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STRUACTURAL HEALTH MONITORING BASED ON SH WAVE SPARSE ARRAY AND PHASED ARRAY SYSTEM

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ABSTRACT

Guided wave based structural health monitoring (SHM) has been regarded as an effective tool in detecting early damages of structures thus avoid catastrophic failure. Unlike Lamb waves based SHM which had been well investigated, SH wave based SHM had been rarely reported due to the lacking of omni-directional SH wave piezoelectric transducer (OSH-PT). In this work, we firstly developed an OSH-PT based on thickness-poled, thickness shear (d_{15}) PZT ring consisting of several elements. After size optimization, it is shown that even for the OSH-PT consisting of two half-rings, it can still generate and receive SH wave with good omni-directivity and the excited SH_0-to-Lamb wave ratio is above 20dB in wideband. Then a sparse array system and a linear phased array system were developed using the half-ring based OSH-PTs, respectively. Results indicated that the proposed two systems can detect both surface defects and through-thickness defects at multi frequencies without baseline. The sparse array system has a good resolution in detecting a 4mm hole at 135kHz (0.17λ) with the locating error of 12mm while the phased array system has a better resolution which can detect a 2mm hole with the locating error of only 6.2mm. Besides, both systems can detect multiple defects simultaneously. This work is expected to promote the applications of SH_0 wave based SHM.

Keywords: guided wave, shear horizontal wave, structural health monitoring, piezoelectric transducer

1. INTRODUCTION

Structural health monitoring (SHM) has been regarded as an effective tool for large engineering structures since it can detect early damages thus avoid catastrophic failure. Among the existing methods, guided wave based SHM seems to be very promising for its large coverage area and is thus cost-effective. Due to that a thickness-poled piezoelectric disk can generate and receive Lamb waves omni-directionally, in past decades, Lamb wave based SHM had been extensively investigated. However, its further development was limited by the inherent dispersion and multi-mode. Strategies such as frequency turning, etc. have to be employed to generate quasi-single mode Lamb wave with little dispersion. However, when transducer array was used, it is rather difficult to ensure all the transducers work in the quasi-single mode, resulting in artifacts and low signal to noise ratio in the detection image.

In comparison, the fundamental shear horizontal (SH_0) wave is more promising for its non-dispersion and uncoupled displacements. However, omni-directional generation and reception of SH_0 wave is always a challenge. Based on magnetostrictive effect and Lorentz force, two omni-directional SH wave transducers were proposed by Kim group. But the large footprint and high power driving made them unsuitable for SHM. The omni-directional SH wave piezoelectric transducers (OSH-PTs) based on synthesized circumferential poled PZT were also proposed. Since the uniform circumferential poling was rather difficult to realize, their performance was thus undesirable.

In this paper, we firstly in Section 2 proposed an OSH-PT based on thickness-poled, thickness shear (d_{15}) PZT ring consisting of several elements. Experimental results indicated that even for the OSH-PT consisting of two half-rings, it can still excite and receive SH_0 wave with high SH_0-to-Lamb wave ratio (SLR) and good omni-directivity. Then a baseline-free sparse array system was built in Section 3 and a linear phased array system was built in Section 4 based on the two-half-ring OSH-PTs, respectively. Results showed these two systems can detect both surface defects and through-thickness defects accurately at varied frequencies without baseline. Conclusions were summarized in Section 5.

2. DESIGN OF THE OSH-PTS

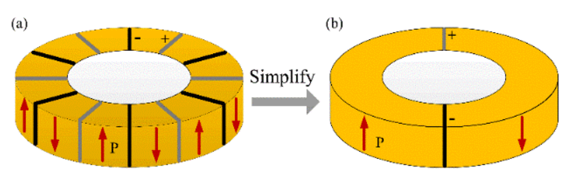

FIGURE 1: THE CONFIGURATION OF THE PROPOSED OSH-PT CONSISTING OF DIFFERENT NUMBER OF ELEMENTS: (a) TWELVE ELEMENTS; (b) TWO HALF-RINGS.

Firstly, the working principle of the proposed OSH-PT was introduced as follows. A PZT ring was poled along thickness direction and then evenly divided into several elements. After spreading the electrodes on its side faces, all elements were bonded together with the poling directions of adjacent elements opposite thus they can share common electrodes. Fig. 1

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presented the configuration of the proposed OSH-PT consisting of twelve and two elements, respectively.

