Centre for Industrial Ultrasonics Open Day
25th April 2018

Flow Measurement Based on Two-Dimensional Flexural Ultrasonic Phased Arrays

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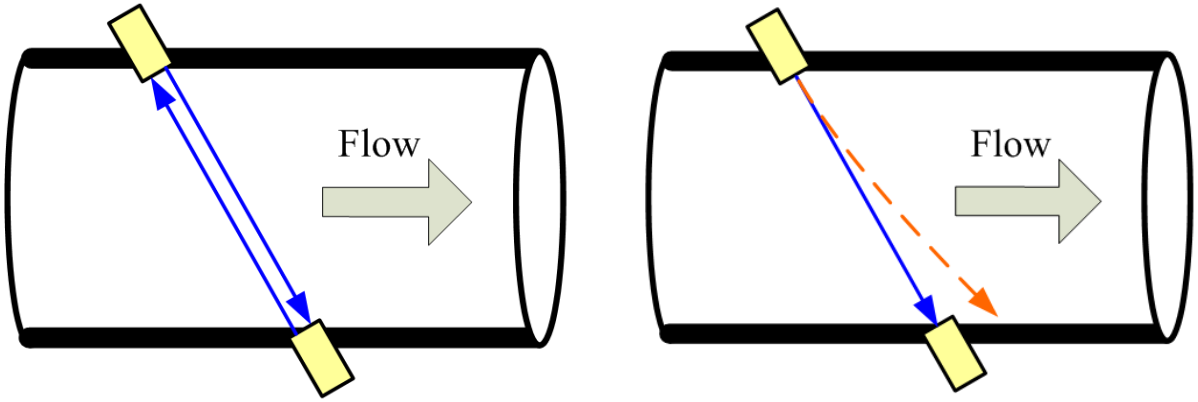
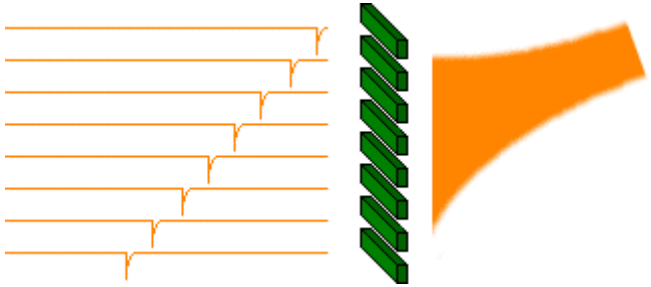
Contents

1 Background and Motivation

- **Ultrasonic transit-time flow measurement** suffers from beam drift effect which reduces the accuracy and range.

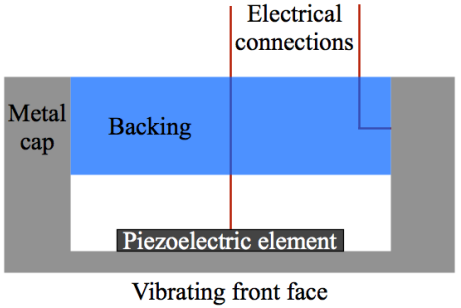


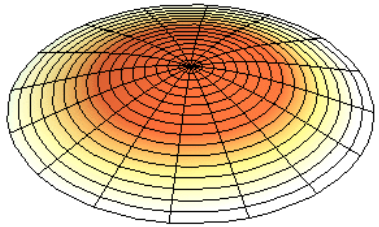
- **Phased Array technology**:
  - Adjusting sound beam electronically and dynamically;
  - Measuring through multiple paths (direct path, reflected paths).



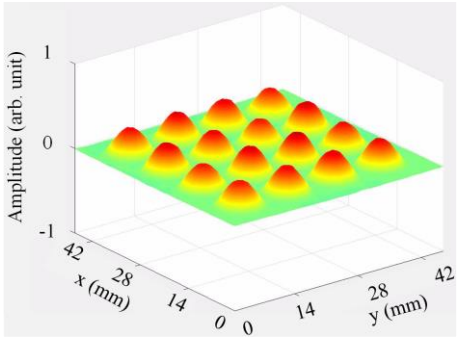
1 Background and Motivation

- **Flexural Ultrasonic Transducers** (unimorph, bimorph):
  - Uses bending modes in a plate;
  - Generates and receives ultrasound efficiently in fluids;
  - Low cost and low voltage supply.

