The Design of Flexural Ultrasonic Transducers for High Pressure Environments

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CYGNUS INSTRUMENTS
DETECTRONIC FLOW MEASUREMENT AND DATA DELIVERY
DYNOPTIC
EES RESEARCH LTD
EPSRC Engineering and Physical Sciences Research Council
FLEXIM when measuring matters
katronic
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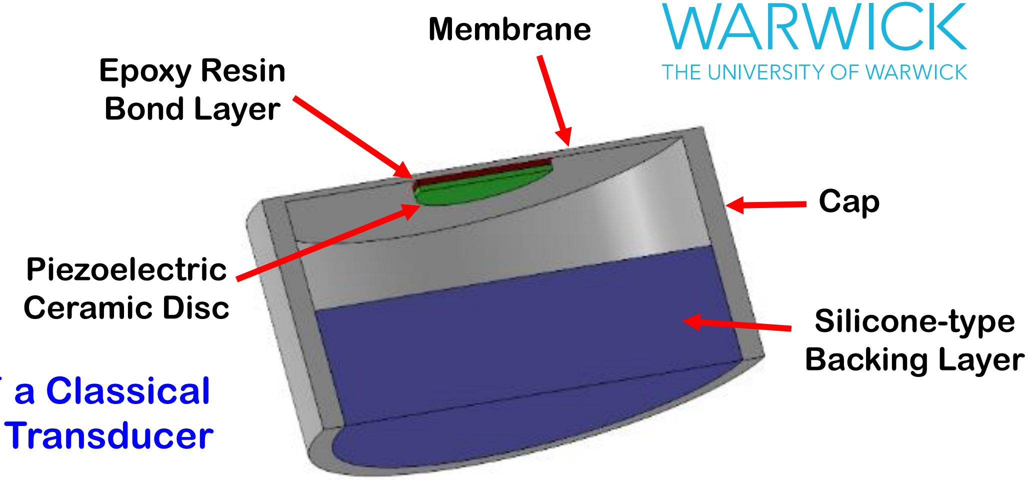
Research Overview

- The flexural ultrasonic transducer is a unimorph for operation in different fluids
- Piezoelectric or electromagnetic
- Proximity sensing and NDE
- Flexural ultrasonic transducers are currently only designed for operation at 1 bar
- New transducers required for industry



Section-view Schematic of a Classical Sealed Flexural Ultrasonic Transducer

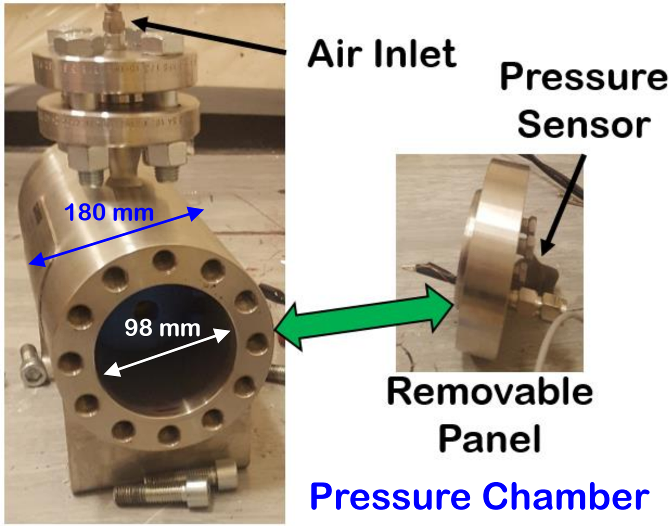
Application	Example Pressure (bar)
Residential gas meters	2
Domestic water meters	20
Industrial gas meters	300
Industrial flow meters	300+

Environment	Example Temperature (°C)
Oil production	120
District heating	250
Petrochemical	350-450
Power plants	560