Then, the performance of the OSH-PT consisting of twelve elements was examined[1]. Results indicated that it can generate and receive SH_0 wave in high SLR with uniform sensitivity. However, its complicated configuration may bring difficulties in actual applications. Thus, we further examined the performance of such a ring with fewer elements[2]. It was found that the SLR of an OSH-PT decreased with fewer elements, which was mainly caused by the reduced out-of-plane stiffness of the OSH-PT. Size optimization was then conducted to improve the SLR. Results showed that the SLR of two half-ring based OSH-PT increased steadily with the decrease of its outer diameter. Experiments indicated that for a two-half-ring OSH-PT with the outer diameter 12mm, inner diameter 6mm and thickness 2mm, the SLR in the case of self-generation/self-reception was above 20dB in wideband, which is good enough for practical applications.

3. BASELIE-FREE SPARSE ARRAY SYSTEM

After validating the performances of the proposed OSH-PT, eight half-ring based OSH-PTs were employed to form a baseline-free sparse array SHM system. Two OSH-PTs were placed closely as a pair so that the scattered waves resulted by defects can easily be isolated in time domain[3]. Then the features contained in scattered waves can be extracted for defect localization without baseline.

Firstly, the capability of the proposed system in detecting a surface defect *i.e.* glued iron rod (20mm in diameter and 100mm in length) on a 2mm-thick aluminum plate was examined. It was found that even at 135 kHz, the proposed system can still detect the surface defect without baseline. Its locating error was only 9.2mm, which is quite good. The high location accuracy was mainly benefited from the employed single mode, non-dispersive SH_0 wave which can greatly decrease the difficulty in signal identification. When driving frequency increased to 250kHz, the defect was successfully located again with the location error of only 4.1mm, which can be attributed to the short wavelength thus stronger scattered wave at high frequency.

Then, the glued iron was removed from the aluminum plate and through-thickness holes with varied diameter were introduced. Fig.2 presented the imaging results of the different size holes at 135kHz and 250kHz. It can be seen that the sparse array system can locate a 4mm hole at 135kHz (0.17λ, where λ is wavelength) with the location error of 12mm. This high resolution can also be attributed to the employed single mode non-dispersive SH_0 wave. With the increase of defect's size, the location error was significantly reduced and it is only 6.4mm for the 10mm hole. This is resulted by the stronger scattered wave from the bigger defect. With regard to the results at 250kHz, it showed the similar tendency but with smaller location error, which should also be attributed to the stronger wave scattering at higher frequency.

Finally, two 10mm holes was introduced to examine its capability in multi defects detecting. Results indicated even at 135kHz, it can still detect the two holes accurately with the location error of 14mm, which is obviously better than that of 27mm for Lamb wave based system. With the increasing frequency, the location error will be further reduced. This result further confirmed the advantages of SH_0 wave based SHM. All the results in Section 3 showed that the proposed SH_0 wave sparse array system can detect both single defect and multiple defects in higher resolution without baseline.

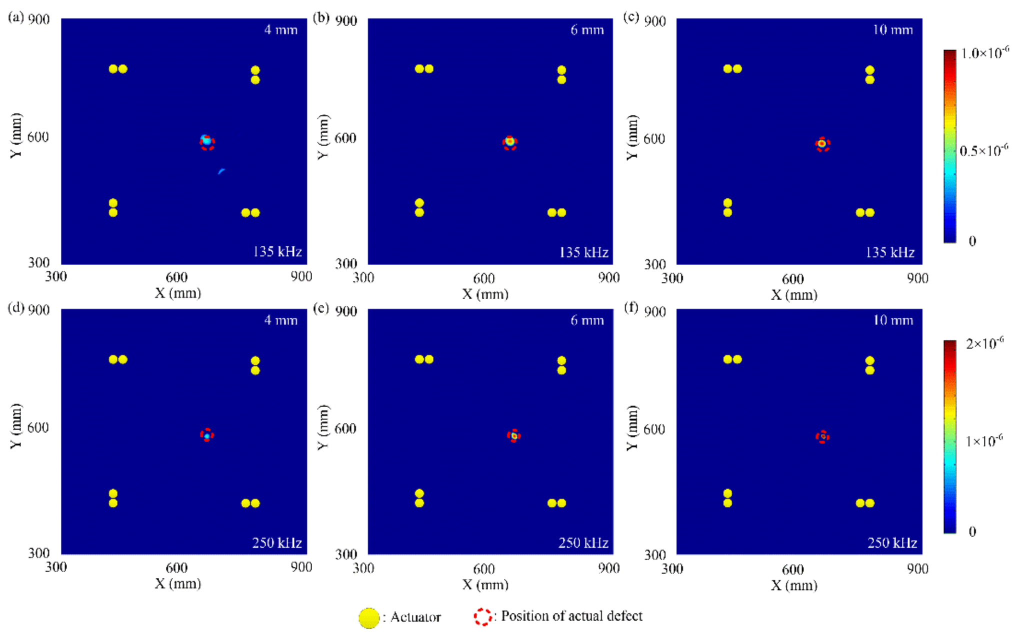

FIGURE 2: IMAGING RSULTS OF THE BASELINE-FREE SH WAVE SPARSE ARRAY SYSTEM IN DETECTING A THROUGH-THICKNESS HOLE WITH DIAMETERS OF 4MM, 6MM AND 10MM. UP: AT 135KHZ; BOTTOM: AT 250KHZ.