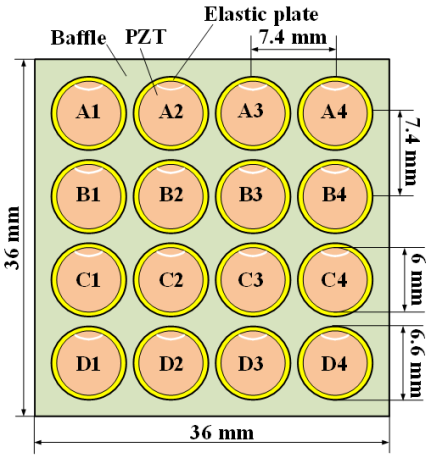


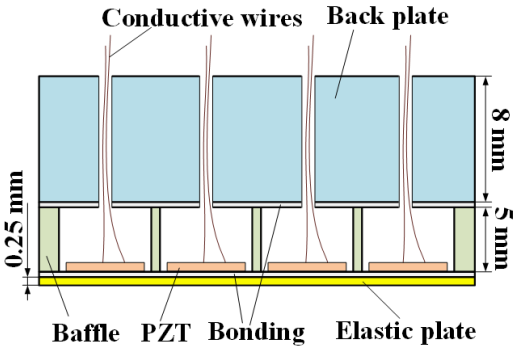


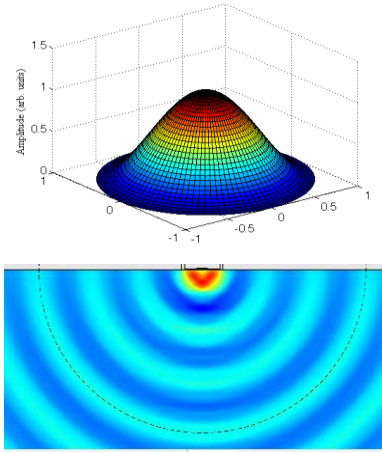
- **Flexural Ultrasonic Phased Arrays**:
  - Combining the advantages of flexural ultrasonic transducers and phased array technology;
  - A potentially economic and low voltage solution for flow measurement with higher accuracy and larger range.