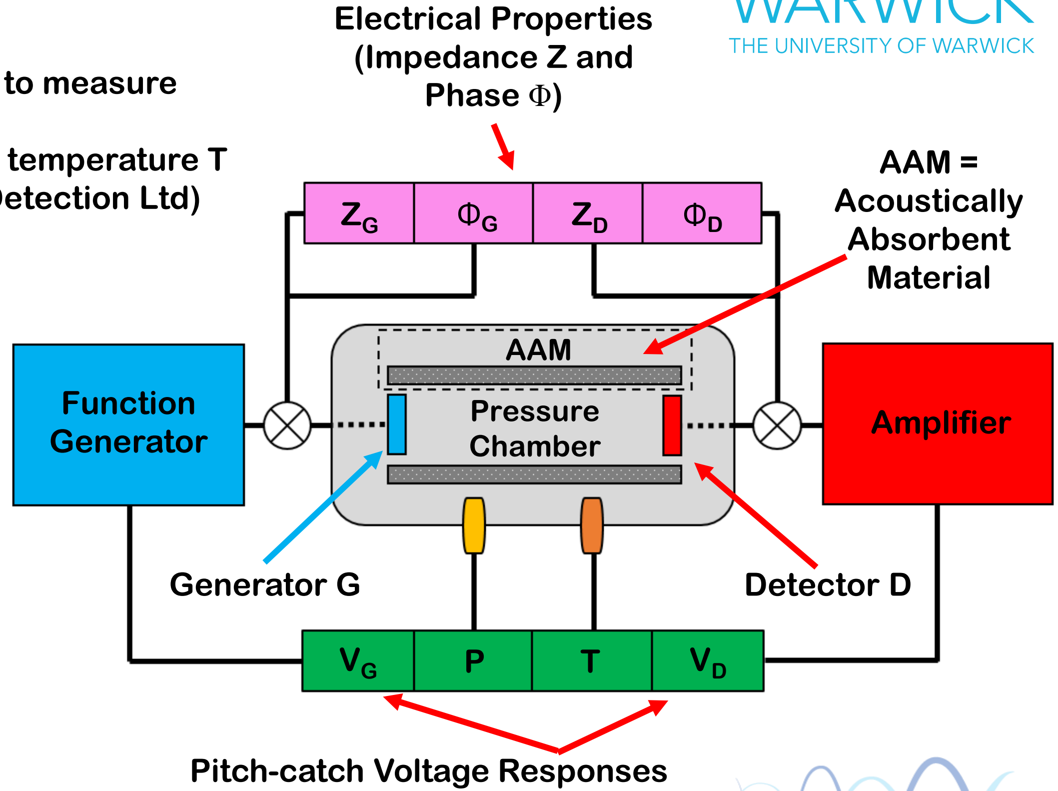
Objective: Develop strategies to design and test flexural ultrasonic transducers at elevated pressure levels

Experimental Method

- Stainless steel pressure chamber
- Ratiometric pressure sensor (Honeywell) to measure pressure level P
- Thermocouple to measure environmental temperature T
- High Pressure Sealing Glands (Thermal Detection Ltd) for insulated wire sealing



Pressure Chamber



Transducer Resonance Characteristics

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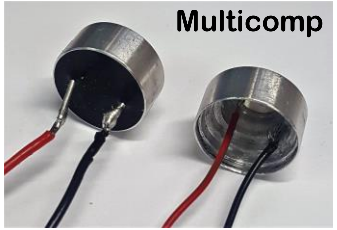
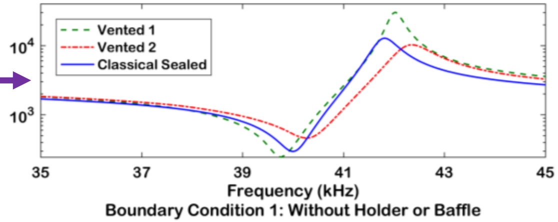
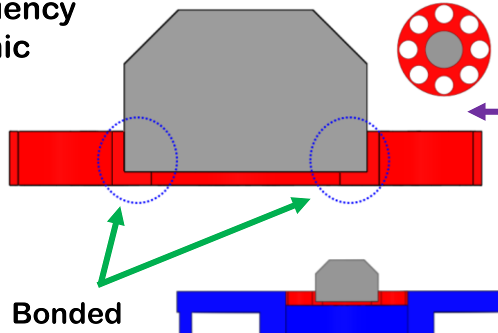
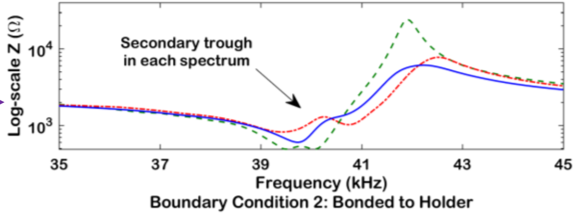
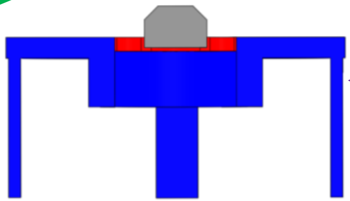
- Two forms of flexural ultrasonic transducer: classical sealed and vented, both aluminium
- Classical sealed: silicone backing seal
- Vented: Removal of seal to balance pressure across membrane
- 3-D printed ABS holders
- Electrical impedance analysis used to monitor influence of holders on resonance frequency
- Important for operating flexural ultrasonic transducers in pressure chamber

