Flow Measurement Based on Two-Dimensional Flexural Ultrasonic Phased Arrays

Lei Kang[1], Andrew Feeney[1], Riliang Su[2], David Lines[2], Axel Jäger[3], Han Wang[3], Yavor Arnaudov[1], Sivaram Nishal Ramadas[4], Mario Kupnik[3], and Steve Dixon[1]

[1]University of Warwick, Department of Physics, Coventry CV4 7AL, United Kingdom
[2]Diagnostic Sonar Ltd, Livingston EH54 7BX, United Kingdom
[3]Technische Universität Darmstadt, Department of Electrical Engineering and Information Technology, 64283 Darmstadt, Germany
[4]Honeywell, United Kingdom

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Background and Motivation

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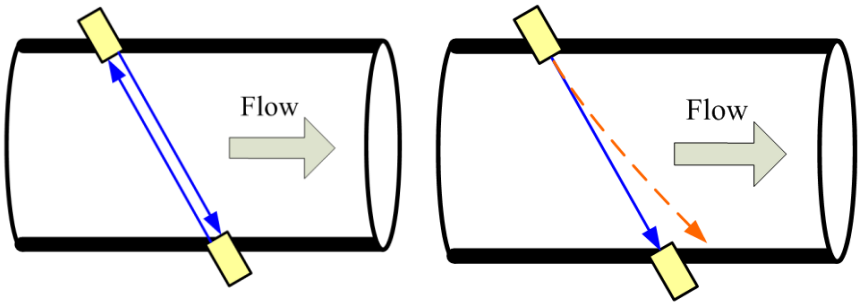
- **Ultrasonic transit-time flow measurement** is affected by the beam drift effect which reduces the accuracy and range.
- **The flexural ultrasonic transducer** exploits plate bending modes, generates and receives ultrasound efficiently in fluids, and is low cost requiring a low voltage supply.
- **The flexural ultrasonic phased array** enables a sound beam to be adjusted electronically and dynamically, measurement through multiple paths, and is a potentially economic and low voltage solution for flow measurement with higher accuracy and larger range.

An example of beam drift in transit-time flow measurement



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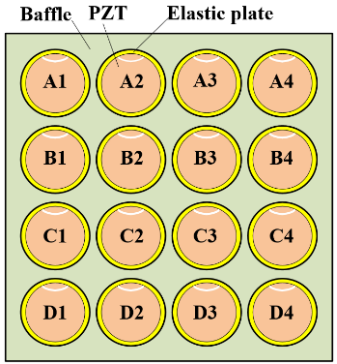
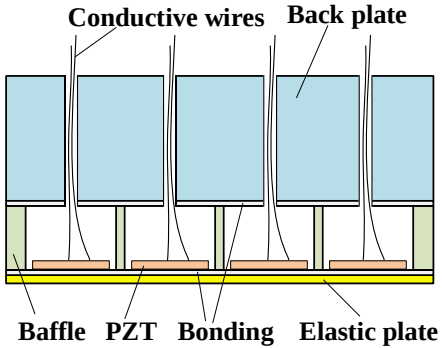
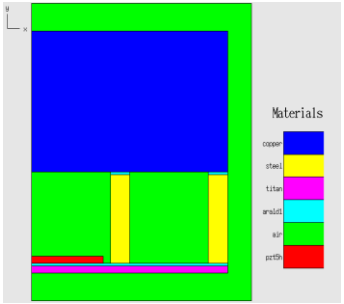
Design and Optimisation



