INVESTIGATION ON THE EFFECT OF IMPERFECT INTERFACE ON THE PROPERTIES OF LOVE WAVE PROPAGATION

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ABSTRACT

Surface waves can be found many practical applications in MEMS and ultrasonic transducers. Love wave devices/sensors are high sensitive devices which can be found much engineering significance in many signal transmission, signal processing and information storage applications. For the piezoelectric film/elastic substrate layered system, in practical applications, piezoelectric ceramics often inherently have a much higher mechanical strength under compressive stresses in order to improve the reliability of transducers. On the other hand, due to the thermal mismatch, intrinsic stress and the brittleness nature of piezoelectric ceramics, there exists unavoidable initial stress in above-mentioned piezoelectric layered structures and imperfection occurs between the interfaces of the structures. These imperfections may influence the propagation behavior of Love waves. Effects of imperfections on the dispersion relations of Love wave in piezoelectric layered structures are taken into account theoretically and experimentally. A new kind of contact-type line-focused transducer is developed for the Love wave to be excited and detected. Experiments concerning the propagation of Love waves in piezoelectric layered structure are carried out to investigate the imperfect interface effect. Results obtained in our research indicate that imperfect interface can greatly influence the propagation properties of Love waves under some certain conditions. Experimental results agree well with the theoretical prediction, which also indicate that the novel Love wave transducer developed by us is effective.

1 INTRODUCTION

As one kind of weakly-nonhomogeneous acoustic waves, Love wave is of great interest because of the absence of a surface-normal component of displacement, and therefore has been extensively studied over the years and can be found widely practical applications in MEMS and ultrasonic transducers [1-7].

Piezoelectric micro-electro-mechanical systems are MEMS with piezoelectric materials as sensing and actuating materials which have received much attention due to their unique and promising features.

For the layered structures, due to the thermal mismatch of the layer and the substrate, all films are in a state of internal stress by whatever means they are produced. Two major causes of thin film stress are intrinsic stress and thermal stress. Excessive initial stress in layered structures can lead to delamination, microcracking, debonding and degradation of the layer, etc. It also can change the dispersion relation corresponding to the wave propagation in above-mentioned structures.

For the typical configuration form of piezoelectric layer/elastic substrate layered system, main research attention focused on the influence of imperfection between the interface of the layer and the substrate on the propagation properties of Love wave. Further investigation is also carried out to study the effect of imperfection interface factor, which proposed by us in reference [8], on the group velocity of dispersion relations of Love waves. The effectiveness of our study is verified by experimental procedures.

2 STATEMENT OF THE PROBLEM

As shown in Figure 1, a typical layer/substrate layered piezoelectric system is taken into account.

The structure involves an isotropic elastic substrate and a transversely isotropic piezoelectric layer with uniform thickness of h, the poling direction of the piezoelectric layer is along z-axis, perpendicular to the x-y plane. Without loss of any generality, it is assumed that Love wave propagation along the positive direction of y-axis. In our research, the interface effect between the layer and the substrate will be taken into account.

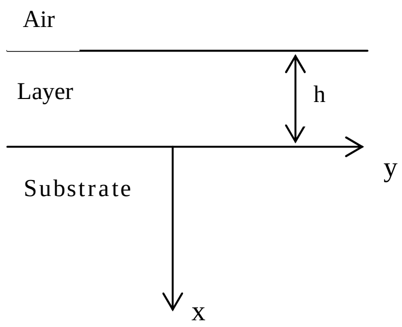

Figure 1: Configuration of the structure and the coordinate system

The governing equation for the piezoelectric layer and the elastic substrate corresponding to the Love wave propagation can be expressed as following forms,

$$c_{44}\nabla^2 w_1 + e_{15}\nabla^2 \varphi_1 = \rho \frac{\partial^2 w_1}{\partial t^2}$$
$$e_{15}\nabla^2 w_1 - \varepsilon_{11}\nabla^2 \varphi_1 = 0 \tag{1}$$

$$\nabla^2 w_2 = \frac{1}{c_{sh}'^2}\frac{\partial^2 w_2}{\partial t^2}$$
$$\nabla^2 \varphi_2 = 0 \tag{2}$$

where w_1, φ_1 and w_2, φ_2 denote the mechanical displacement component and electrical potential function in the layer and substrate, respectively. ∇^2 is the Laplace's operator, and $c'_{sh} = \sqrt{c'_{44}/\rho'}$ is the bulk shear wave velocity in the substrate. Here we introduce the imperfection interface factor R_t to indicate the imperfections exist between the interface of the layer and the substrate as follows,

$$w^{(2)}(0,y) - w^{(1)}(0,y) = R_t \tau_{zx}^{(2)}(0,y)$$
$$\tau_{zx}^{(1)}(0,y) = \tau_{zx}^{(2)}(0,y) \tag{3}$$

Above eqns (1)-(3) together with suitable boundary conditions (mechanical and electrical conditions) and continuous condition, the dispersion equation of the problem can be finally obtained. Both theoretical and experimental analyses are carried out to investigate the effect of the factor on the properties of Love waves.