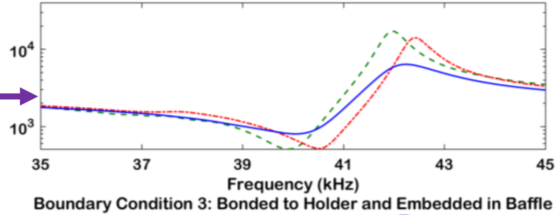


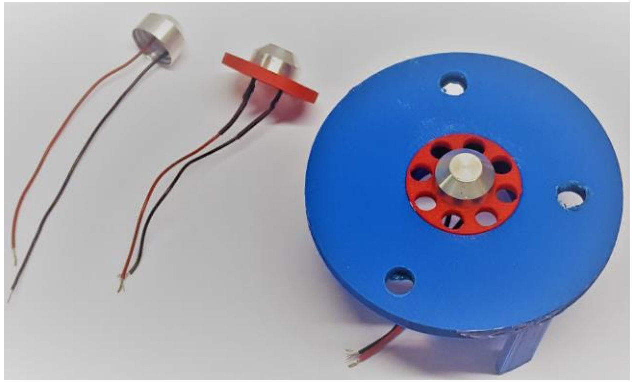












Boundary Condition Analysis

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Transducer Resonance Characteristics

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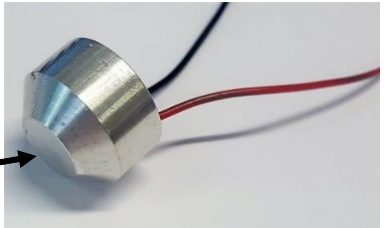
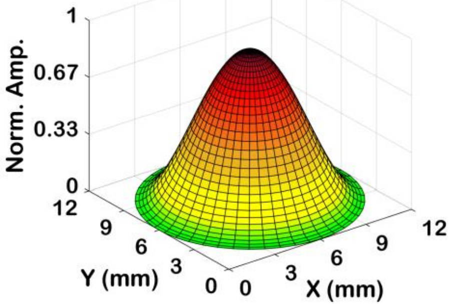
- Nominal frequency of the fundamental (0,0) operating mode: 40 ± 1.0 kHz
- Simulation showing the mathematically computed mode shape using the physical properties of the transducer membrane
- Laser Doppler vibrometry used to measure mode shapes
- Differences in resonance frequency caused by minor variations in transducer physical characteristics