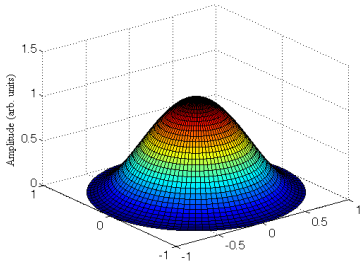


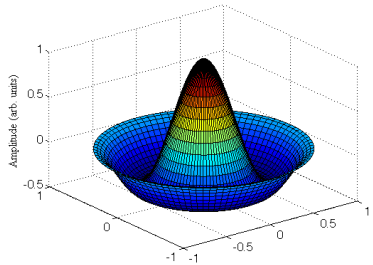


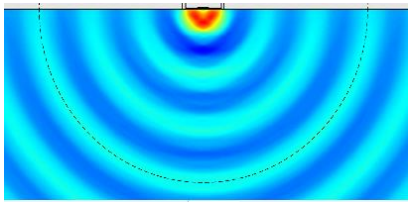
3D Axisymmetric Finite Element Model

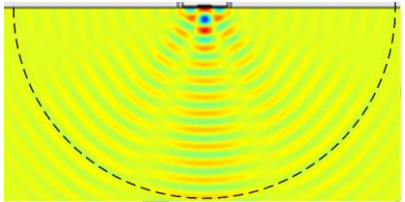
(0,0) mode: PZT/Mem=0.92

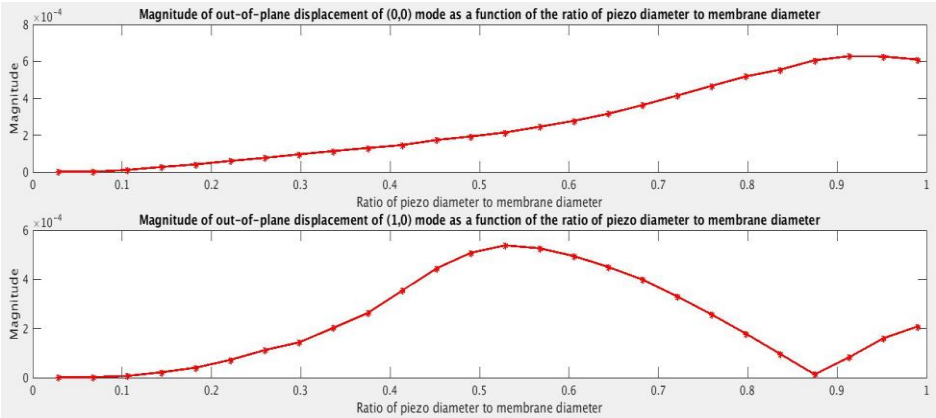
(1,0) mode: PZT/Mem=0.53











Phased Array Fabrication

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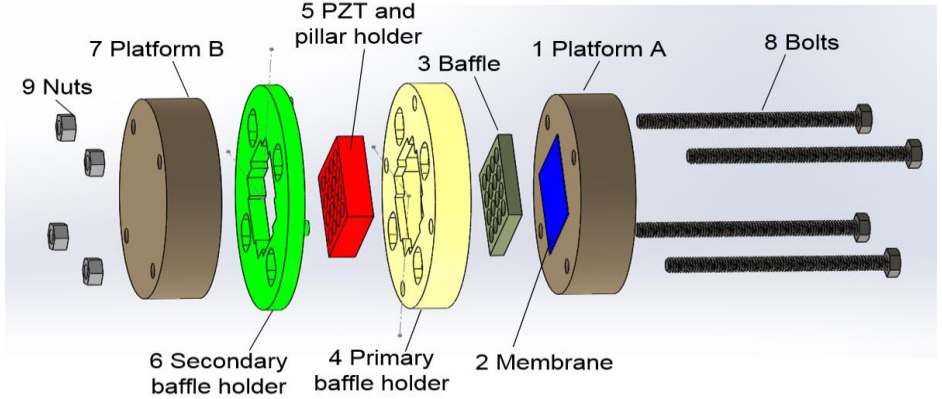

