HiFFUT – A New Class of Transducer

Project Meeting

April 2017

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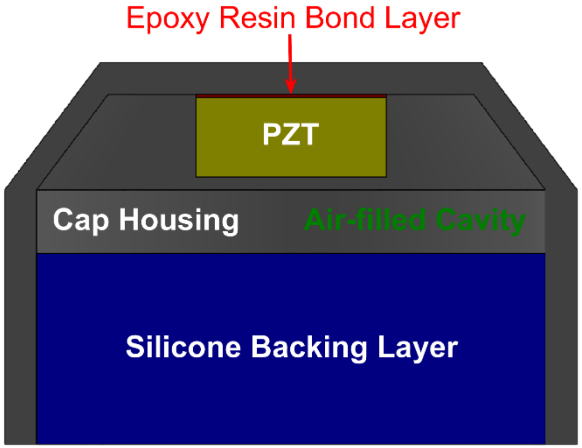
Current Research Contributions

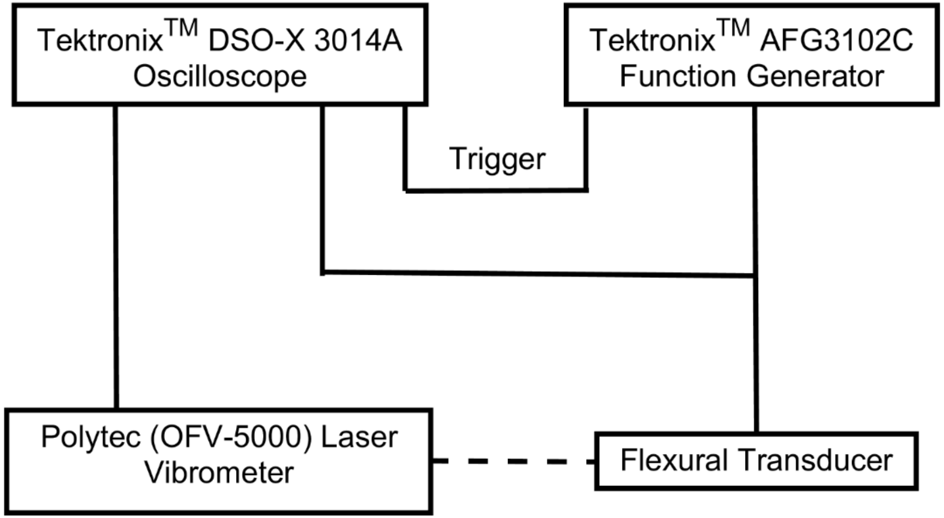
- Study of the electro-mechanical behaviour of flexural ultrasonic transducers
- This work will help us to design HiFFUTs for particular applications, and be able to control the response during operation by expediently tuning to the resonance frequency of the transducer.
- Research conducted with MPhys candidates Michael Ginestier and Chris Wells.
- Commercial transducer used for the research, the schematic for which is shown.
- Research submitted to Applied Physics Letters
- Expanded version being produced for Ultrasonics



Commercial transducer schematic (not to scale)

Current Research Contributions

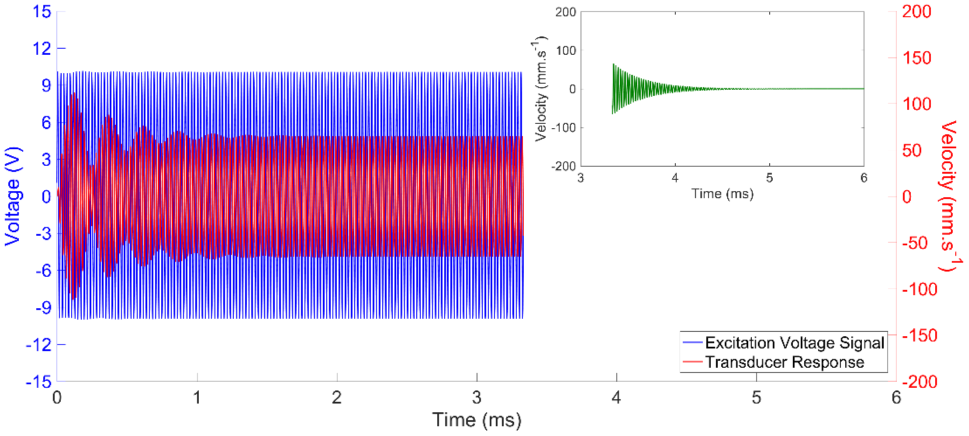
- Experimental setup shown opposite, consisting of a function generator and oscilloscope.
- The function generator is used to drive the transducer, and the oscilloscope is used to measure the voltage across the electrical contacts of the flexural transducer. The mechanical vibrations are recorded by the laser Doppler vibrometer.
- The response of the transducer can therefore be monitored for different input signal frequencies, amplitudes, and number of cycles.