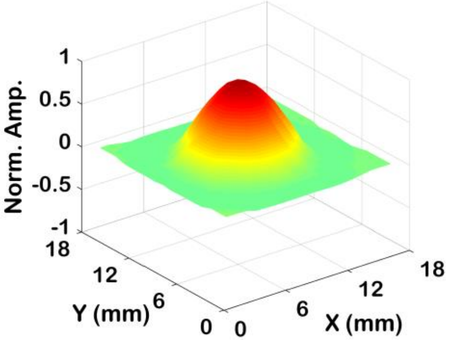
Key Properties

- Material Type
- Membrane Diameter
- Membrane Thickness

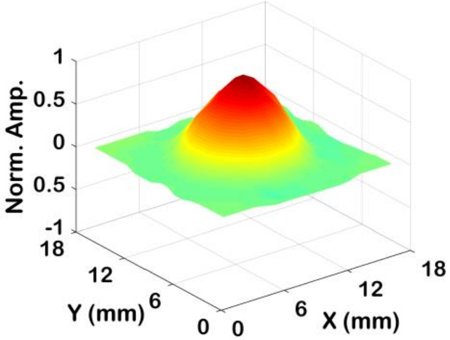




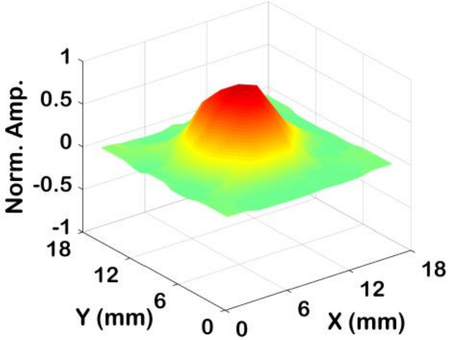
Mathematical Simulation



Classical Sealed
40.0 kHz



Vented 1
39.6 kHz



Vented 2
40.4 kHz

Even with the removal of the sealing, the resonance frequency of each vented transducers is in the 40 ± 1.0 kHz range, showing dominance of membrane dynamics

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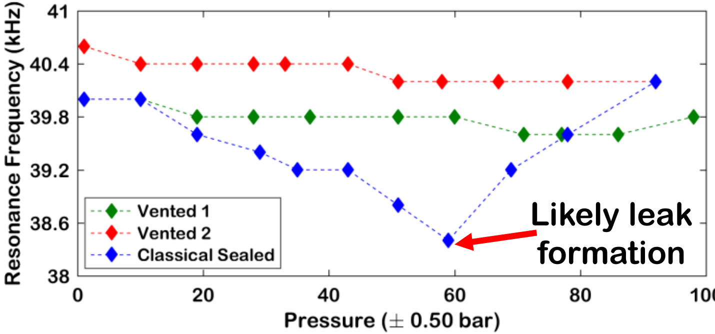
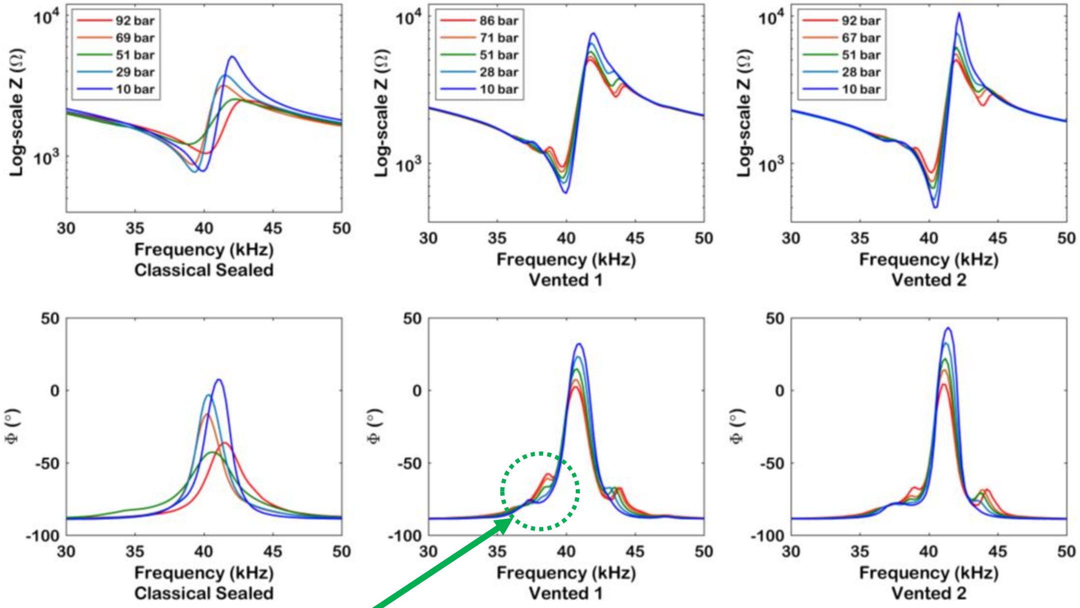
Electrical Characteristics with Pressure

