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AXIAL AND CIRCUMFERENTIAL SH WAVE PIEZOELECTRIC TRANSDUCERS FOR PIPELINE STRUCTURAL HEALTH MONITORING

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ABSTRACT

Pipeline structural health monitoring (SHM) is being paid more and more attention to in energy and chemical industries. In this work, we presented two SHM strategies for pipelines based on axial shear horizontal (SH) waves (or torsional waves) and circumferential SH waves piezoelectric transducers. Firstly, we show that the single-mode torsional wave T(0,1) can be excited by a transducer ring consisting of 24 pieces of d_{24} face-shear mode PZT wafers. Then, three types of shear-mode piezoelectric wafers, including d_{24}, conventional d_{15} and thickness-poled d_{15} mode, were systematically compared in terms of SH wave excitation and reception. Results show that the d_{24} mode wafer outperforms the other two, especially for SH wave reception. Finally, a bidirectional SH wave transducer is proposed based on antiparallel d_{15} piezoelectric strips, which can excite single-mode bi-directional SH waves and it is frequency tunable. It can also be used to excite circumferential SH wave in large-diameter pipes.

Keywords: structural health monitoring, pipeline, guided wave, SH wave, piezoelectric transducer

1. INTRODUCTION

The structural integrity of pipelines is very important in oil and chemical industries, as the failure may result in a great loss of lives and property. Non-destructive testing (NDT) and structural health monitoring (SHM) techniques are required to inspect possible defects such as corrosion, pitting, cracks, etc. in pipelines. The guided wave method can cover tens of or even one hundred meters from a single point and is thus very promising for long-distance inspection. In the past two decades, guided wave based NDT methods had been intensively studied and has been successfully applied in pipeline inspections[1].

Most NDT methods for pipes are based on axially propagated guided waves, including the longitudinal waves, torsional waves and flexural waves. In applications, the longitudinal wave mode L(0,2) and the fundamental torsional wave T(0,1) are widely used. Researches had shown that the T(0,1) wave is more promising as it is totally non-dispersive and simplifies the signal identification. Furthermore, it is little affected when the pipeline is immersed in or contains liquids.

Currently, there are two methods that can be used to excite T(0,1) wave in pipes. One is by using magnetic patch transducer (MPT) ring and the other is by using thickness-shear (d_{15}) mode piezoelectric ring. Both methods work quite well for NDT applications. However, for SHM applications, they both have some problems. MPT requires a high power to generate waves and preamplifier circuits for reception. The d_{15} piezoelectric ring usually required a clamping device to fasten it onto the pipe and the clamping force may vary during long term monitoring and thus affect the wave excitation and reception.

In this work, we firstly show that pipeline SHM can be realized by using bonded face-shear (d_{24}) mode piezoelectric ring without further clamping. The number of d_{24} piezoelectric wafers required to excite single-mode T(0,1) wave were specially investigated. Then, three types of shear-mode piezoelectric wafers, including d_{24}, conventional d_{15} and thickness-poled d_{15} mode, were systematically compared in terms of SH wave excitation and reception. Finally, a bidirectional SH wave transducer is proposed based on antiparallel d_{15} piezoelectric strips, which can also be used to excite circumferential SH wave in large-diameter pipes. The information provided in this work could serve as guidance for practical pipeline SHM.

2. MATERIALS AND METHODS

2.1 Finite element simulations

Finite element (FEM) simulations were conducted based on the commercial software ANSYS. The PZT element was modeled by SOLID5 elements and both the aluminum pipe and the bond layer were modeled by SOLID185 elements in the ANSYS software. The largest size of FEM elements is less than 1/20 the shortest wavelength and the time step is less than 1/20fc, where fc is the central frequency of the drive signal. The selected drive signal is a five-cycle Hanning window-modulated sinusoid toneburst.

2.2 Experimental testing

The experimental setup is shown in Fig. 1(a). A function generator (3320A, Agilent, USA) delivered a five-cycle Hanning window-modulated sinusoid toneburst signal to the power amplifier (KH7602M). Then the amplified drive signal was sent to the exciter to excite guided waves. The wave signals measured by the receiver were collected by an oscilloscope (Agilent DSO-X 3024A) with 128 times trace averaging. Fig. 1(b) is a photo of the experimental setup.

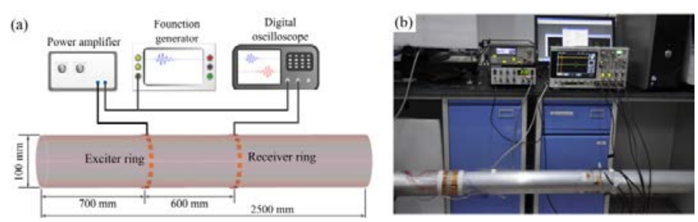

FIGURE 1: (a) SCHEMATICS OF THE EXPERIMENTAL SETUP FOR EXCITATION AND RECEPTION OF THE T(0, 1) MODE ON AN 100MM-DIAMETER ALUMINUN PIPE. (b) THE PHOTO OF THE EXPERIMENTAL SETUP.

