17. Application of Micro-Electro-Mechanical System (MEMS) Ultrasonic Transducer for Flow Metering

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Objectives: (1) Design a small-scale experiment to test the flow sensing potential of Micro-Electro-Mechanical System ultrasonic transducer array (MEMS-UTA) (see Figure 1). (2) Make use of numerical methods to study the interactions between the ultrasonic fields produced by the MEMS-UTA and the turbulent structures in a well-characterized flow field.

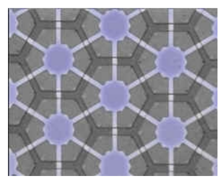

Figure 1. Surface features of MEMS-UTA flow sensor where each cell (drum) is the width of a human hair.

Problem: For twenty years, piezoelectric ultrasonic transducers have been used to evaluate fluid velocities in flow meters. Today, ultrasonic flow meters have replaced orifice plates as the defacto industrial flow meter for new high-pressure gas flow measurements in transmission pipelines throughout the World. In spite of this success, current ultrasonic technology has failed to deliver flow metering solutions where complex installation effects are present and for pipelines smaller than 100 mm.

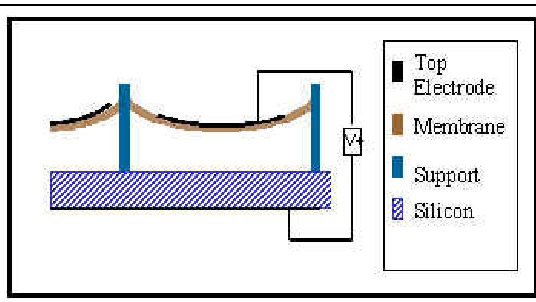

Figure 2. Schematic diagram of MEMS ultrasonic drum.

In 1996, a Stanford electric engineering research group, under the direction of Prof. B. T. Khuri-Yakub, initiated work on the development of MEMS based ultrasonic transducers. Their research led to a new type of transducer, which consisted of an array of metalized membranes over silicon pits (see Figure 2). The small size and wide dynamic range of these transducers allow them to be used in many applications traditionally not open to piezoelectric transducers. This technology has become commercially available and is used in medical imaging and non-destructive testing, and is being considered for flow metrology applica-tions (see Figure 3).

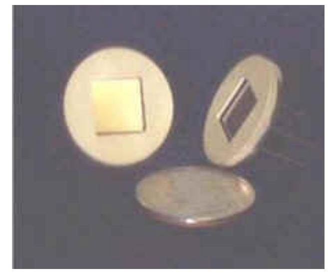

Figure 3. 2MHz MEMS-UTA for gas sensing applications.

Approach: A small-scale experiment allows assessment of the performance characteristics of the MEMS-UTA. In this experiment, sensors were flush-mounted into parallel plates (see Figure 4). Air passes through the gap between the plates to generate flow fields ranging from Poiseuille flow (laminar case), to fully developed channel flow (turbulent case). Using this configuration, the mechanical coupling between the sensor and the housing (smaller = better), the dynamic acoustic range of transmission (larger = better), the fluid attenuation (smaller = better), and the electro-mechanical impedance mismatch are determined. In addition, since the sensors are structured as an array of micro drums, the cross coupling between adjacent drums can be evaluated (smaller = better). Provided this cross coupling can be controlled, the possibility exists for phase matching of the drums to enable features such as ultrasonic beam steering (something not possible with piezoelectric transducers).

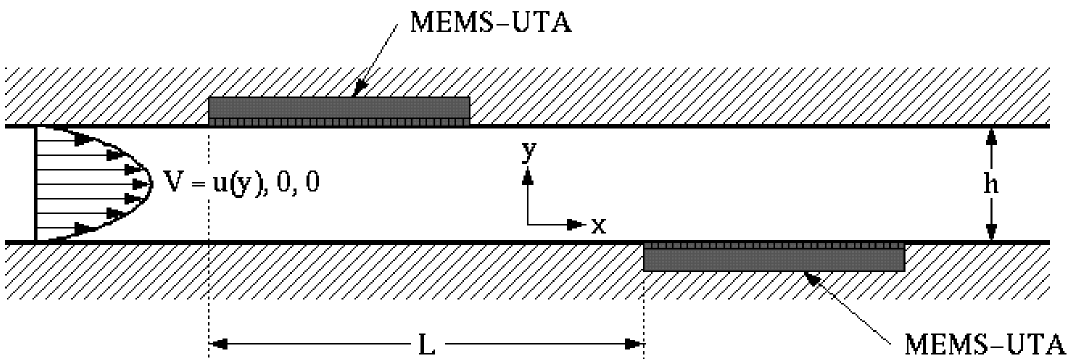

Figure 4. Schematic diagram of parallel plate testing configuration for MEMS-UTA.

The hydrodynamics can be readily modeled using computational fluid dynamics, while the acoustics can be modeled using a ray-tracing algorithm for inhomogeneous moving media. The hydrodynamics of the problem will be modeled using a closed-form solution of the Navier-Stokes equations (laminar case) and a Large Eddy Simulation (turbulent case). Using these numerical results it will be possible to study the interaction between a turbulent flow field and an ultrasonic wave front to assert the validity of using Reynolds averaged solutions to model ultrasonic propagation in flow fields.

Results and Future Plans: At the beginning of the year, 1 MHz immersion transducers were obtained: conventional arrays in 3 mm^2 and 5 mm^2 geometries, and pulse-echo transducers. To drive the transducers, we purchased a HP 33120A function generator, the signal of which was also sent to a dual-channel 150MHz digital scope for diagnostic purposes. As expected, the bandwidth of the square transducers was very good (> 100%) but the pulse-echo transducers showed poor performance due to mechanical coupling. In both cases problems arose in the form of defective waterproof coatings, which failed after a few hours of operation. After a few weeks of use, all transducers had short circuited due to bridged coatings. The transducer manufacturer was made aware of the problem and they promised to look into it. We also solicited a more user-friendly design for the air transducers.

The air transducers (center frequency of 1.1 MHz) arrived late in the year, after much delay in the micro-fabrication process. These transducers have a lower bandwidth than the immersion type but are useful for flow applications. The new design makes use of a housing in which the 1-cm diameter transducer chip is mounted. This housing carries all the essential electronics. Testing of these devices is yet to commence.