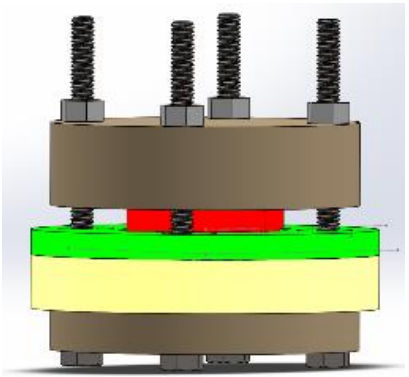

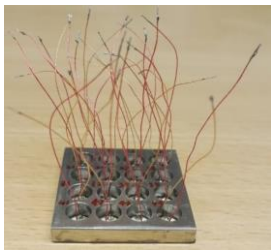

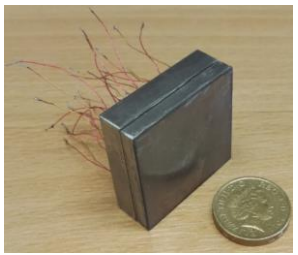

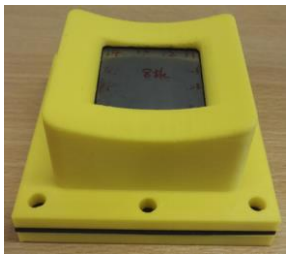

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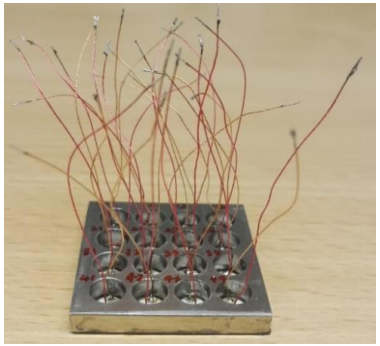
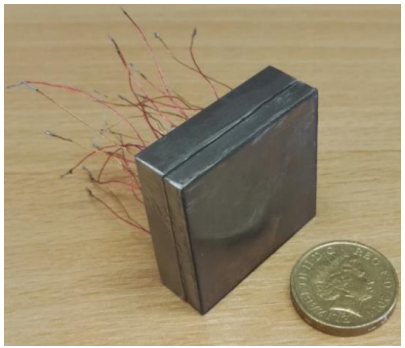
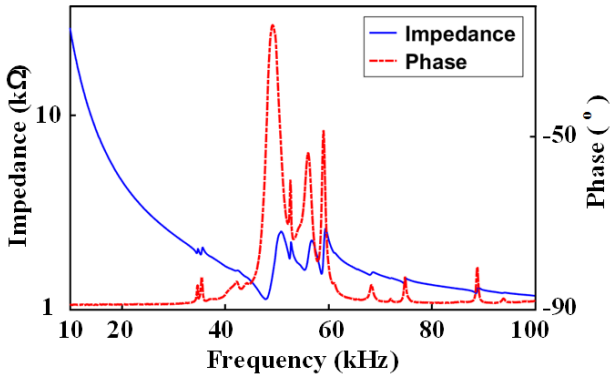
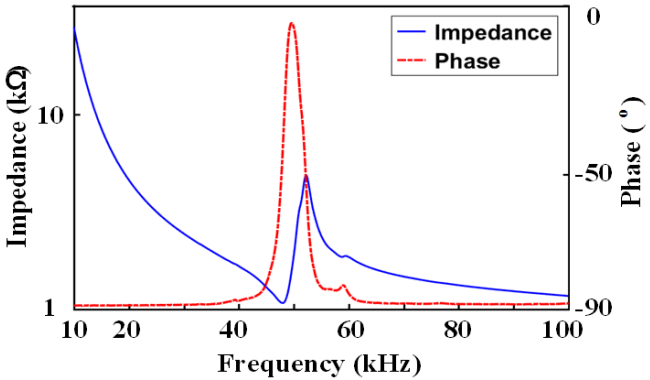
Electrical Characterisation