Experimental setup

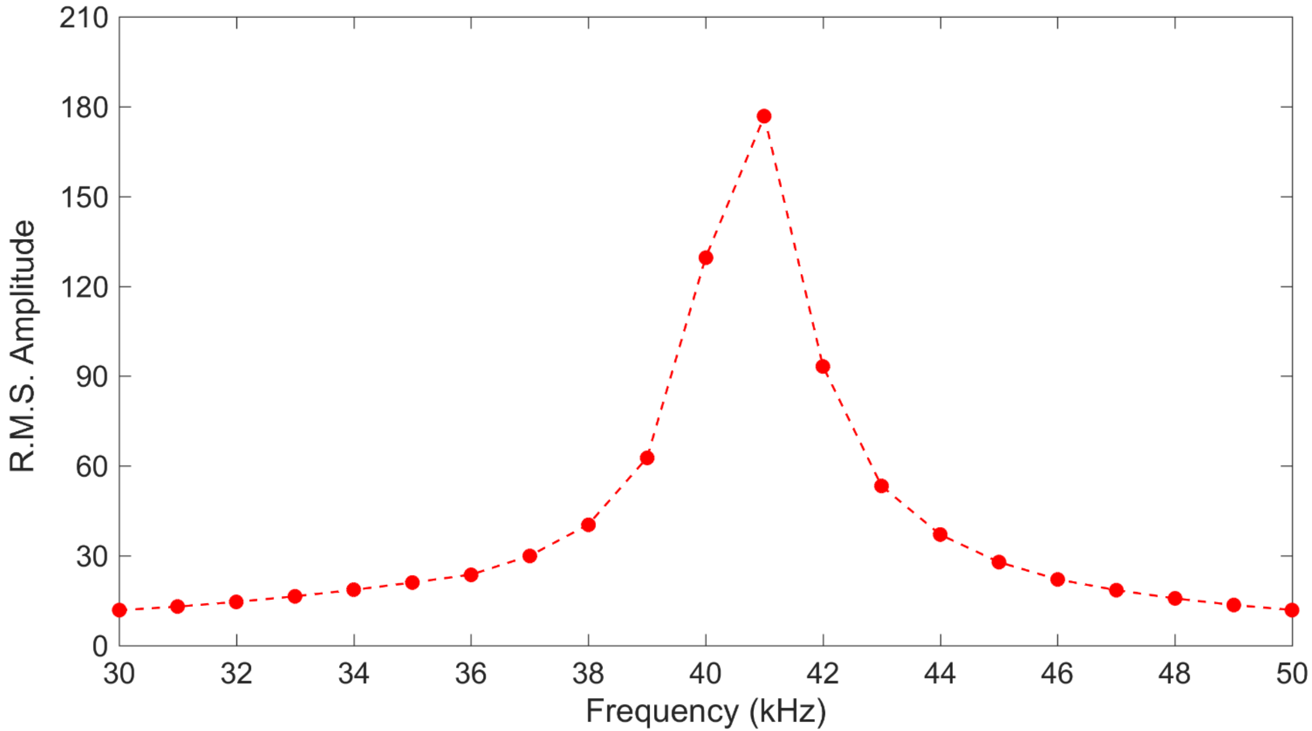
Current Research Contributions

- Once the driving voltage is terminated, the flexural transducer response decays to zero, which is a ring-down at resonance.
- The measurements demonstrate that the transducer vibrates at its resonance frequency almost instantly after the driving excitation signal is switched off, giving a useful and fast indicator of transducer resonance frequency, just with an oscilloscope and function generator. When the drive signal is switched off, a discontinuity in the measured voltage signal occurs due to a phase difference between the driving signal and the vibration displacement of the membrane
- However, this is only true for driving frequencies close to resonance, with a deviation of a few percent. For driving frequencies further from resonance, the effective vibration frequency oscillates before converging on the resonance frequency of the transducer.



