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**Flexible Ultrasonic Transducers for Structural Health Monitoring of Pipes at High Temperatures**

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### **Background, Motivation and Objective**

Structural health monitoring (SHM) and non destructive evaluation (NDE) of pipes in power, chemical and petroleum plants and other structures have become increasingly important in the improvement of safety and in the extension of these structures' lifespans. In these applications, ultrasonic transducers (UTs) may need to be conformed to structures that have surfaces with different curvatures and may need to be operated at elevated temperatures. Conventional piezoelectric UTs having rigid flat end surfaces may not be convenient for such type of inspections due to poor signal to noise ratio (SNR) in the pulse-echo mode. The main goal of this research is to develop a simple and an economical on-site sensor fabrication approach. One objective is to develop piezoelectric flexible ultrasonic transducers (FUTs) including those formed in array configurations that can be made in the lab. Another objective is to develop an on-site bonding technique such as brazing to bond FUTs onto pipes to achieve excellent bonding for permanent SHM and NDE purposes.

### **Statement of Contribution/Methods**

The sol-gel fabricated thick piezoelectric films coated directly onto 75 µm thick steel or titanium membranes serving as FUTs have been developed with a rapid thermal treatment and a poling under ultraviolet light technique. Top electrodes, electrical wire, conductive bonding and connectors were also developed for operation at up to 500°C. Array configurations in 1D and 2D were made by varying the arrangements of the top electrode layouts. Special induction heating techniques were developed to braze such FUTs directly onto steel pipes, where the brazing material between the FUT and the external surface of the pipe served as a permanent high temperature couplant for SHM and NDE applications.

### **Results**

At room temperature, the ultrasonic signal strengths of the developed FUTs made of PZT composite films were the same as those of the commercially broadband UTs centered at 5 – 10 MHz. Such FUTs centered at around 11 MHz and brazed onto steel pipes with a 26.6 mm outer diameter and a 2.5 mm pipe thickness showed ultrasonic echoes with a signal-to-noise ratio (SNR) of at least 26 dB at 150°C in pulse-echo mode. FUTs made of bismuth titanate composite films and centered around 12 MHz were also made and brazed onto steel pipes and their operation temperature reached up to 500°C. Individual ultrasonic performance of the 16-element 1D and 2D FUT arrays also showed to be similar.

### **Discussion and Conclusions**

FUTs and arrays are small, lightweight and have a high level of sensitivity that is comparable to commercially available broadband UTs at room temperature. They can be conformed to pipes and this ensures high SNR during pulse-echo measurements. Since FUTs together with all necessary electrical connections can operate at up to 500°C and can be fabricated on-site, they are excellent candidates for the purposes of SHM and NDE of pipes.