HIGH-FREQUENCY RESONANT CHARACTERISTICS OF TRIPLE-LAYERED PIEZOCERAMIC BIMORPHS

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Summary The vibration characteristics of three-layered piezoceramic bimorphs are studied in high-frequency by experimental measurements, theoretical analysis, and numerical calculation. An optical measurement, called electronic speckle pattern interferometry (ESPI), is used to measure the transverse and planar resonant frequencies and mode shapes. Piezoceramic bimorphs have three-dimensional coupled vibration characteristics in normal connections. Only in-plane vibration motions can be excited at high frequency range for abnormal connection and the resonant characteristics are similar to the single-layered piezoelectric plate.

INTRODUCTION

Piezoelectric bimorphs are fabricated by incorporated piezoelectric materials into enhanced structure layer which is made by metal or composite fiber-reinforced material. It can produce more transversal deflection by means of combining two layers of piezoceramic plates and have the strong structure by integrating the structure layer. Piezoelectric bimorphs have two basic types by means of the various poling direction of the piezoelectric layers. The parallel-type and series-type piezoelectric bimorphs can be further divided into four cases as shown in Fig. 1. Parallel-type piezoelectric bimorph in series electrical connection and series-type piezoelectric bimorph in parallel electrical connection are the abnormal mode which is indicated in Fig. 1 (a) and Fig. 1 (b), respectively. Parallel-type and series-type piezoelectric bimorphs connected electrically in parallel and series connection are denoted as the normal mode as shown in Fig 1 (c) and Fig. 1 (d), respectively. It is important to understand the vibration characteristics and conversion mechanism in electrical and mechanical fields. Three-dimensional and coupled vibration characteristics at high frequency region are investigated for the parallel-type and series-type piezoelectric bimorphs in normal and abnormal connections by two experimental measurements and finite element method (FEM). The theoretical analysis based on the simplify three-layer piezoelectric bimorph as single-layer piezoceramic plate is used to obtain the resonant characteristics from the superposition method proposed by Holland.

EXPERIMENTAL TECHNIQUES

The main experimental technique used for measuring the vibration characteristics of piezoelectric bimorph in high frequencies is the ESPI method. The ESPI technique is a non-contact, real-time and full-field vibrations measurement method. It was proposed for the vibration measurement of circular disk by Butters and Leendertz in 1971. Wang et al. proposed the amplitude-fluctuation ESPI (AF-ESPI) to grab the video images from vibrating state instead of stress-free state. In this paper, the self-arranged ESPI optical setup for the out-of-plane and in-plane vibration measurements is shown schematically in Fig. 2. The ESPI technique based on the time-averaging method can measure the out-of-plane and in-plane mode shapes and resonant frequencies. Impedance analysis is also used to measure the in-plane resonant and anti-resonant frequencies for piezoelectric devices.

EXPERIMENTAL, NUMERICAL AND THEORETICAL RESULTS

The response curves obtained from impedance analysis for parallel- and series-type piezoelectric bimorphs in normal and abnormal connections are presented in Fig. 3. It is noted that the in-plane vibration characteristics observed by impedance analysis of piezoelectric bimorphs in abnormal connection are different from that in normal connection for high frequency range. The results of in-plane resonant frequencies and mode shapes obtained from AF-ESPI, FEM, and theoretical analysis for the first vibration modes of the parallel-type piezoelectric bimorph in series connection (Fig. 1

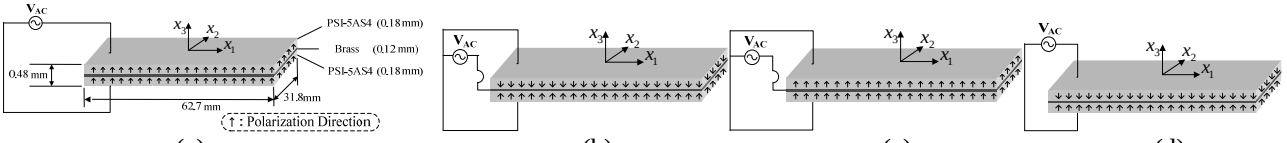

Fig. 1. Schematic diagram of the geometric dimension for the piezoelectric bimorph in abnormal connection: (a) and (b); in normal connection: (c) and (d)

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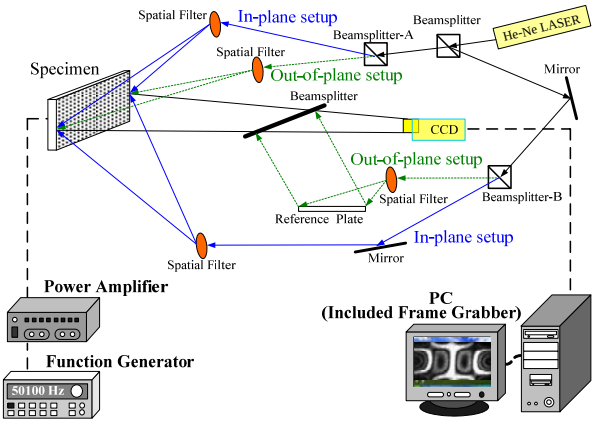

Fig. 2. Optical setup of AF-ESPI.