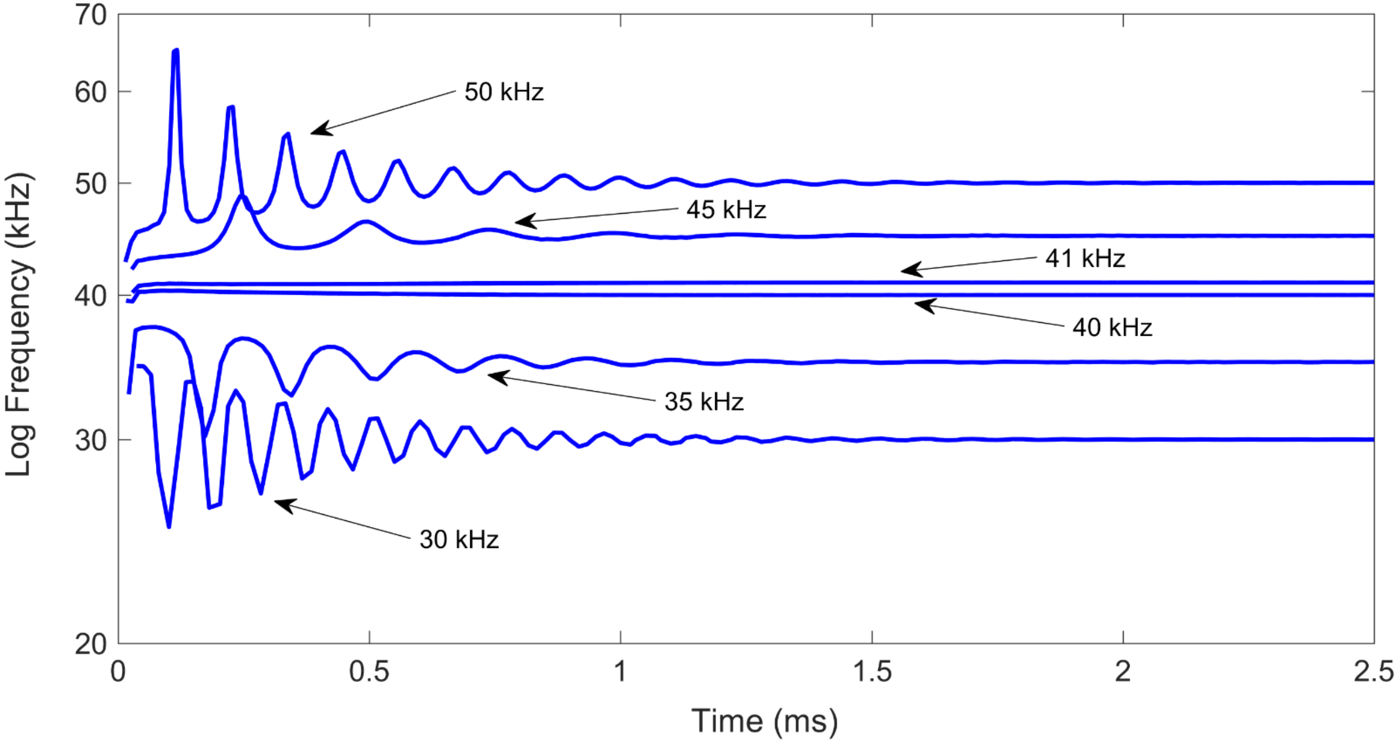
Transducer response for a 45kHz drive excitation, with (inset) the resonant ring-down response

Current Research Contributions



Amplitude-frequency response of the FUT

Current Research Contributions



Effective frequency as a function of time for a range of drive frequencies around resonance

