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TOWARDS AN IMPROVED PIEZOELECTRIC FIBER PATCH FOR SH0 GUIDED WAVE GENERATION

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ABSTRACT

Piezoelectric fiber patch (PFP) is suitable for guided wave based structural health monitoring (SHM) due to its light, thin, and flexible characteristics. In previous work, it was shown that PFPs can be designed to preferentially generate shear horizontal waves (SHPFP). The working principle and the potentials of SHPFP are discussed, and new designs with improved performances are proposed. Numerical simulations are conducted to validate the performance of the proposed designs.

Keywords: Guided wave, piezoelectric fiber patch, shear horizontal wave

1. INTRODUCTION

Guided elastic waves (GEW) play an important role in both, long range ultrasonic testing and structural health monitoring of plate and shell like structures. Objects can be tubes for fluids as oil and gas pipes or pipes for hot gases in power plants. Other interesting objects are the pillows for offshore wind turbines or the airplane skin. We can distinguish symmetric and antisymmetric Lamb waves and horizontal polarized shear waves as types of guided wave modes in plate like structures with isotropic material properties. For each type there is an infinite series of modes characterized by their dispersion, which is the frequency dependence of the phase velocity.

Most of the GEW applications are based on Lamb waves, having particle displacements in the sagittal plane. They are easy to excite by piezoelectric waver active sensors and actuators. These sensors have a lot of advantages as low weight and low price. But, it is difficult to excite a single mode alone with high purity. Additionally, the big challenge for the application of all lamb waves are their dispersive characteristics, which make it complicated to use localization methods based on the travel time of signals. While there are methods to compensate for the dispersion [1], it is best to use wave modes, which are nondispersive. The fundamental order of the shear horizontal mode (SH0) fulfils this condition. Moreover, the SH0 is the only horizontal polarized plate mode for frequencies below the cutoff frequency of the SH1 mode. That is why there is increasing effort to find efficient ways to generate and detect SH0 waves.

A way to generate shear waves is to apply surface tractions or corresponding volume forces perpendicular to the intended propagation direction. On the receiving side, we have to detect in-plane motion also perpendicular to the propagation direction. There are several transducer types available. Electromagnetic Acoustic Transducers (EMAT) are well known [3]. They are based on the conductivity and partially magnetic properties of metals to excite the wave directly in the object. The disadvantage is that the application is limited to metals. For SHM applications, another disadvantage is their rather large size and heavy weight. Another type of proposed transducers are based on the magnetostrictive effect [4,5]. They have the same disadvantage of large mass, coming from the magnets, which are needed for magnetic fields.

There are several options to generate surface tractions by piezoelectric elements [6]. For generation of SH waves, the face shear and the thickness shear modes are appropriate (see Fig 2 of [6]). There are a number of recent papers about transducers based on these principles. The thickness shear mode is studied for example in [7] and the face shear mode in [8].

By dividing solid piezoelectric material into fibers and forming fiber patches, very flexible piezoelectric fiber transducers can be fabricated. They are studied rather extensively as Lamb wave transducers (see e.g. [9,10]) where 3D Scanning Laser Doppler Vibrometer was used [11,12].

In the present contribution, we follow a recent work of generating SH0 waves by piezoelectric fiber patches (PFP). By combining two patches opertating in ortogonal directions and with opposite sign, a pure in plane shear is generated [13]. This transducer type combines the high flexibility of PFPs with pure in-plane shear operation. While the basic operation priciples

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were explained and confirmed by modelling and experimantal verification [6], there is much room for improvement in various perspectives.

2. BASIC IDEAS AND OPPTIMIZATION POTENTIAL

2.1 SHPFP operation

Two rectangular shaped PFPs with fiber orientation and electrode orientation at ±45° relative to the patch length orientation are used to form SHPFP.

One PFP is overlaid by another PFP with orthogonal fiber orientation, and exciting them simultaneously. By controlling the sign of the excitation signal at each PFP, the SHPFP can generate surface tractions parallel to its 4 edges (see Fig 6f of [6]).

It should be mentioned that SHPFP generates SH0 waves through 4 different directions, and not only SH0 waves but also unwanted S0 lamb wave are generated from each corner (Fig 1).

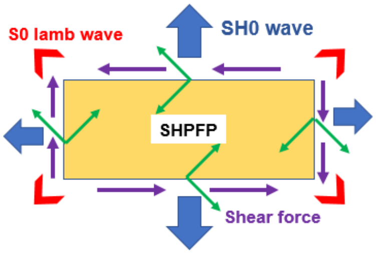

FIGURE 1: SHPFP operation configuration. Green arrows show the forces generated in the individual PFPs of the two layer PFP stack. Purple arrows are the resulting surface tractions generating shear. Blue and red arrows show the orientations of SH0 and S0 lamb wave respectively.