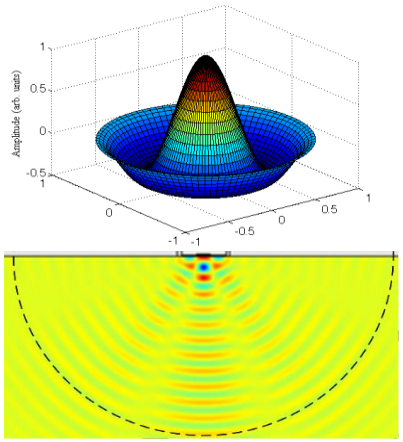
2 Design and Optimization



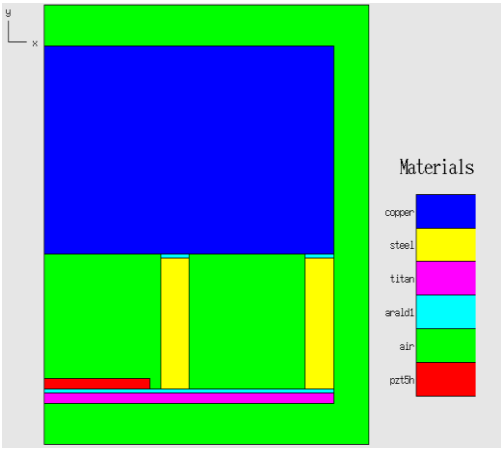




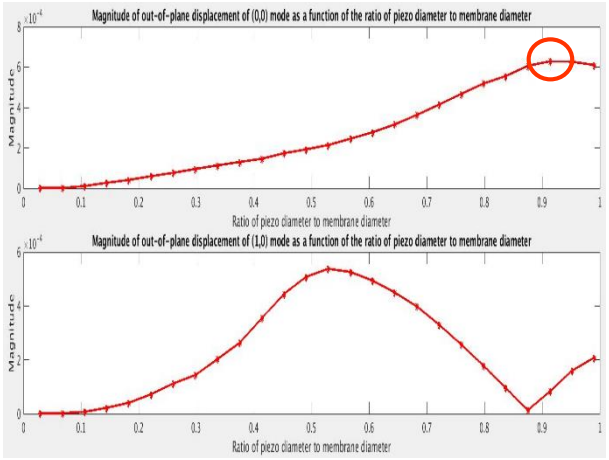
(0,0) mode



(1,0) mode



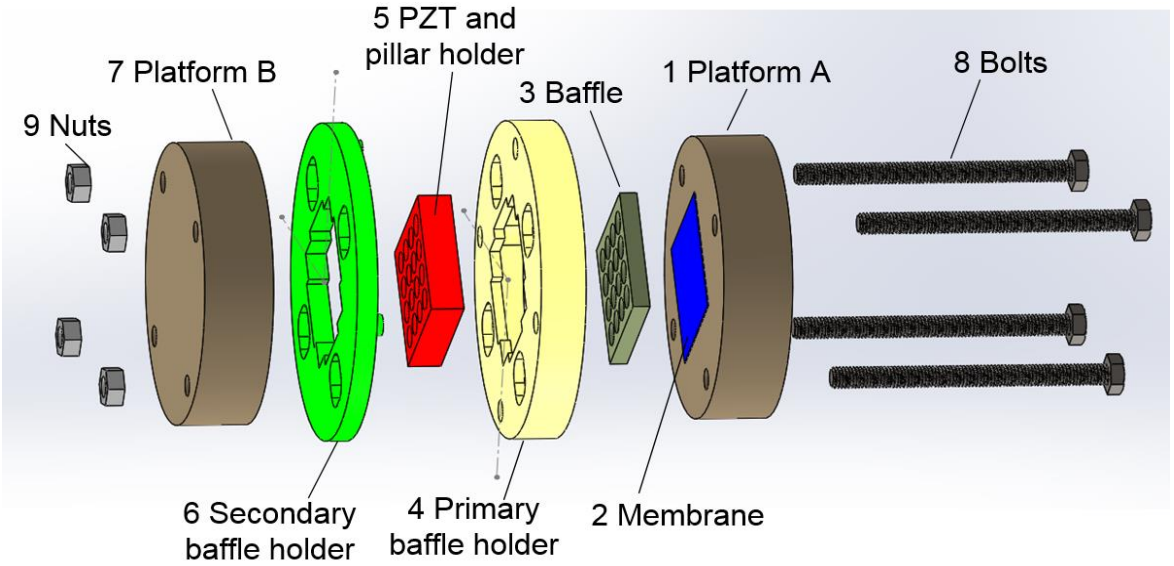
3D Axisymmetric FE model

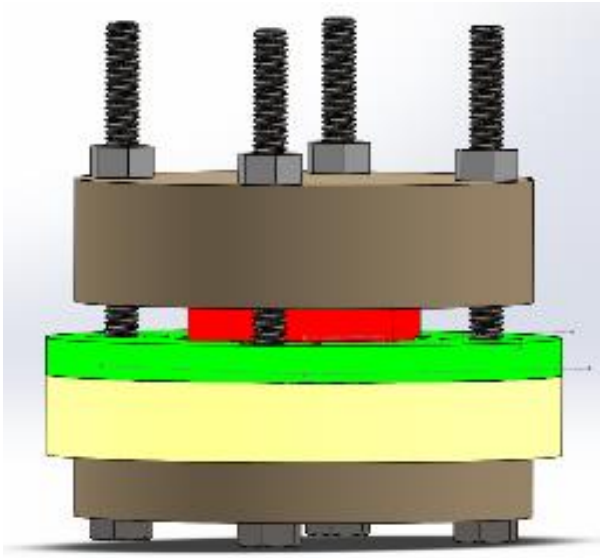


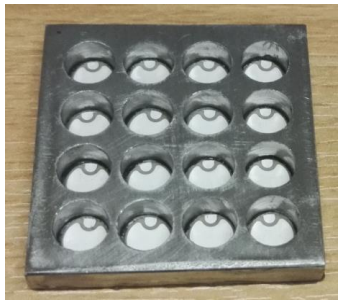
(0,0) mode: PZT/Mem=0.92

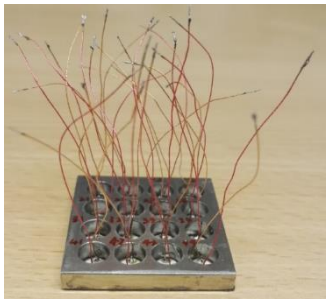
(1,0) mode: PZT/Mem=0.53

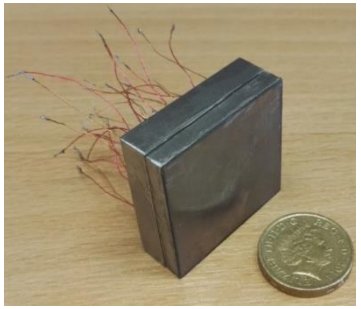
3 Fabrication

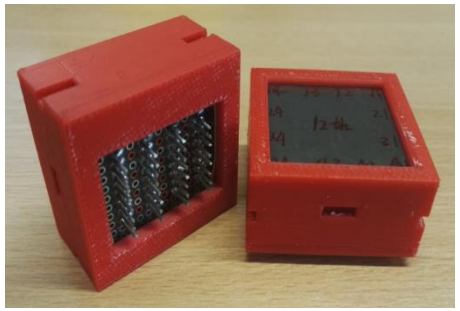


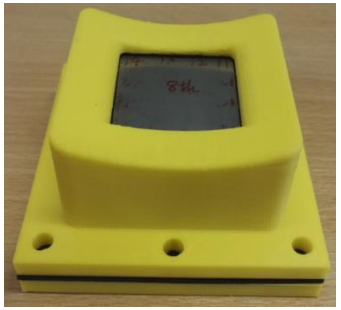




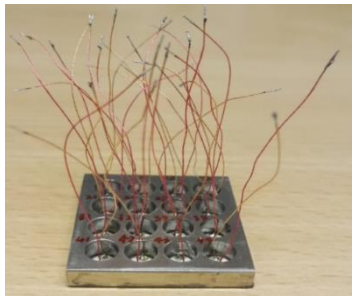








4 Characterization – impedance analyzer