Analysis of electro-mechanical transducer behaviour

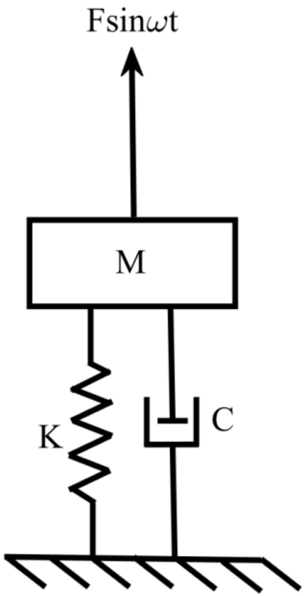
Current Research Contributions

- A mechanical analogue has been developed for the analysis of transducer response. This analogue, whilst not providing physical understanding, can be used, for example, to fit with experimental data to assess the quality of a flexural transducer.
- The flexural transducer is modelled on a simple spring-dashpot configuration.
- Three response regions have been assumed. The first is the build-up to steady-state, where the drive signal is applied to the transducer at rest. The transducer takes time to reach steady-state, which is the second region. The third region appears after the cessation of the drive frequency, and characterised by exponential decay, or ring-down at resonance.

Region 1 $$M\ddot{x} + C\dot{x} + Kx = Fsin\omega t.H(t_0 - t)$$

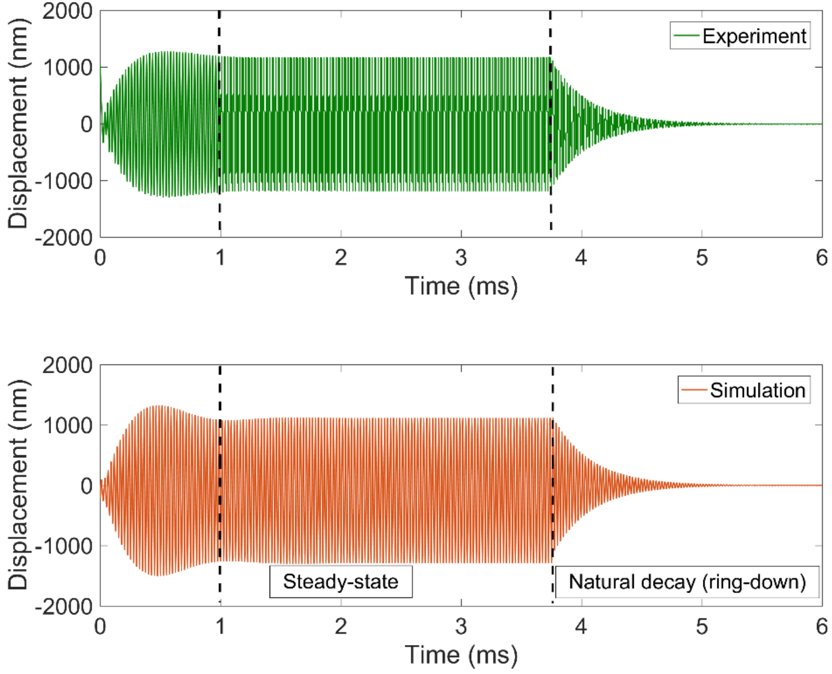
Region 2 $$M\ddot{x} + C\dot{x} + Kx = Fsin\omega t$$