2 THEORETICAL ANALYSIS RESULTS

Firstly, theoretical analysis concerned with the effect of imperfection interface factor on the dispersion relation of Love wave in the piezoelectric layer/elastic substrate combination system are taken into account.

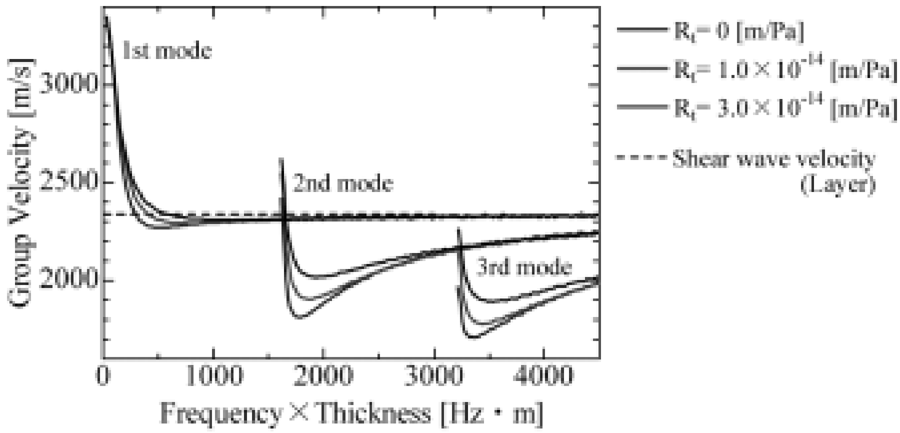

Figure 2: Effect of imperfect factor on the group velocity of Love wave

From the theoretical analysis results shown in Figure 2, we can observe the fact that imperfection interface factor actually affect the propagation of Love wave in piezoelectric layered structure. With the increase of the interface factor, the Love wave group velocity decrease, from the fundamental mode to the higher-order modes, similar tendency can be observed.

3 EXPERIMENTAL RESEARCHES

To verify the theoretical analysis results, corresponding experiment research is carried out. A novel contact-type line-focused transducer is developed to study the Love wave propagation experimentally, which is named as “Love wave transducer”, as shown in Figure 3.

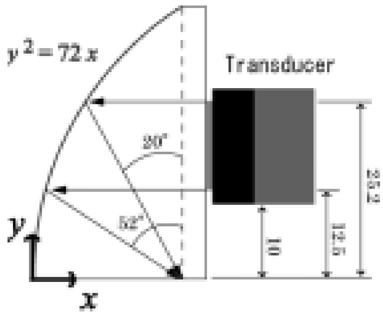

Figure 3: Love wave transducer

Corresponding experimental procedure can be described as follows: a pair of transducers is placed at a distance d facing each other. A conventional pulser/receiver (Krautkrämer, USIP12) was used to drive the transducers. Received signals were recorded by a digital oscilloscope (Hewlett Packard, 54522C). Corresponding experimental setup can be seen in Figure 4.

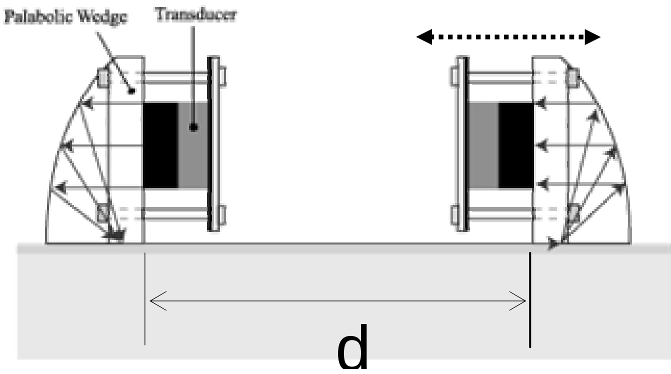

Figure 4: Experimental setup for Love wave testing

The piezoelectric ceramic layer is supplied by Fuji Ceramics Co., a company in Japan, and the substrate is Pyrex glass, which are commercially available ones. Their material parameters are summarized in Table 1.