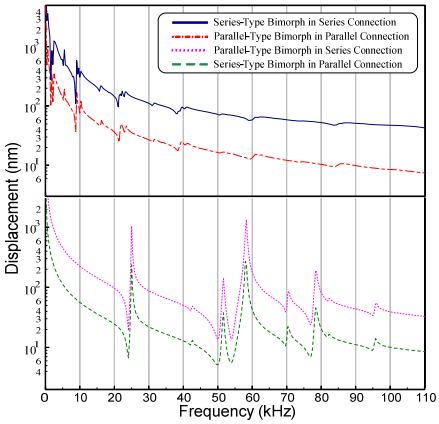

Fig. 3. The impedance response curve of the piezoelectric bimorphs in normal and abnormal connections.

(a)) with free boundary condition are shown in Fig. 4. Only the in-plane vibration can be observed by AF-ESPI and impedance analysis at high frequency for piezoelectric bimorphs in abnormal connection. The in-plane modes are symmetric motion along the central line of x_2 (x_1) direction (anti-symmetric) for U mode shapes, and symmetric motion along the central line of x_1 (x_2) direction (anti-symmetric) for V mode shapes. The dynamic characteristics for triple-layer piezoelectric bimorphs in abnormal connection are similar to single-layer piezoelectric plates. The dynamic characteristics of series-type piezoelectric bimorph in parallel connection (Fig. 1(b)) are similar with the previous case. The resonant frequencies, mode shapes, and normalized displacements, of parallel- and series-type piezoelectric bimorphs in normal electric connection are quite different from the cases for abnormal electric connection. The parallel-type piezoelectric bimorph in normal electric connection (Fig. 1(c)) is the same as that used for abnormal electric connection. For the parallel-type piezoelectric bimorph in parallel connection, the resonant modes at high frequency is shown in Fig. 5. The results of series-type piezoelectric bimorph in series connection (Fig. 1(d)) are similar with the case in normal connection.

CONCLUSIONS

By comparing the experimental results with the theoretical analysis and FEM, the dynamic behaviours are completely analyzed for both parallel- and series-type piezoelectric bimorphs in normal and abnormal connections. No coupled vibration characteristic is occurred and one of the in-plane modes is the dominated motion in FEM and theoretical analysis. For the piezoelectric bimorphs in normal connection, the out-of-plane and in-plane modes can be measured by AF-ESPI in the same resonant frequencies. The out-plane modes are the dominated motion and only one of the in-plane mode shapes measured by AF-ESPI can be identified from FEM. Excellent agreements between two experimental measurements and two theoretical calculations for piezoelectric bimorphs in abnormal and normal connections are presented in this study.

References

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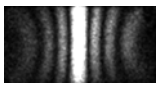
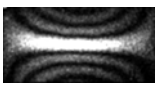
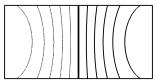
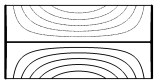
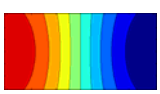
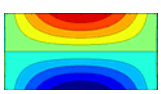
	Mode	Mode Shapes U	Mode Shapes V	Frequency (Hz)	*Error (%)*
1	ESPI			24166	
	FEM			24027	*-0.58*
	Theory			23378	*-3.26*
	Imp.			24112	*-0.22*

Fig. 4. Resonant characteristics of the parallel-type piezo-electric bimorph in bimorph parallel connection

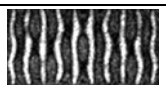
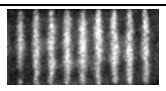
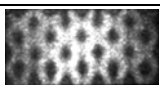
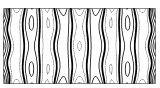
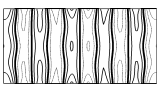
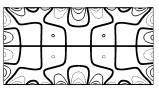
	Mode	Mode Shape W	Mode Shape U	Mode Shape V
1	**ESPI**			
	Freq. Hz		15919	
	Voltage, volts	1.5	12	25
	FEM			
	Freq. Hz		15632 *(-1.80 %)*	
	Normalized Disp.	1	0.1026	0.0398
	Impedance		15822 *(-0.61 %)*	

Fig. 5. Resonant characteristics of the parallel-type piezoelectric in series connection obtained from AF-ESPI and FEM