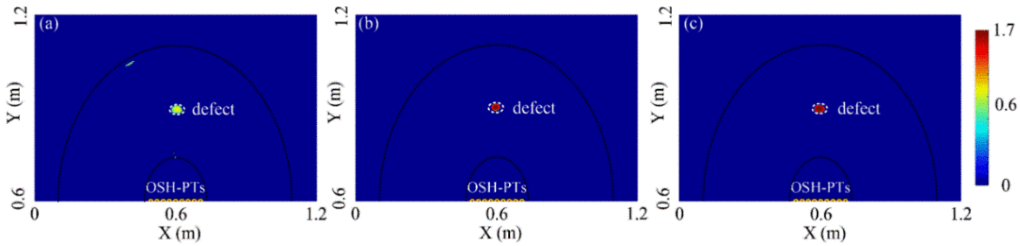

FIGURE 3: IMAGING RSULTS OF THE SH WAVE PHASED ARRAY SYSTEM IN DETECTING THROUGH-THICKNESS HOLES WITH DIAMETER OF (a) 2MM, (b) 4MM and (c) 6MM IN AT 145KHZ.

4. LINEAR PHASED ARRAY SYSTEM

A SH_0 wave linear phased array system consisting of nine half-ring based OSH-PTs was developed for SHM. The working principle of the system was similar to the Lamb wave based one[4] and will not be presented here. Note that as SH_0 is non-dispersive, this system is simpler and can work at varied frequencies.

Firstly, the capability of the proposed system in detecting a surface defect *i.e.* glued iron rod (20mm in diameter and 100mm in length) was examined. The results indicated that even at 100kHz, the proposed system can still detect the surface defect effectively without baseline although there appeared some artifacts. The corresponding location error was only 12mm. With the increasing of frequency, the artifacts gradually faded away and the location error was also reduced, which can be attributed to the stronger scattered waves resulted by the defect at higher frequency.

When turning to the location results for the through-thickness holes in Fig.3, it can be seen from that even for the 2mm hole, only one highlight zone corresponding to the defect appeared in the imaging result with a little noise, indicating that the proposed system has a super resolution in detecting a 2mm through-thickness hole at 145kHz. The corresponding location error was only 6.3mm, which is very desirable. The high resolution in defect detecting was mainly benefited from the employed single mode of non-dispersive SH_0 wave, which can greatly decrease the difficulty in signal identification. With the increase of defect's size, the amplitude corresponding to the defect were obviously enhanced, as shown in Fig. 3(b) and (c), and the noise also faded away. Besides, the location error was also reduced, which was about 5.1mm for the 4mm hole and only 2.2mm for the 6mm hole. Both the increased contrast ratio of the defect's zone and the decreased location error can be attributed to the stronger scattered waves for the larger defect.

Finally, the capability of the linear phased array system in detecting multiple defects was examined. Two 6mm through-thickness holes were introduced as defects. Results indicated that the system can detect both holes simultaneously at 145kHz. The location errors were 2.8mm and 6.4mm, respectively, which is larger than that of single defect case but is still quite good. The increased location error may be caused by the interaction of the echoes from two defects. Even so, this level of location error was negligible considering its large inspection area. From all the results in Section 4, it can be concluded that the proposed SH_0 wave phased array system can detect both surface defects and through-thickness defects accurately without baseline. Besides, it can detect multiple defects simultaneously.

5. CONCLUSION

In this paper, we proposed an OSH-PT based on thickness-poled, thickness shear (d_{15}) PZT ring consisting of two half-rings. Experimental results indicated after size optimization, it can generate and receive SH_0 wave in high SLR with uniform sensitivities. Then a baseline-free sparse array system and a linear phased array was developed based this OSH-PT. Results indicated that both systems can detect surface defects and through-thickness defects accurately at varied frequencies without baseline. Besides, the sparse array has a high resolution which can detect a 4mm hole and the phased array has a better resolution which can even detect a 2mm hole. In addition, both systems can detect multiple defects simultaneously. This work will promote the applications of SH wave based SHM.

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