2.2 Optimization criteria

The first optimization criterion will be the purity, which is represented as the ratio of the SH0 wave amplitude to the next highest amplitude of other (spurious) wave modes. Another criterion will be the directivity. Depending on the application, either an omnidirectional operation or a strongly directional operation could be advantageous. We optimised for a rather strong directivity of the SH0 component.

3. RESULTS AND DISCUSSION

3.1 Rounding corner SHPFP

A possible reason for the unwanted S0 lamb waves could be the right-angled corners. To find out whether the sharpness of the corners is crucial and to increase the purity ratio, the rounding corner design SHPFP was tested.

The rounding corner SHPFP has semicircle area at both ends of its length orientation (Fig 2). The performance of the rounding corner SHPFP, as matter of the purity was evaluated by Finite Element Method (FEM) simulation with ANSYS.

By changing the design, the maximum amplitude of SH0 wave increased by 1.9%, and the maximum amplitude of S0 lamb wave decreased by 12.8%. Therefore the purity ratio ($SH0/S0$) increased by 16.8% (5.6 -> 6.54). It should be noted that, both the original SHPFP and the rounding corner SHPFP have same length and width. Therefore, actual active area of the rounding corner design is smaller than the original design.

It is a certain improvement in the purity, but considering the effort to change the design and production, the benefit is marginal.

FIGURE 2: Rounding corner SHPFP. In FEM simulation, the rounding corner SHPFP has the same length and width size of the original SHPFP.

3.2 Dual SHPFP

As shown in Fig 1, the original SHPFP generates SH0 wave through 4 directions, 2 main directions (length edges) and 2 minor directions (width edges). The two minor SH0 waves decrease the directivity and also affect the purity by increase the S0 lamb wave amplitude.

To reduce the effects of minor direction SH0 waves, the Dual SHPFP design is proposed. As shown in Fig 3, two SHPFPs are placed one beside each other and being operated with opposite sign. The surface tractions on minor edges are facing the opposite directions, and they will cancel each other out partially. Therefore, the minor direction SH0 wave amplitudes will be decreased (directivity), and the amplitude of unwanted S0 lamb waves at each corner will also be decreased (purity).

By adopting the Dual SHPFP design, the directivity is clearly improved (Fig 4). Not only the directivity, but also the signal amplitude is increased (92% increment at 100 kHz central frequency excited signal). Another criterion is the purity. The purity ratio increased from 5.15 (SHPFP) to 9.01 (Dual SHPFP), which is 75% of improvement.

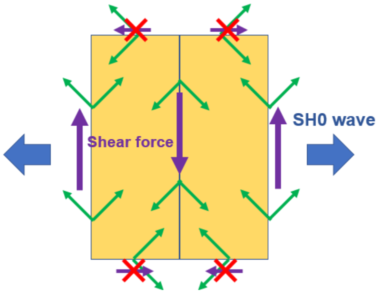

FIGURE 3: Dual SHPFP. Green arrows show the forces generated in the individual PFPs of the two layer PFP stack. Purple arrows are the resulting surface tractions generating shear. The red crosses represent that surface tractions at the short sides of both SHPFPs which are counteracting and eliminating each other partially. Blue arrows show the orientations of the propagating SH0 waves.

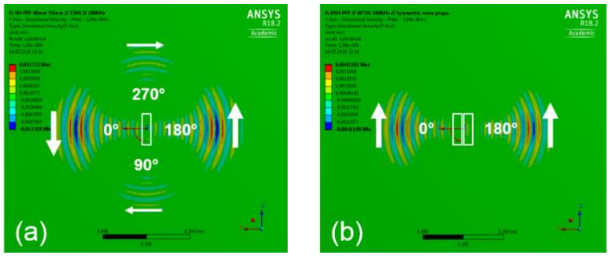

FIGURE 4: (a) SHPFP and (b) Dual SHPFP performances comparison: by FEM simulation. The arrows are representing directions of driven shear forces, and amplitudes. 3-cycle Hanning-windowed sine signal of 100 kHz central frequency was used as the excitation signal.

4. CONCLUSION / FURTHER WORK

We found, that

- Changing the shape of the transducers with rounding corners give certain improvement in purity but the benefit is marginal and does not justify the effort.
- The change from a single SHPFP design to the Dual SHPFP design gives significant improvements in directivity, signal amplitude and purity.

We will further work on the SHPFP and extend the dual SHPFP, such that the number of acting elements exceeds two. This will be done by techniques of individual excitation of separate electrode finger groups as demonstrated already for Lamb Wave PFP [14].

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