- Z and Φ monitored with air pressure
  Stability of Z and Φ spectra with pressure for the vented transducers
- The classical sealed transducer exhibits inconsistent Z and Φ changes
- This is a direct consequence of the seal
- Steady increase in Z and decrease in Φ for the vented transducers
- Z spectra used to determine resonance frequency
- Likely leakage point determined

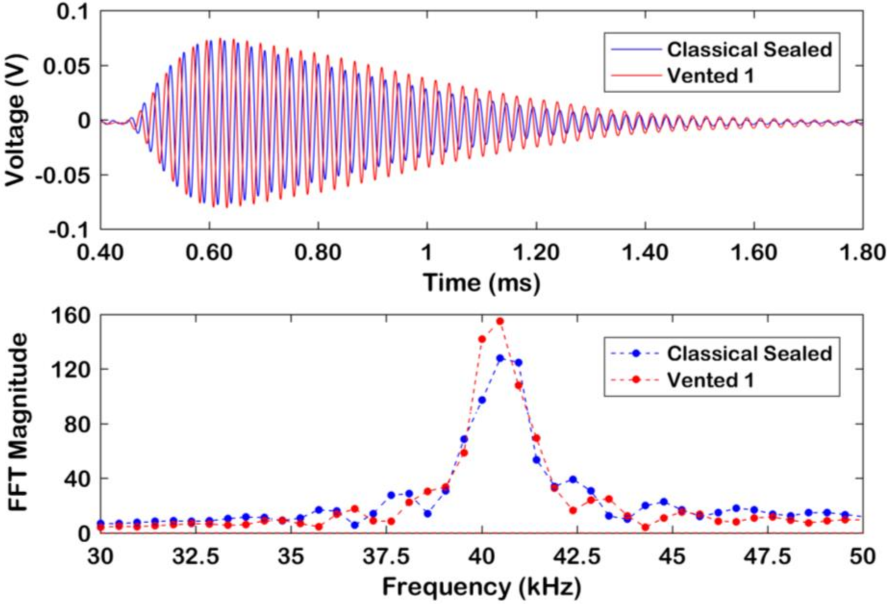




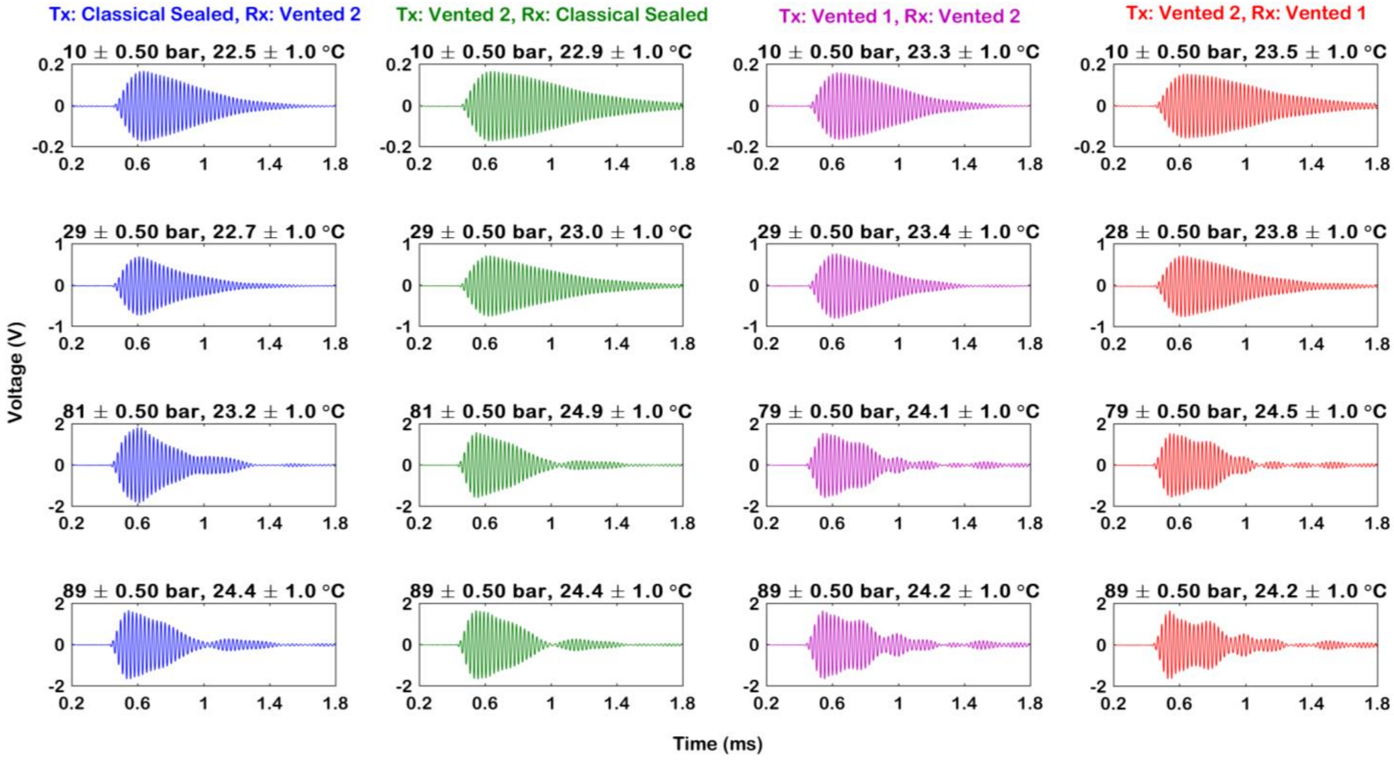
Emergence of additional modes at elevated pressure levels in the vented transducers