Region 3 $$X(t) = Fe^{-\zeta\omega_n t}\cos(\omega_d t + \theta)$$

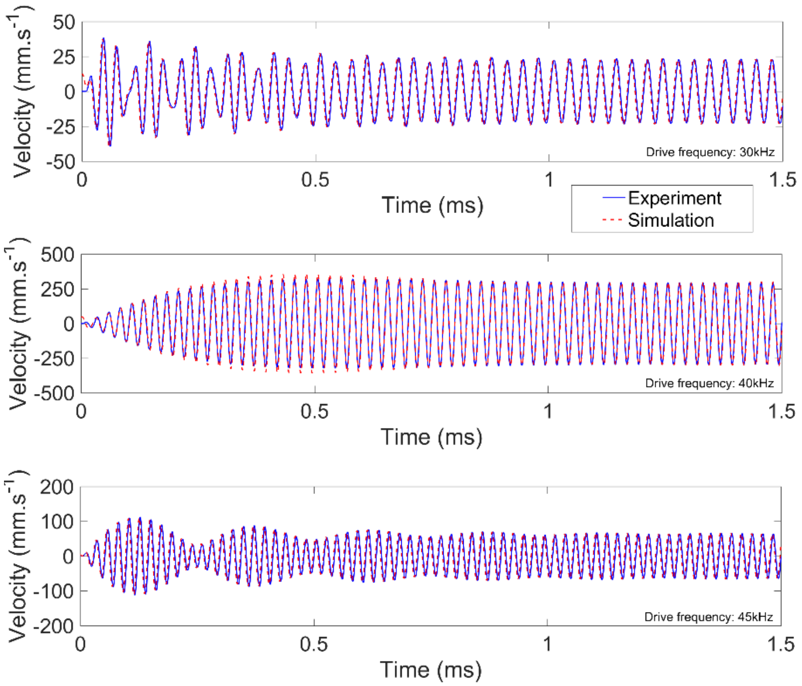


Analogue schematic of the transducer

Current Research Contributions



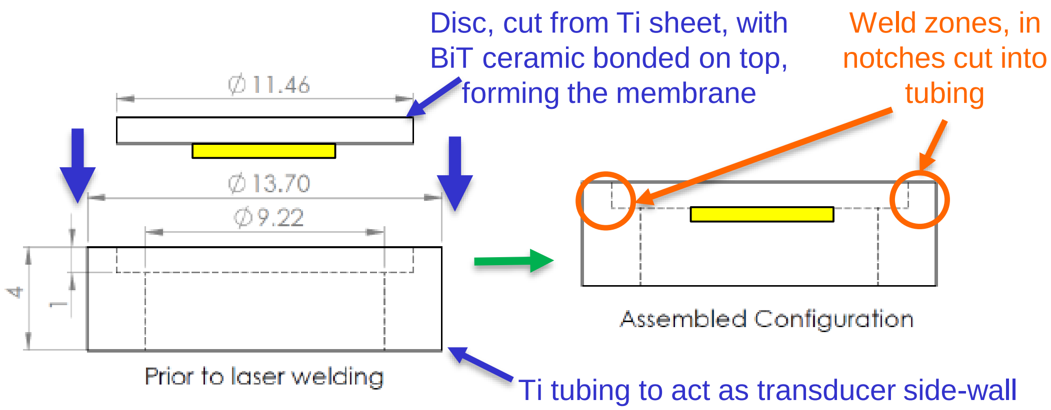
Experimental versus analogue results for a 40kHz drive signal

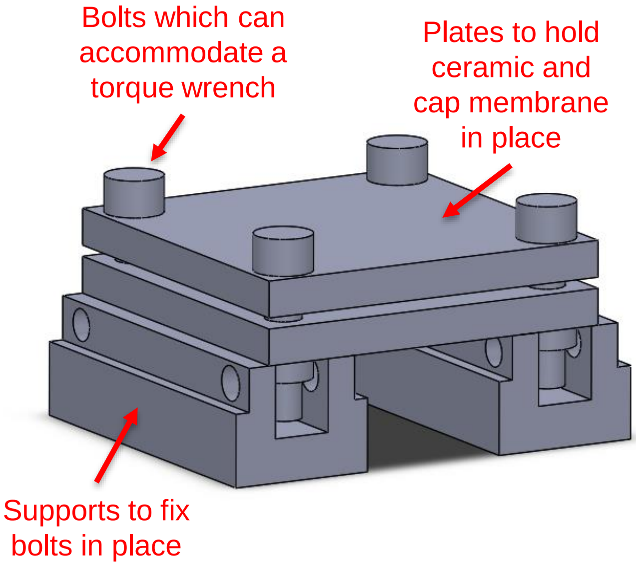


Experimental versus analogue in Stage 1

Current Research Contributions

- Laser welding chosen as a new approach to the fabrication of flexural transducers, and hence HiFFUTs.
- Efficiency, repeatability and precision of transducer manufacture.
- Titanium (Grade 2 ASTM) chosen as the base material, to produce a cap of 13.70mm total diameter, side-wall support length of 4.00mm with wall-thickness of 2.24mm, and membrane thickness of 1.00mm.
- Bismuth titanate (BiT) ceramic, 0.89mm thick, 6.35mm in diameter.