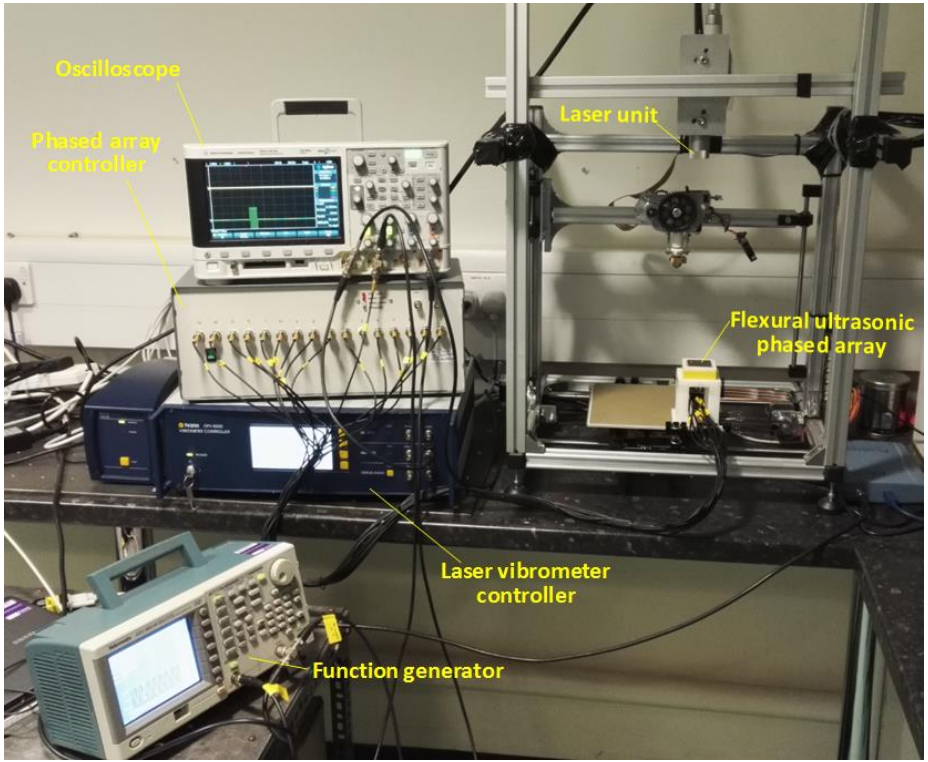


Centre frequency of typical array elements, kHz

	Column 1	Column 2	Column 3	Column 4
Row A	50.44	49.53	49.71	49.90
Row B	49.00	49.88	50.08	49.18
Row C	48.64	48.46	49.14	48.28
Row D	47.03	47.37	47.47	47.29

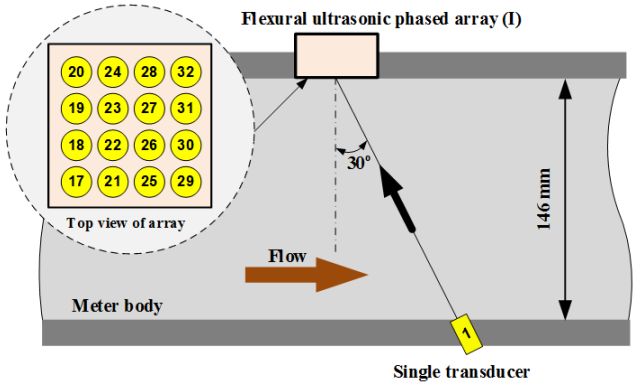
- The back plate not only enhances the mechanical robustness of the array, but also improves the performance of the array in terms of its amplitude, mode purity, and mechanical crosstalk.
- Average -6 dB bandwidth: 1.5 kHz.

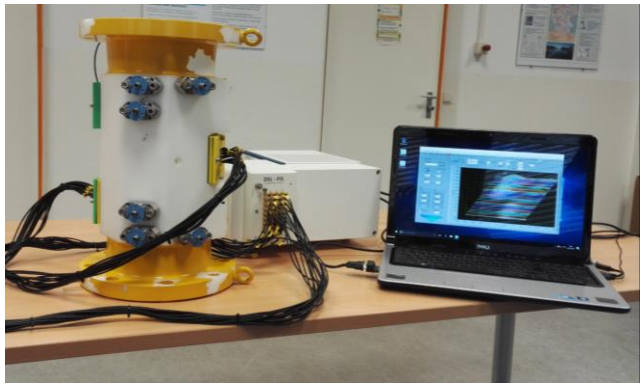
Laser Doppler Vibrometry

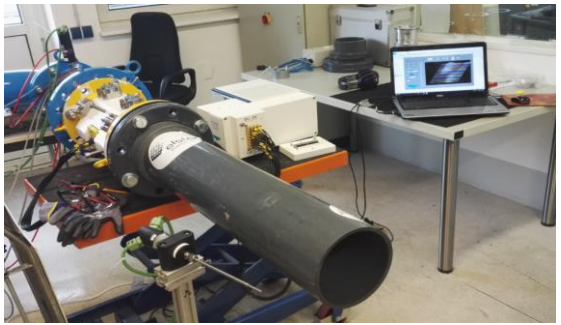


- The phased array is supported on an XY table.
- The array can be driven by either a phased array controller or a function generator.
- The out-of-plane displacement amplitude of the array is detected by a Polytec laser Doppler vibrometer.