Pitch-catch Measurement at 1 bar

- One generator transducer and one detector transducer facing each other
- Excitation: 40 kHz, 2-cycle sine burst, 20 V_{P-P}
- No evidence of ultrasonic wave reflection
- Pressure chamber hence suitably configured
- Longer 'ring-down' for the vented design
- Due to lack of silicone-type sealing which can also act as a damper



Voltage Responses with Pressure



Little evidence of ultrasonic wave interference

Interference detected in responses at elevated pressure levels – changing acoustic properties of air

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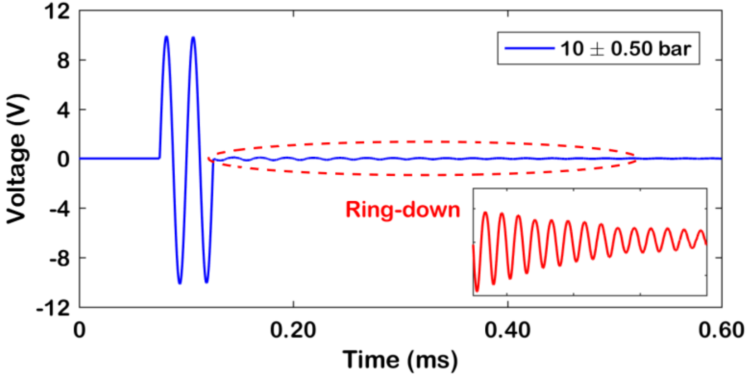
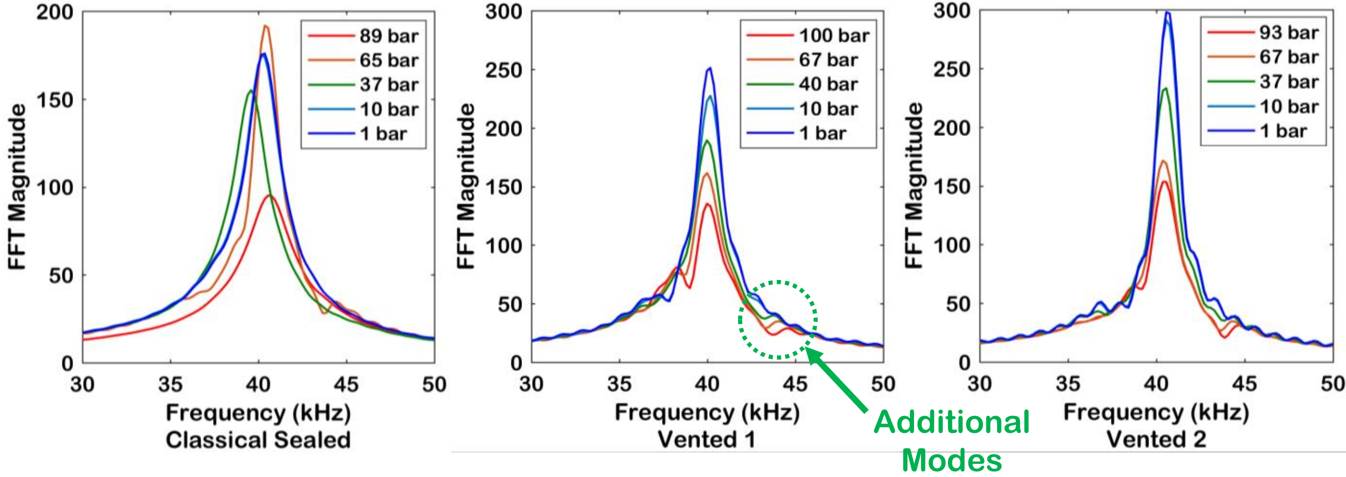
Resonant Decay Analysis