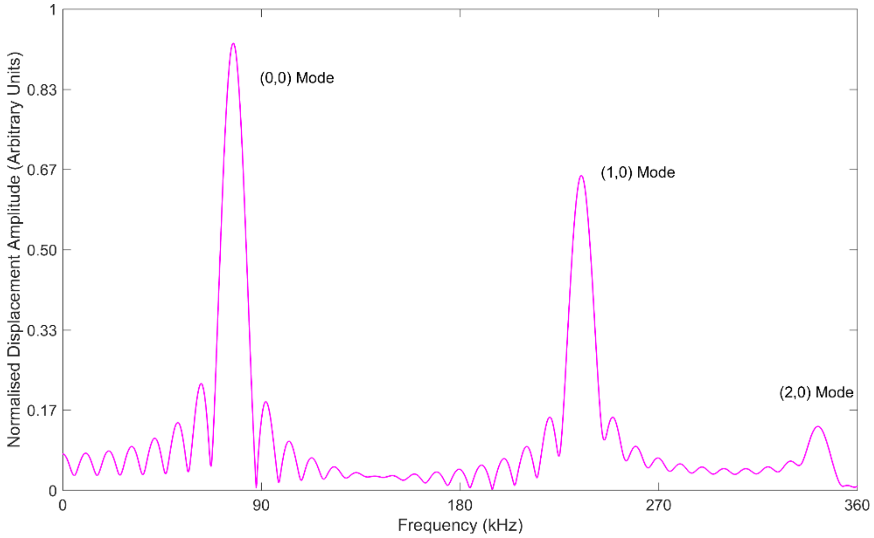




Curing rig designed for the controlled bonding of piezoelectric ceramic discs to transducer cap membranes

Current Research Contributions

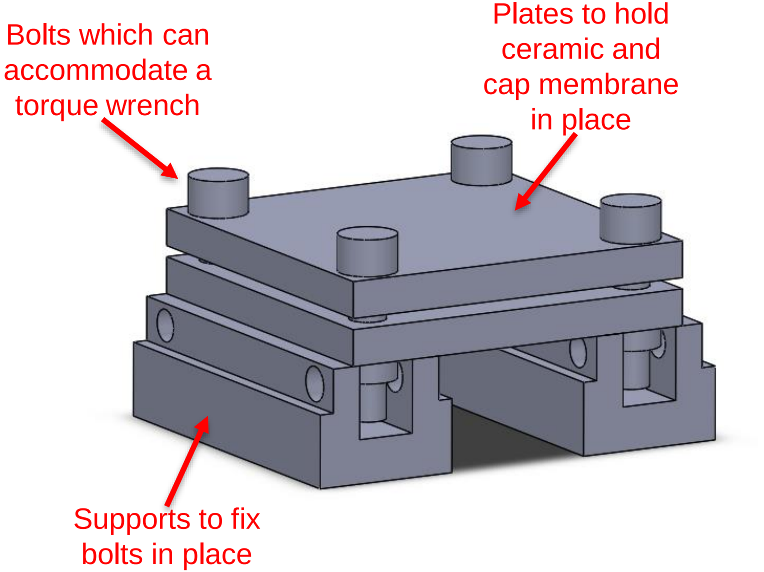
- Transducer designed to operate in the (0,0) mode at high frequency, calculated to be 78887Hz.
- Bismuth titanate has a Curie temperature of 650°C (Ferroperm), thereby permitting high-temperature operation.
- High-temperature epoxy resin used as the bonding agent (Epo-Tek 353ND). This agent can be used at 250°C (continuous) or 350°C (intermittent). From Physik Instrumente (PI) GmbH & Co. guidelines, a bonding pressure of 5-7bar should be applied.