3. RESULTS AND DISCUSSION

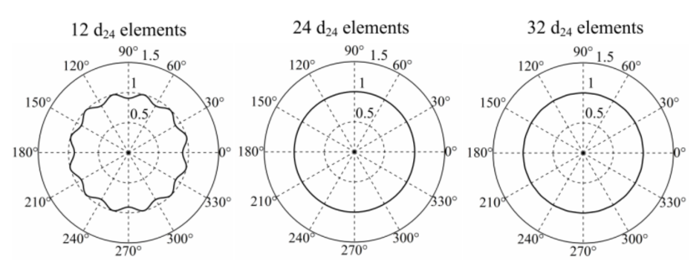

FIGURE 2: TANGENTIAL DISPLACEMENT ANGULAR PROFILE SIMULATIONS OF GUIDED WAVES EXCITED BY DIFFERENT NUMBER OF FACE-SHEAR D24 PZT ELEMENTS AT 150 KHZ IN AN ALUMINUM PIPE (OUTER DIAMETER OF 100 MM AND THICKNESS OF 3 MM) AT THE AXIAL DISTANCE OF 100 MM FROM THE TRANSDCUER.

Finite element (FE) simulations were firstly conducted to study the number of d_{24} wafers required to excite single-mode T(0,1) wave in an 100mm-diameter aluminum pipe and the results were shown in Fig.2. It can be seen that when using 12 pieces of d_{24} PZT wafers, the excited axial SH wave (or torsional wave) was not single-mode T(0,1). While when the element number increased to be 24 and 32, perfect T(0,1) wave can be excited.

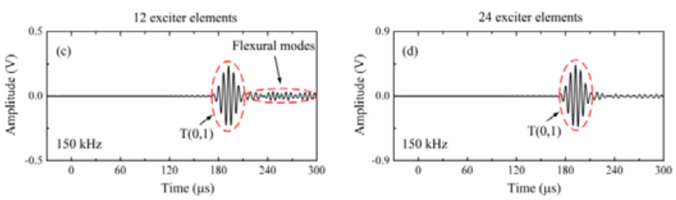

FIGURE 3: WAVE SIGNALS EXCITED USING A RING ARRAY OF TWELVE (LEFT) AND TWENTY-FOUR (RIGHT) FACE-SHEAR D24 PZT ELEMENTS AT 150 KHZ AND RECEIVED USING A RING OF TWELVE D24 PZT ELEMENTS 600 MM AWAY FROM THE EXCITER.

Experimental study were then conducted to check the ring consisting of different numbers of d_{24} wafers in exciting and receiving T(0,1) wave and the results were shown in Fig.3. It can be seen that when using twelve exciter elements, the flexural wave cannot be completely suppressed. While when using twenty-four elements, the flexural wave can be totally removed and single-mode T(0,1) wave can be excited. When the ring serves as receiver, it is shown that the twenty-four element ring can filter flexural waves and excite single mode T(0,1) wave. Therefore, twenty-four element ring is suggested to excite/receive T(0,1) wave in a 100mm-diameter pipe. More results can be found in Ref.[2].

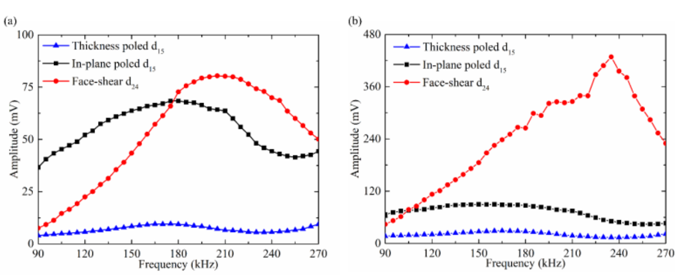

FIGURE 4: THE SH0 WAVE AMPLITUDE VERSUS FREQUENCY ON A 2MM-THICK ALUMINUM PLATE USING THREE TYPES OF SHEAR MODE PZT WAFERS IN SELF-EXCITATION/SELF-RECEPTION MANNER. (a) FIXED DRIVE VOLTAGE OF 20 V, (b) FIXED POWER CONSUMPTION OF 0.08 W.