- Typical ring-down response in the generator transducer signal
- FFT of the ring-down indicates resonance frequency
- Resonance of the vented design is more stable than the classical sealed as pressure level changes
- Z exhibits a steady decrease as P increases for the vented
- The Z change is irregular for the classical sealed transducer



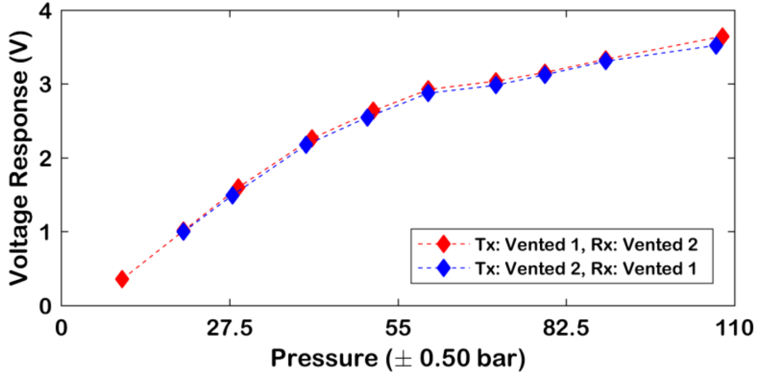
Each Pressure level shown is ± 0.50 bar

FFTs of the ring-down region only

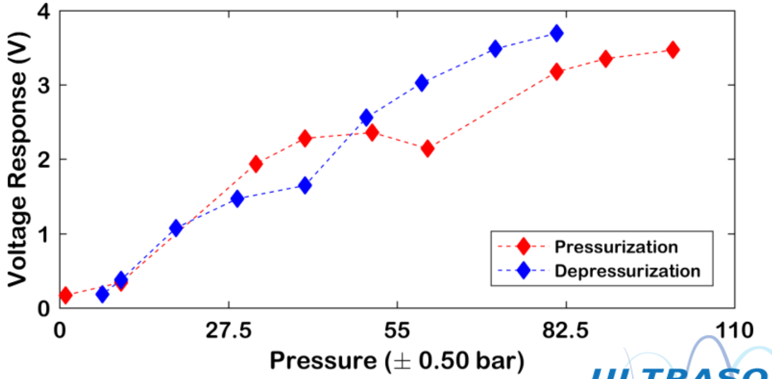
Hysteresis Phenomena

- Important to understand the influence of fluctuations in pressure level (increases or decreases)
- Voltage responses studied in two tests for patterns of hysteresis
- Stability of the vented design demonstrated compared to the classical sealed