Simulated resonance frequency spectrum for the laser-welded flexural transducer, from PZFlex® finite element analysis

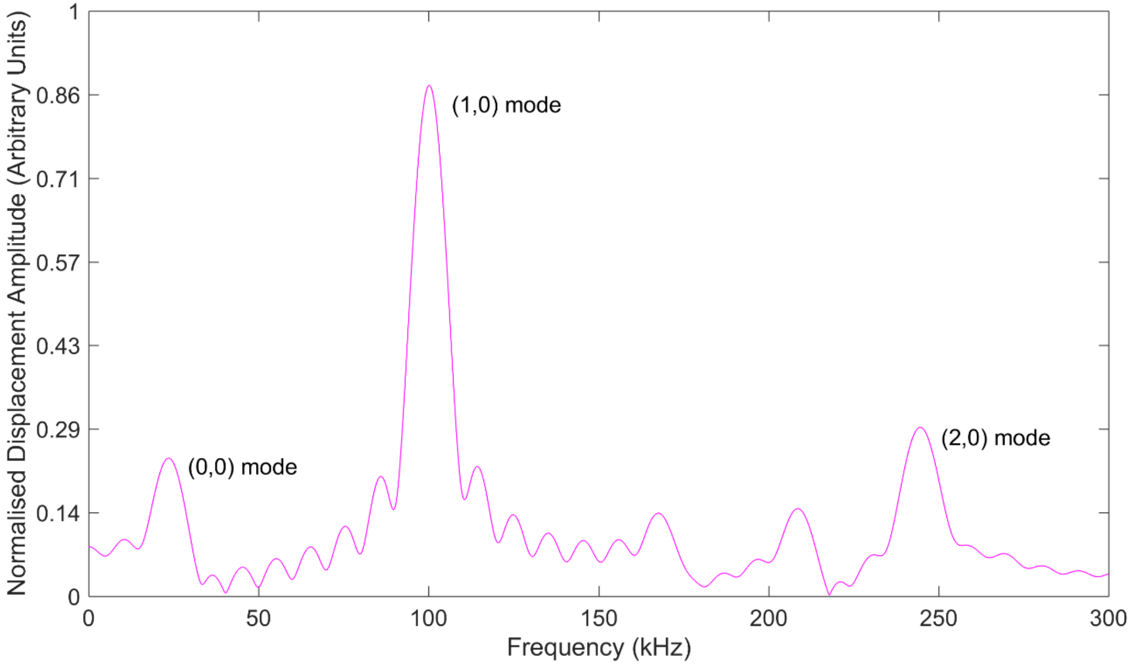
Current Research Contributions

- More detailed understanding is required of the influence of applied bonding pressure in the fabrication of flexural transducers.
- The curing rig shown on the right can be used, designed for the laser-welded flexural transducer, with a cylindrical insert to apply pressure to the ceramic surface only.
- Different “pre-load” pressures can be studied, and the transducers then characterised using an impedance gain/phase analyser (Agilent 4294A), for example to determine electromechanical coupling performance. Further analysis using laser Doppler vibrometry and radiation pattern measurement will also be important.
- Acquired piezoelectric ceramics (PMN-PT(30%)), with thickness of 2.00mm, diameter of 9.97mm.
- Titanium cap designed for a (0,0) mode at 25948Hz, with total diameter of 17.80mm, side-wall length of 6.00mm, side-wall thickness of 0.90mm, and a membrane thickness of 1.00mm.



Curing rig designed for the controlled bonding of piezoelectric ceramic discs to transducer cap membranes

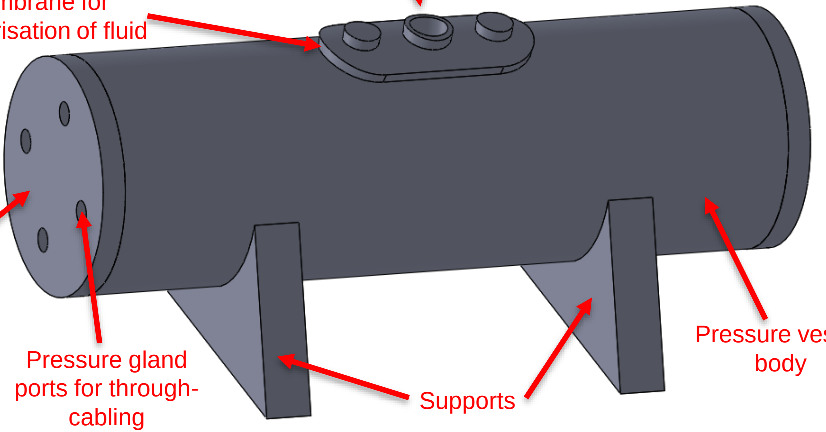
Current Research Contributions



Simulated resonance frequency spectrum for the flexural transducer for bonding pressure analysis, from PZFlex® finite element analysis