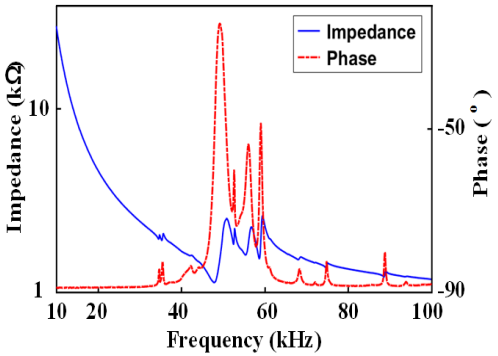
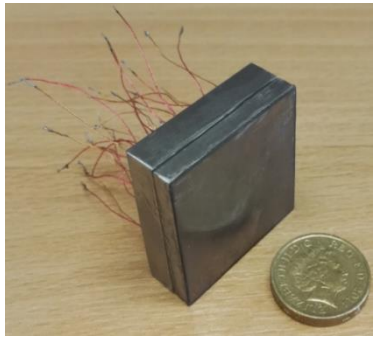
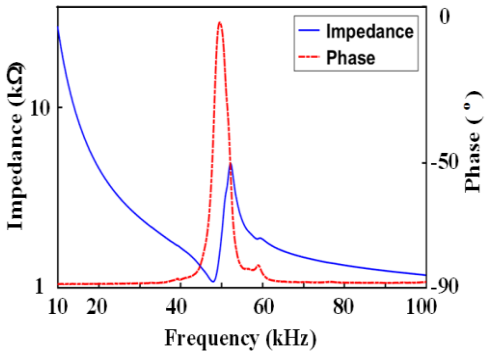


Table 1: Centre frequency of elements of a typical array (unit: kHz)

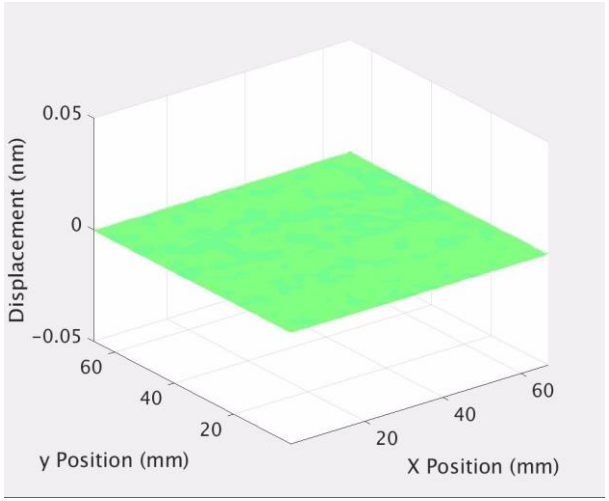
	Column 1	Column 2	Column 3	Column 4
Row A	50.44	49.53	49.71	49.90
Row B	49.00	49.88	50.08	49.18
Row C	48.64	48.46	49.14	48.28
Row D	47.03	47.37	47.47	47.29



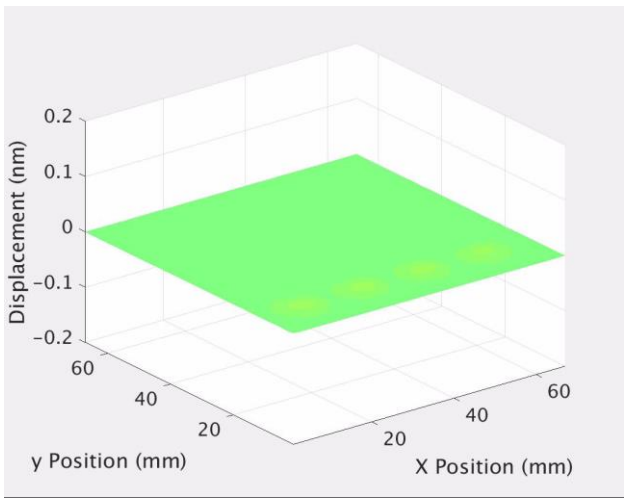


- Backplate not only enhances the mechanical robustness of the array, but also improves the performance of the array in terms of its amplitude, mode purity, mechanical crosstalk.
- Averaged -6 dB bandwidth: 1.5 kHz.