We further compare the performances of three types of shear mode PZT wafers, i.e., face-shear d_{24}, conventional d_{15} and thickness-poled d_{15} mode, in excitation/reception of SH waves in plate which is similar to the torsional wave in pipes[3]. It can be seen from Fig.4 that under the fixed drive voltage, the SH wave responses excited/received by both types of d_{15} wafers varied slightly with increasing frequency. In comparison, the responses by d_{24} wafer increases steadily with drive frequency below 210kHz and then slightly drop off. Under the fixed driving power of 0.08W, the responses by d_{24} wafer also increases steadily with drive frequency up to 240kHz. Furthermore, in a wide frequency range, the SH wave responses by d_{24} wafer is much larger than that by the conventional d_{15} wafer. In both cases, the responses by the thickness-poled d_{15} wafer were the smallest, although it is conveniently to excite omni-directional SH waves in plates. Therefore, rings consisting of d_{24} wafers are suggested to excite/receive T(0,1) wave in pipes.

Finally, we proposed that bidirectional SH wave can be effectively excited by antiparallel d_{15} piezoelectric strips (APS) in a plate and it can also be used to excite circumferential SH waves in pipes. FEM simulations were firstly conducted to validate this tunable design and the results were shown in Fig.5. Here we define the ratio of maximum displacement of Lamb wave to that of SH_0 wave as LSR. It can be seen from Fig.5 that the excited LSR by a single 12mm-long and 24mm-long d_{15} strip is about 24% and 16%, and that by 12mm-long and 24mm-long APS is reduced to about 16% and 10%. Simulation results also indicated that the APS of small thickness (say <0.5mm) is more favorable to suppress the Lamb waves. Experimental studies validated the design of the bidirectional SH wave transducer. The proposed APS based bidirectional SH wave transducer can also selectively excite SH_1 wave and suppress SH_0 wave in a large frequency-thickness product plate.

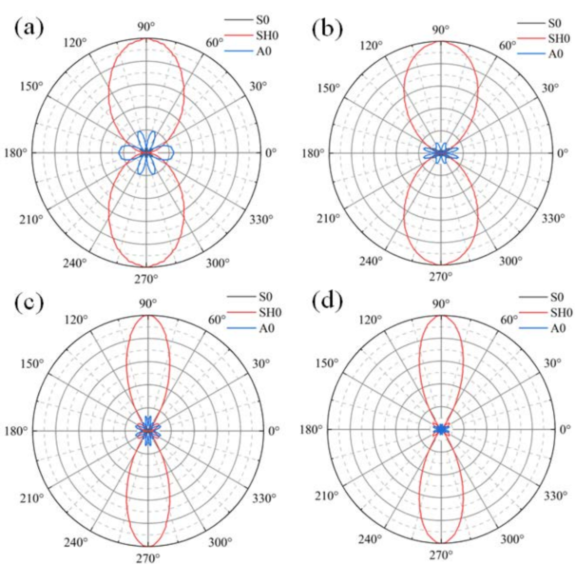

FIGURE 5: FEM SIMULATED DISPLACEMENTS OF DIFFERENT GUIDED WAVE MODES GENERATED IN A 1MM-THICK ALUMINUM PLATE AT 196kHz BY USING 2MM-WIDE, 0.8MM-THICK D15 PIEZOELECTRIC STRIPS: LEFT: SINGLE STRIP OF 12MM LENGTH (a) AND 24MM LENGTH (c); RIGHT: ANTIPARALLEL STRIPS OF 12MM LENGTH (b) AND 24MM LENGTH (d). THE INTERVAL BETWEEN ANTIPARALLEL PIEZOELECTRIC STRIPS IS 8MM.

4. CONCLUSIONS

In summary, we proposed that single-mode T(0,1) wave can be excited in pipes by a piezoelectric ring consisting of face-shear d_{24} wafers, whose efficiency is better than that consisting of d_{15} wafers in a wide range of frequencies. We further proposed a bidirectional SH wave transducer based on antiparallel d_{15} piezoelectric strips, which can also be used to excite circumferential SH wave in pipes. Both simulations and experimental studies were conducted to validate the proposed design.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Alleyne, D. N., Pavlakovic, B., Lowe, M. J. S., and Cawley, P., 2001, “Rapid, Long Range Inspection of Chemical Plant Pipework Using Guided Waves,” pp. 434–441.

[2] Miao, H., Huan, Q., Wang, Q., and Li, F., 2017, “Excitation and Reception of Single Torsional Wave T(0,1) Mode in Pipes Using Face-Shear D24 Piezoelectric Ring Array,” Smart Materials and Structures, **26**(2), 025021.

[3] Huan, Q., Chen, M., and Li, F., 2018, “A Comparative Study of Three Types Shear Mode Piezoelectric Wafers in Shear Horizontal Wave Generation and Reception,” Sensors, **18**(8), 2681.