Flow Measurement







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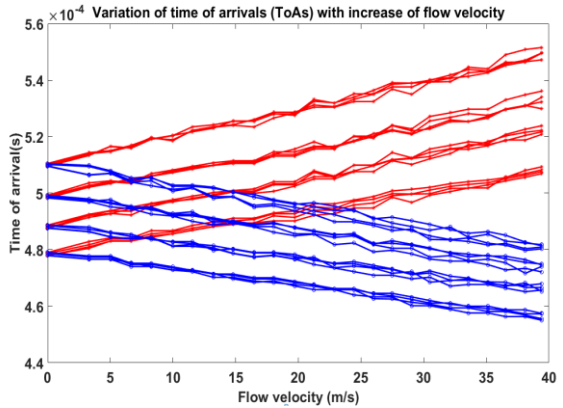
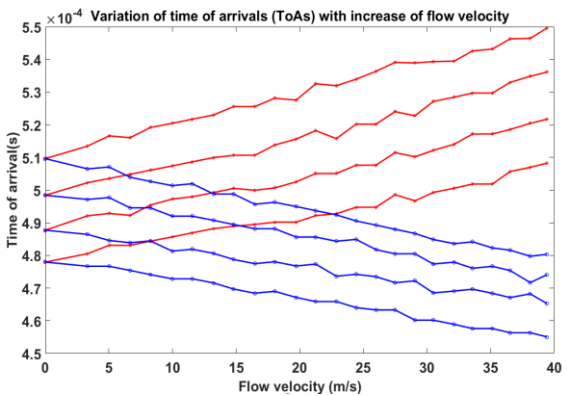
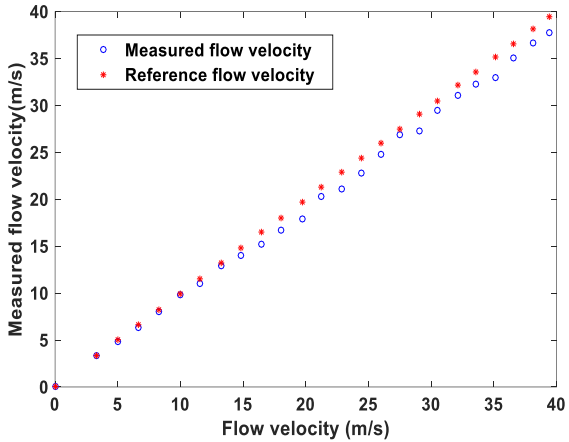
Flow Measurement







$\overline{t}_{up}$: averaged time of flight measured upstream;

$\overline{t}_{down}$: averaged time of flight measured downstream;

c: velocity of ultrasound;

$\overline{v}_P$: averaged flow velocity over the projection of ultrasonic path on cross-section of pipe;

D: inner diameter of pipe;

θ: an angle between ultrasonic path and diameter of pipe;

$\overline{v}_A$: averaged flow velocity over cross-section area of pipe;

k_c: meter factor.

$$\overline{t}_{up} = \frac{1}{16} \times \sum_{i=17}^{32} \overline{t}_{up(1,i)}$$

$$\overline{t}_{down} = \frac{1}{16} \times \sum_{i=17}^{32} \overline{t}_{down(i,1)}$$

$$\begin{cases} \overline{t}_{down} = \dfrac{D}{\sin(\theta) \times [c + \overline{v}_P \cos(\theta)]} \\ \overline{t}_{up} = \dfrac{D}{\sin(\theta) \times [c - \overline{v}_P \cos(\theta)]} \end{cases}$$

$$\overline{v}_A = \frac{D}{\sin(2\theta)} \times \frac{\overline{t}_{up} - \overline{t}_{down}}{\overline{t}_{up} \times \overline{t}_{down}} \times k_c$$

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Summary and Future Research

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Summary

- The design, fabrication and characterisation of two-dimensional flexural ultrasonic phased arrays are presented.
- Flow measurement is demonstrated, and it is shown that the optimum steering angle of the array varies with the change of flow rate.
- Phased arrays are a potentially economical and low-voltage solution for flow measurement with high accuracy.

Future Research

- Compare various data processing techniques to further improve accuracy.
- Perform multi-path flow measurement.

Acknowledgement

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