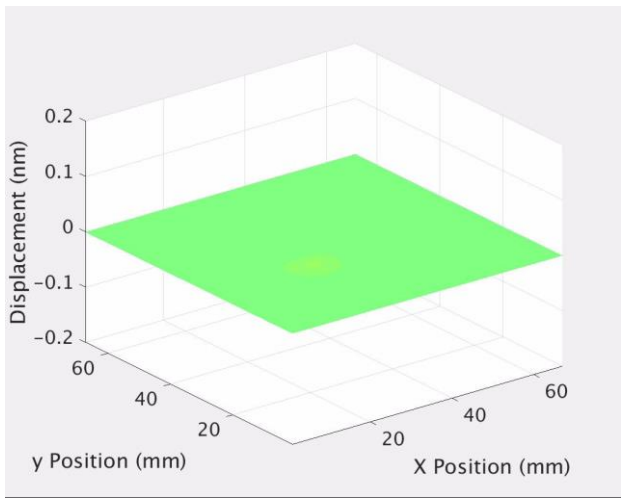
4 Characterization – laser vibrometer



8-cycle tone burst signal transmitting simultaneously



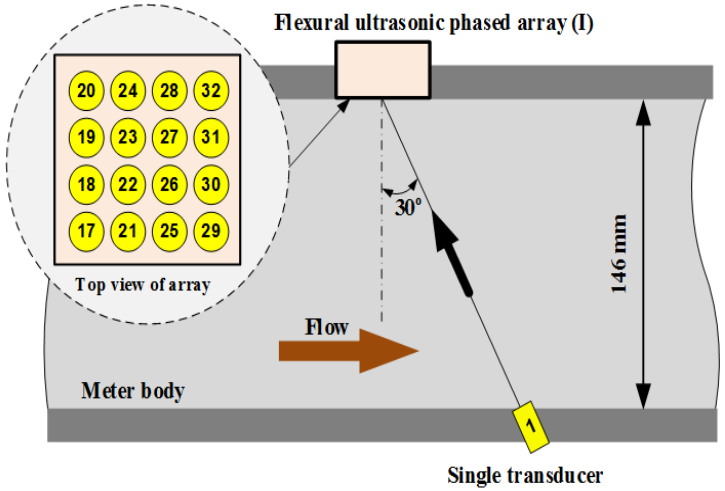
8-cycle tone burst signal transmitting with time delay (30^{o} beam steering mode)

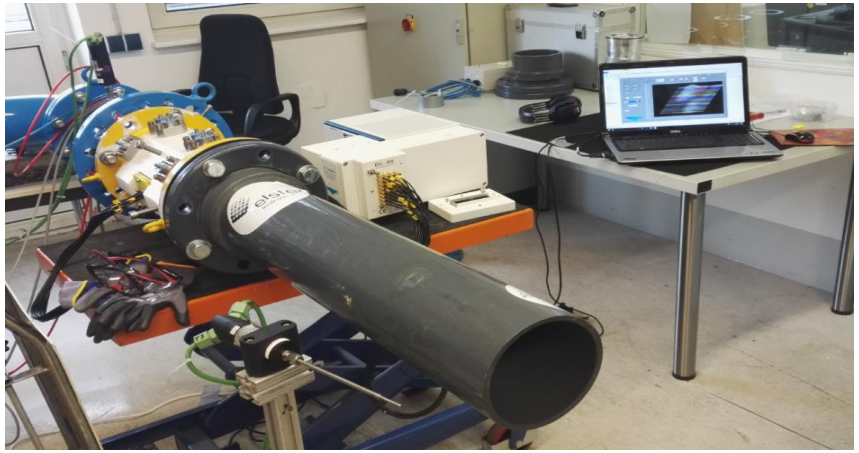


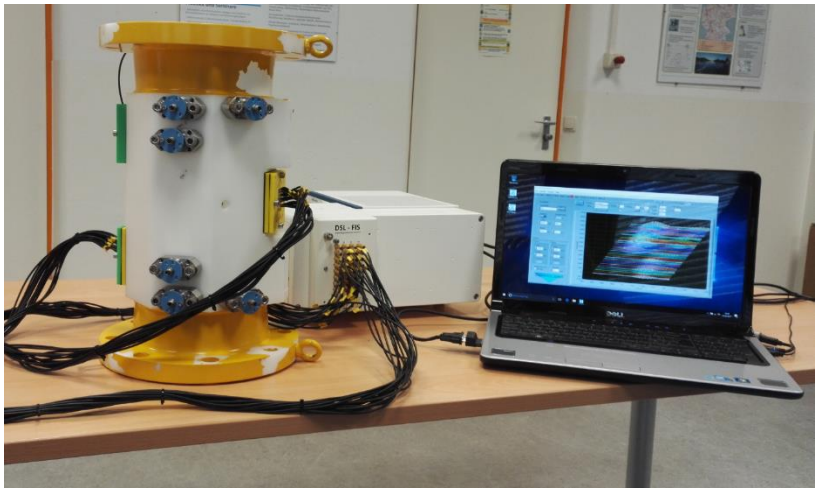
Only one element is driven (study of mechanical cross)

- Array elements vibrate in the (0,0) mode;
- No obvious debonding or weak bonding is observed;
- Crosstalk between neighbouring elements doesn't severely affect performance.