Current Research Contributions

- Correspondence with Gilwood (Fabricators) Company Ltd. And FlexEJ Limited for manufacture.
- The main vessel will be manufactured to 4” Sch120 pipe, where the general dimensions are shown in the table.
- The vessel is designed in accordance with ASME VIII Div.1 (NCMS) and certified to the PED 2014/68/EU.
- Membrane temperature limit: 140°C, vessel temperature limit: 300°C.
- Gland specification: Seals multiple wires, supplied by Thermal Detection Limited.



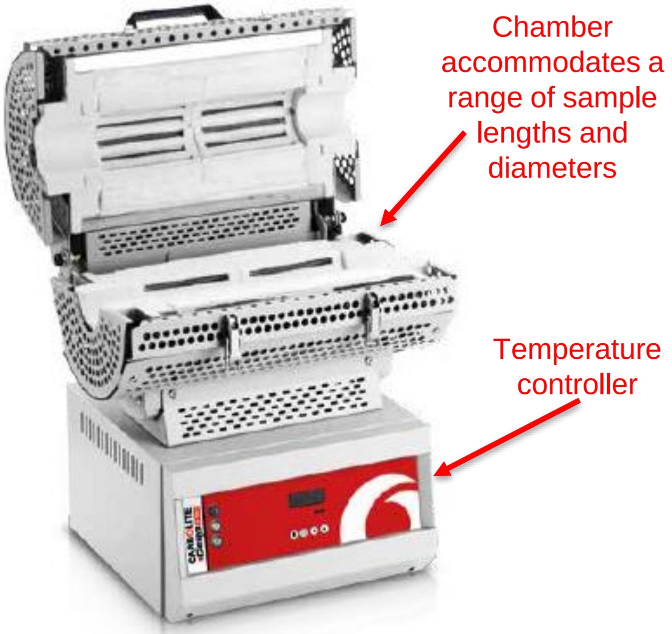
High Pressure Insulated Wire Sealing Gland (HPPL)
- Seals up to 2070bar (at 20°C)
- Grade 316L stainless steel

MK4 Hill Air Pump
- 1/8” BSP Connection
- Rated up to 4000psi (276bar)

Nominal size [inches]	Outside diameter [inches]	Outside diameter [mm]	Wall thickness [inches]	Wall thickness [mm]	Weight [lb/ft]	Weight [kg/m]
4	4.500	114.3	0.438	11.13	19.00	28.32

Current Research Contributions

- Carbolite® Gero Compact Horizontal Split Tube Furnace - EST / EZS
- Maximum operating temperature of 1200°C
- Fully-integrated temperature controller
- Customisation options available, including for over-temperature protection
- Can operate for a range of modified atmospheres including vacuum and gas
- It is proposed that a separate cylinder is fabricated for testing HiFFUTs in liquid, similar to the vessel for the pressure testing
- This cylinder will incorporate measurement cabling access, and correspondence with Carbolite® Gero on this will be essential for safety assessment
- The volume of liquid tested at particular temperatures will need to be closely monitored due to pressure increases



Furnace vessel

Next Steps

- Conduct laser welding to fabricate the Titanium caps.
- Fabrication of a laser-welded flexural transducer with BiT piezoceramic driver, followed by a characterisation process comprising:
  - ❖ Measurement of electrical properties of the transducer, including admittance loops to quantify the quality and coupling in the device. This method can be used to monitor transducer impedance, phase and resonance frequency as a function of temperature, to determine performance at high-temperature levels.
  - ❖ Laser Doppler vibrometry to verify the mode shapes of the transducer.
  - ❖ Radiation pattern measurement to quantify the output of the transducer.
- Report on the influence of bonding pressure level on the performance of flexural transducers.
- Finalise acquisition of the pressure vessel.
- Design of candidate transducers for testing in a pressurised environment, around 200bar.
- Agree on the date of the next meeting.

Project Gantt Chart

Activity of PDRA1, PI & Technician
Activity of PDRA2, PI & Technician