Table 1: Material parameter used in computation

Materials	c_{44} $\times 10^{10}\ N/m^2$	ρ $\times 10^{3}\ kg/m^3$	e_{15} C/m^2	ε_{11} $\times 10^{-10}\ F/m$
C-6	1.90	7.65	14.5	91.95
Pyrex glass	2.58	2.19	0	0.407

The dispersion relation is often a key for evaluating elastic constants, thickness, or subsurface defects in ultrasonic NDE of plates and films. If an ultrasonic pulse is detected at two locations along the direction of wave propagation, the wave velocity can be determined from the difference between arrival times at these locations. References [9, 10] indicate that group velocity of the wave can be determined by means of wavelet transform. Here Gabor wavelet is used to determine the group velocity of the Love wave.

4 ON THE IMPERFECTION INTERFACE FACTOR

The physical meaning of imperfection interface factor R_t, which we proposed in reference [8], will be investigated here again.

The specimen state when the experiment is being carried out will be considered. The thickness of the adhesive layer is h_3, the shear modulus of adhesive material is G_3, so we can obtain the following expressions

$$
\begin{aligned}
&\Delta w = w^{(1)}(0, y) - w^{(2)}(0, y) \\
&\tau_{zx}^{(3)}(0, y) = \tau_{zx}^{(1)}(0, y) = \tau_{zx}^{(2)}(0, y) \\
&-\tau_{zx}^{(3)}(0, y) = G_3 \frac{\Delta w}{h_3}
\end{aligned}
$$

From above expressions, together with eqns (3), we know the fact that $R_t = h_3 / G_3$, this factor directly concerned with the properties of adhesion layer between the layer and the substrate. And we understand the fact that imperfect interface factor, which proposed in our preceding research, indicate the interface state between the layer and the substrate.

By using the KEYENCE VH-7000 type microscope, the thickness of the adhesive layer can be measured to be $5.7\mu m$, and the Young's modulus of the ultraviolet hardening adhesive (adhesion type: A-1546C) is 785MPa, Poisson's ratio of the hardening adhesive is 0.3, thus the shear modulus can be determined to be 302MPa. Then we can know that for the experiment we are being carried out, the exact value of the imperfection interface factor equals to 1.9×10^{-14} m/Pa. based on above knowledge, corresponding experiment is carried out to verify the theoretical prediction.

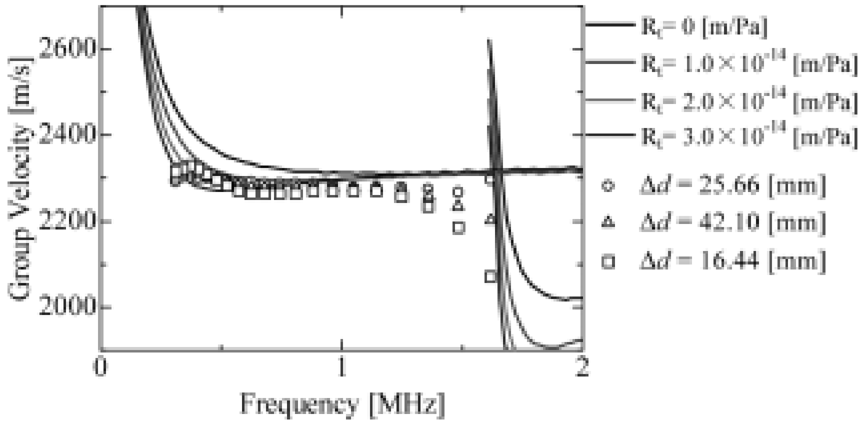

Figure 5: Comparison between the theoretical and experimental results

In our experimental analysis, by adjusting the relative distance of the transducers, different excited and detected signals can be recorded and can be used to determine the group velocity of Love wave by means of wavelet transform technique. As shown in Figure 5, three groups of experimental data can be obtained when relative distance Δd equals to 16.44mm, 25.66mm and 42.10mm, respectively. The corresponding group velocities determined by these three group data reveal similar tendency and agree well each other, only some little difference occur at the place when the 1st mode and 2nd mode of Love wave mixed together.

Experimental results shown in Figure 5 also indicate that the theoretical analysis results corresponding to R_t equals to 2.0×10^{-14} m/Pa agree well with the experimental results.

5 CONCLUSIONS

The contact-type line-focused Love wave transducer developed by us is effective in exciting and detecting the Love wave signals.

Imperfection interface factor directly concerned with the properties of the adhesive layer, it directly indicate the interface state of the layered structures.

Our research possesses the potential of being applied in the non-destructive evaluation of layered structures, especially in the fields of MEMS and ultrasonics.

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