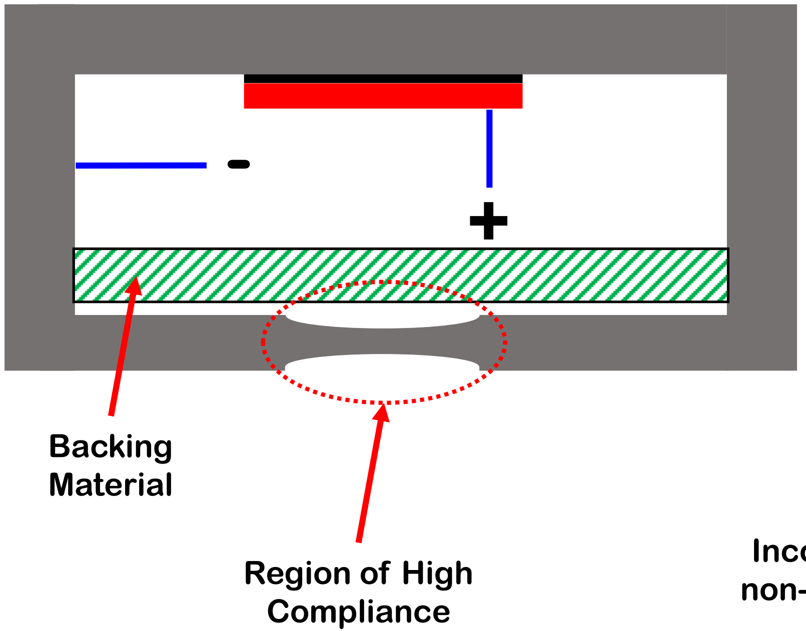
Advantageous for an application such as ultrasonic flow measurement

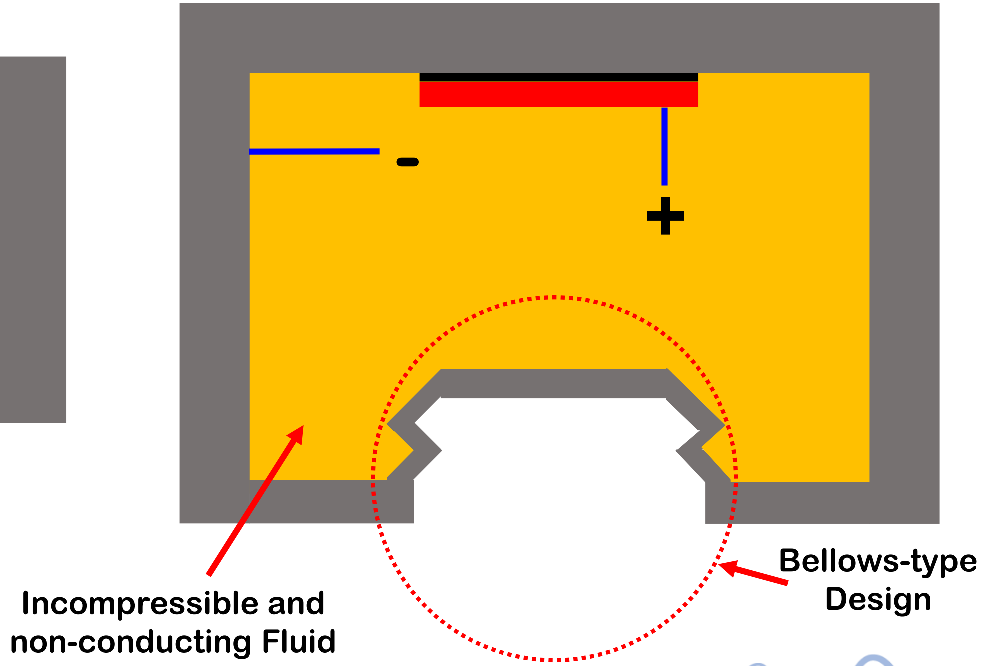


Generator: Classical Sealed
Detector: Vented 2



Alternative Configurations





Summary and Future Research

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Summary

- Dynamic performance of different flexural ultrasonic transducers at elevated pressure levels in air demonstrated.
- The vented design permits balanced pressure across transducer membrane.
- Stable dynamic response observed for the vented design compared to the classical sealed design.

Future Research

- Optimization of the measurement environment, and further mitigation of interference at elevated pressure levels.
- Investigate new designs of transducer, including oil-filled, and deployment in different fluid environments.
- Study the influence of different excitation conditions in small pressure chambers.

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