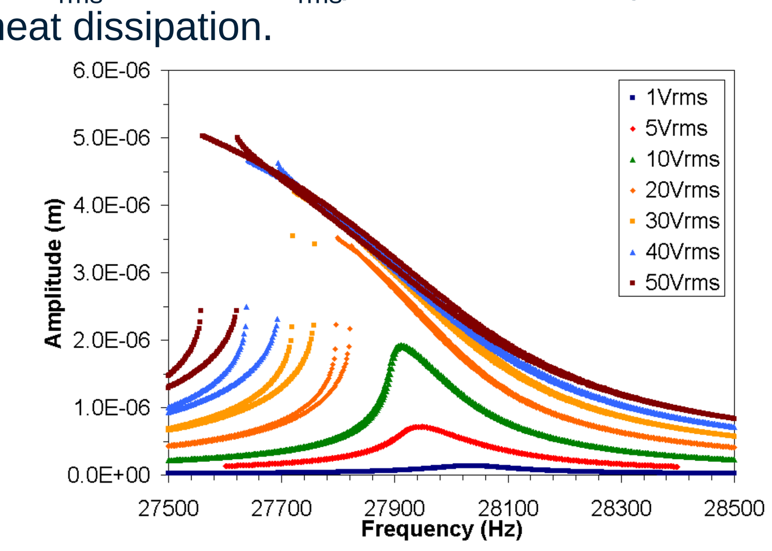
Normalised stress distribution

Nonlinear characterisation

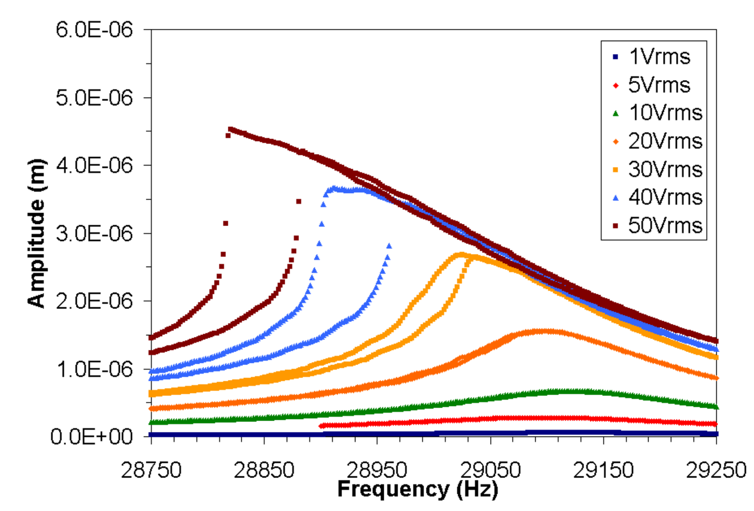
The transducers were characterised through the burst sine sweep method through a frequency range corresponding with 1st longitudinal mode of vibration. Both stress and temperature increases can adversely change the performance and behaviour of piezoceramic materials [2-3], therefore to separate the thermal effect from that of stress, the transducers where driven using a short burst under constant voltage (between $1V_{rms}$ and $50V_{rms}$). A time delay was also incorporated between successive bursts to allow heat dissipation.



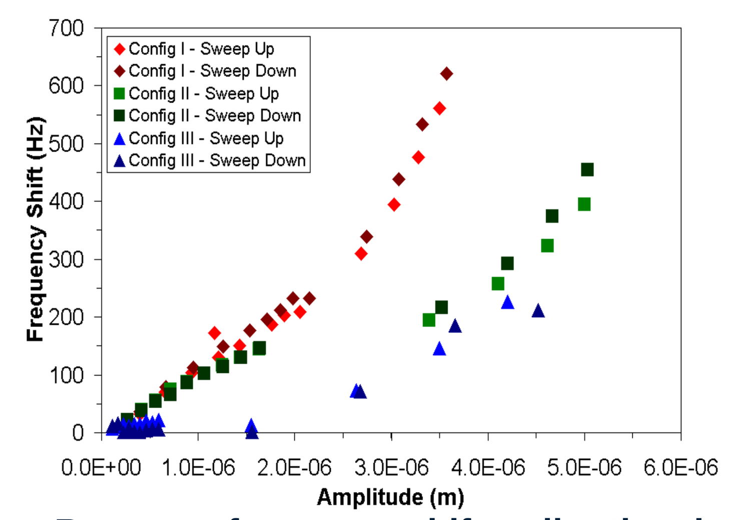
Configuration I: Vibrational response



Configuration II: Vibrational response



Configuration III: Vibrational response



Resonant frequency shift v vibrational response of transducers

Conclusions

The behaviour of Langevin transducers with differing piezoceramic stack positions has been investigated at low and high levels of vibrational amplitude. From this work a number of observations can be made;

- Good correlation was achieve between resonant frequencies and mode shapes predicted through FEA and found through EMA.
- The predicted average level of normalised stress within the piezoceramic stack of the transducer is reduced further its position from the nodal point.
- Level of vibrational amplitude is a significant factor regarding performance of transducers with differing stack positions. Nonlinear phenomena such as resonant frequency shifts and amplitude jumps, although present in all transducer configurations, does not simultaneously occur at a common excitation voltage or vibrational response. Hence a stress threshold may have to be reached before nonlinear phenomenon manifests or strongly influences the behaviour of the transducer.

Acknowledgement

This work has been funded by the Engineering and Physical Science Research Council (EPSRC) Grant no.: EP/E025811/1. A special thank you to the Power Ultrasonic Group at the Instituto de Acustica (CSIC) of Madrid, Spain for laboratory assistance.

References

[1] Berlincourt, D.A. Curran D.R. & Jaffe, H. "Piezoelectric and piezomagnetic materials and their function in transducers". *Physical Acoustics, Principles and Methods*, Academic Press, New York, USA,1964, Chpt 3.
[2] Aurelle, N. Guyomar, D. Richard, C. Gonnard, P. & Eyraud, L. "Nonlinear behavior of an ultrasonic transducer". *Ultrasonics*, 1996, *34*, pp187-191.
[3] Umeda, M. Nakamura, K. & Ueha, S. "Effects of Vibration Stress and Temperature on the Characteristics of Piezoelectric Ceramics under High Vibration Amplitude Levels Measured by Electrical Transient Responses". *Japanese Journal of Applied Physics,* 1999, *38*, pp5581-5585.
[4] LeMaster, R. & Graff, K. "Influence of Ceramic Location on High Power Transducer Performance". *Ultrasonics Symposium,* 1978, pp296-299.