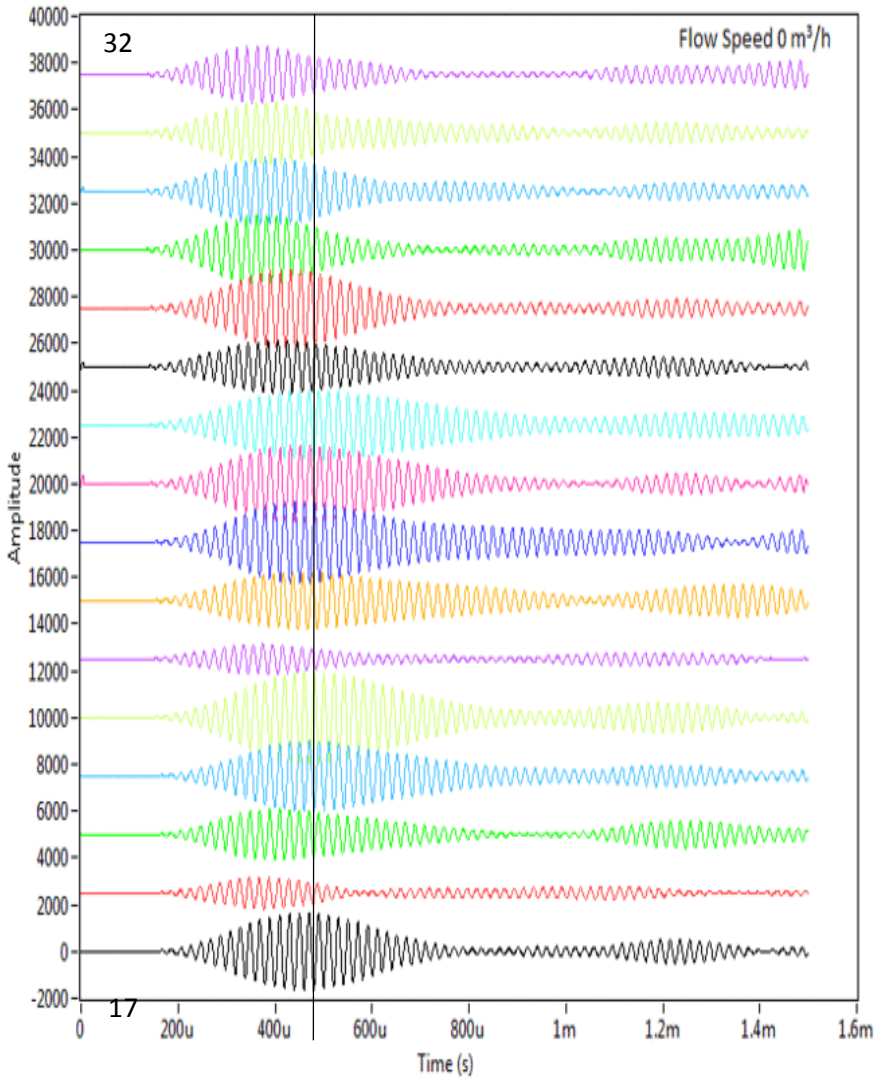
5 Flow measurement tests



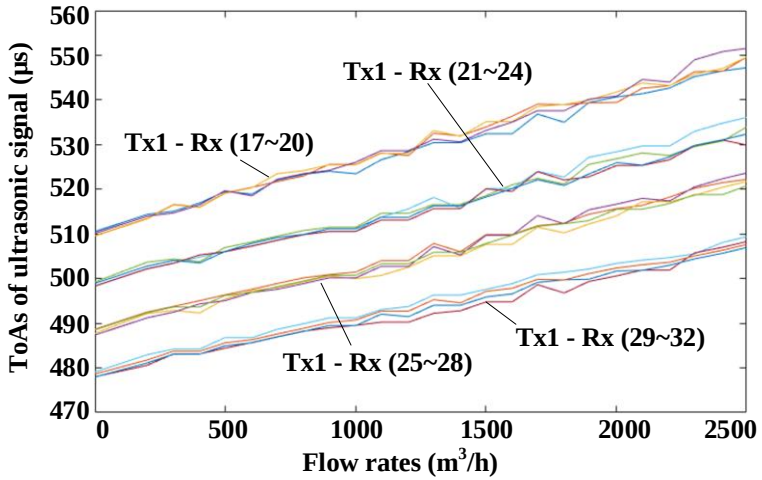




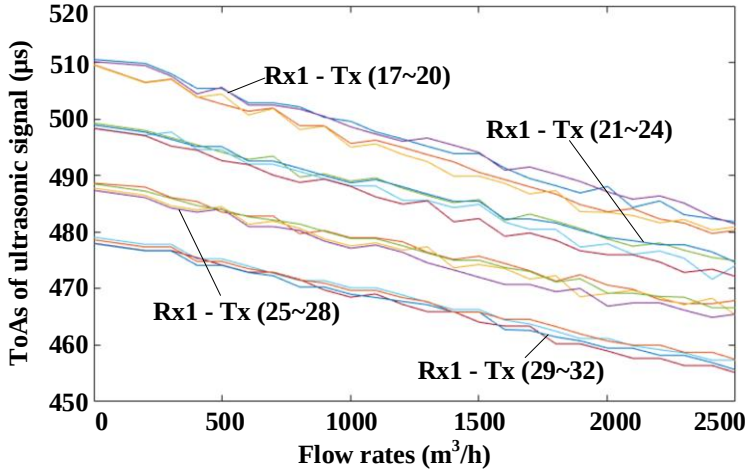
5 Flow measurement tests



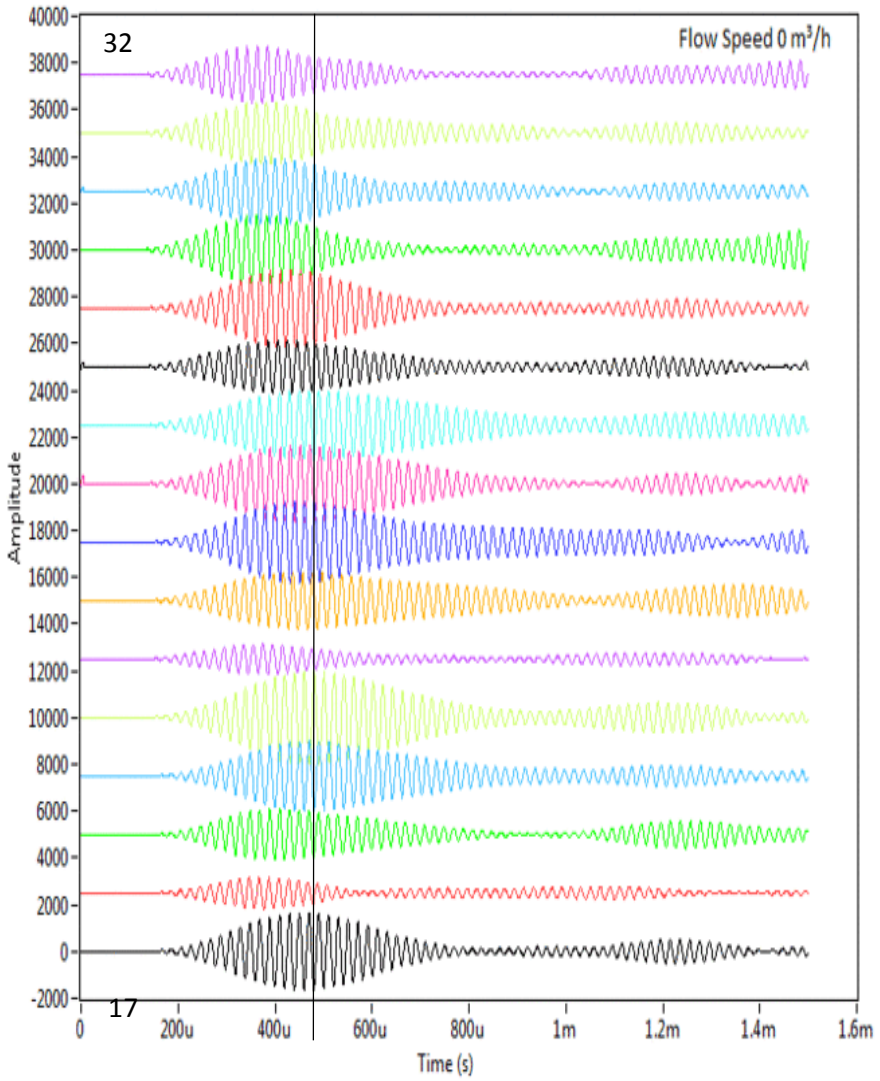
Upstream



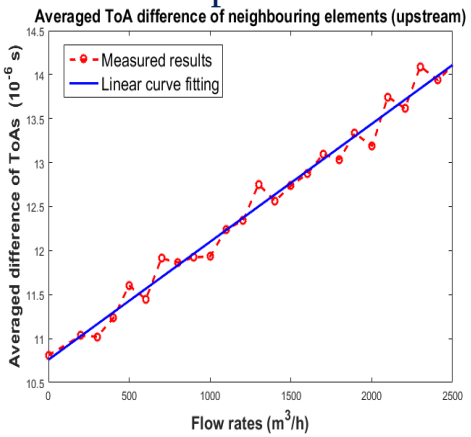
Downstream



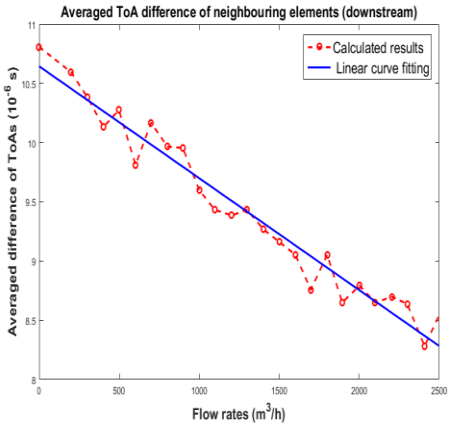
5 Flow measurement tests



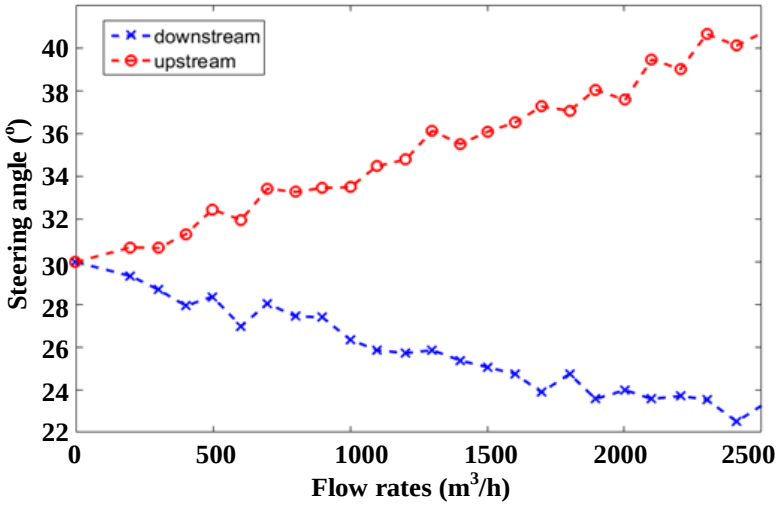
Upstream



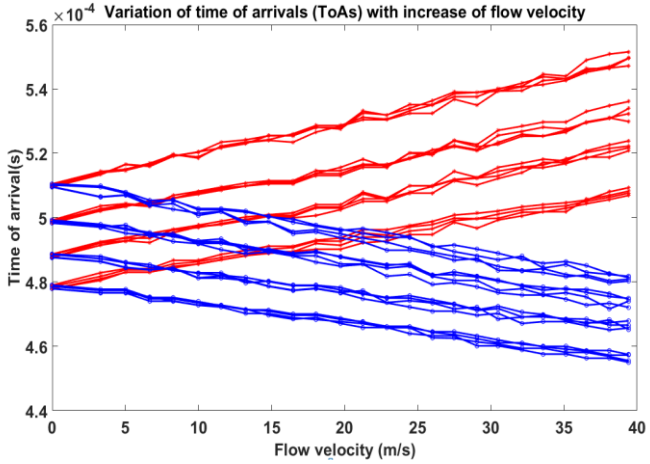
Downstream

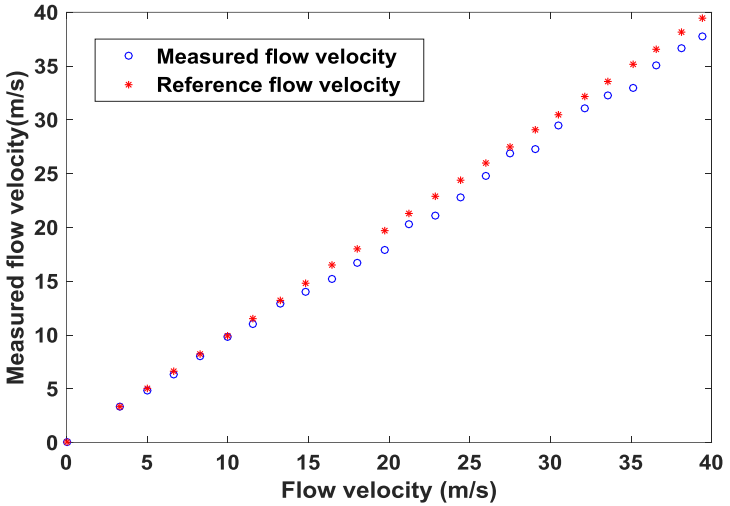


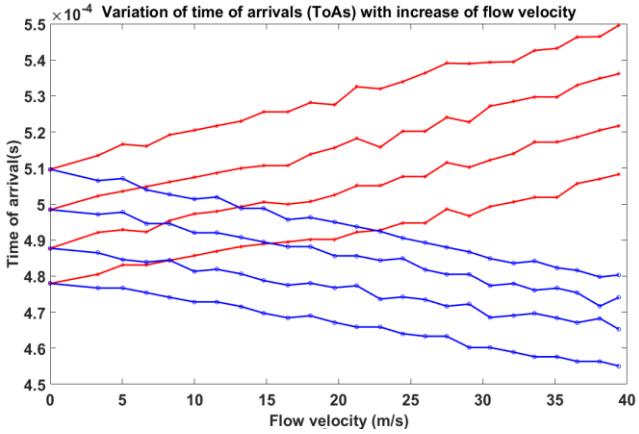
Variation of optimum steering angle with flow rates



5 Flow measurement tests







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

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

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

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

$\overline{t}_{up}$: 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.

6 Summary and Future Research

Summary

- The design, the fabrication and the characterization of two-dimensional flexural ultrasonic phased arrays are presented;
- Flow measurements with the arrays are conducted and the results closely correlate with those measured by a calibrated mechanical flow meter;
- Flexural ultrasonic phased arrays are a potentially economic and low-voltage solution for flow measurement with higher accuracy and larger range.

Future Research

- Compare various data fusion technologies to further improve accuracy;
- Carry out multi-path flow measurement using the 2D phased arrays.

Thank you for your attention!

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