http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 13 (4): 703-708, 2014
ISSN 1812-5638 / DOI: 10.3923/itj.2014.703.708

Design of Miniature Patch Longitudinal Bending Cylindrical Ultrasonic Motor

[1,2,3]Qichao Song and [1,2]Zhen Zhou
[1]Higher Educational Key Laboratory for Measuring and Control,
Technology and Instrumentations of Heilongjiang Province,
[2]College of Measurement-Control Technology and Communications Engineering,
Harbin University of Science and Technology, 150040, Harbin, China
[3]HeiLong Jiang Institute of Technology, 150050, Harbin, China

Abstract: In order to improve the mechanical performance of ultrasonic motor, a miniature patch longitudinal bending composite excitation cylindrical traveling wave ultrasonic motor is proposed. The motor is composed of a cylinder and a longitudinal-bending transducer which is located on the lateral wall of the cylinder. The transducer is made up of a pair of bending vibration piezoelectric ceramic plates, a pair of longitudinal vibration of piezoelectric ceramic plates and a rectangular aluminum piece whose front end is amplitude transformer. The motor is designed and simulated by using finite element method based on the analysis of the working principle of the motor which realized frequency degeneracy of two basic vibration modes of the motor. The vibration characteristics are tested. The test results well agree with the results of finite element method. The test results show that longitudinal vibration mode, bending vibration mode and cylindrical bending vibration mode well match with each other.

Key words: Ultrasonic motor, longitudinal bending, vibration mode, patch, frequency degeneration

INTRODUCTION

Rotary traveling wave ultrasonic motor with the advantages of simple structure, convenient control rotating, two-phase superposition of standing wave, good frequency consistency and so forth acquires more and more studies (Zhao, 2002; Zheng *et al*., 2008; Park *et al*., 2006). The structure of rotary traveling wave ultrasonic motor can be classified into ring type, cylindrical type and so on (Zhao, 2007). However, the amplitude of the annular axial bending vibration mode in ring-type traveling wave ultrasonic motor is not consistent which will restrict the mechanical output performance seriously (Liu *et a1*., 2009). The ultrasonic motor using piezoelectric ceramic excitation has the advantage of high power density, so the efficiency can be the same nearly while the size of the motor decreased. Therefore, the miniaturization and micromation of ultrasonic motor is an important development trend.

A patch longitudinal bending composite excitation cylindrical traveling wave ultrasonic motor is proposed based on the advantages of working mode of d31 and d33. It is good for miniaturization of the motor, since the proposed motor uses patch ceramic excitation. In addition, the structure of motor is simple and the processing and assembly technique is simplified.

STRUCTURE OF THE MOTOR

The motor consists of stator and rotor. The stator comprises a cylinder and a longitudinal bending transducer and the transducer is located on the lateral wall of the cylinder. The transducer is made up of a pair of bending vibration piezoelectric ceramic plates, a pair of longitudinal vibration of piezoelectric ceramic plates and a rectangular aluminum piece whose front end is amplitude transformer. The exponential amplitude transformer converge the vibration energy, effectively increase the amplitude and the vibration velocity of particle on the surface of driving gear and improve mechanical output performance of the motor. The amplitude transformer's tip end of the rectangular aluminum piece connects with the outside of the cylinder and both of them are processed on one piece of metal material which eliminates the adverse effects to the vibration wave of stator caused by other connection methods between transducer and cylinder. All of the piezoelectric ceramics pieces of stator polarize along the

Corresponding Author: Qichao Song, Higher Educational Key Laboratory for Measuring and Control, Technology and Instrumentations of Heilongjiang Province, Harbin University of Science and Technology, 150040, Harbin, China

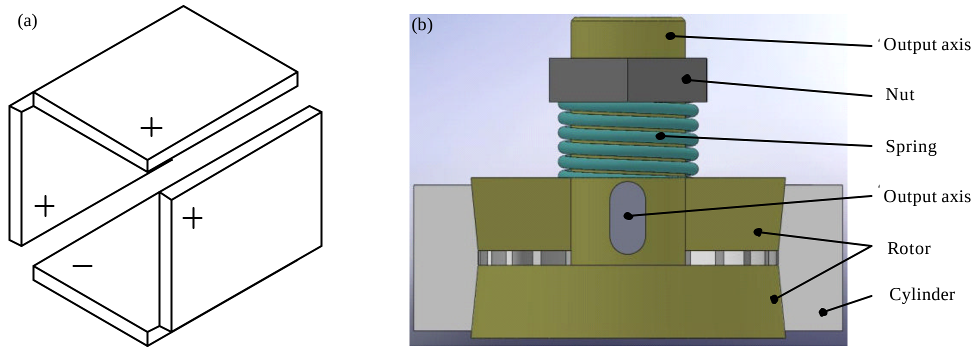

Fig. 1(a-b): Structure of patch longitudinal bending composite excitation cylindrical traveling wave ultrasonic motor (a) Polarization mode of piezoelectric ceramics and (b) Partial cutaway view of motor

thicknes direction, as shown in Fig. 1a. The polarization direction of two longitudinal vibration piezoelectric ceramics pieces which are horizontal is opposite and the polarization direction of two longitudinal vibration piezoelectric ceramics pieces which are vertical is the same. There are a series of pectiniform drive gear on the internal surface of the cylinder. The structure of the rotator is shown in Fig. 1b. The stator and the rotor connected by a nut-spring system. The connection region between stator and rotor is the end edge of the drive gear.

PRINCIPLE OF THE MOTOR

The patch longitudinal bending composite excitation cylindrical traveling wave ultrasonic motor uses patch piezoelectric metal beam longitudinal bending vibration excitation cylinder to generate cylindrical radial bending vibration whose space phase difference is 90°. Longitudinal vibration piezoelectric ceramic plate and the bending vibration piezoelectric ceramic plate of the motor use two-phase AC exciting voltage, respectively. d31 stretching vibration of piezoelectric ceramic plate can generate longitudinal vibration and bending vibration in the transducer. The longitudinal vibration and bending vibration of the transducer generate a column of standing wave respectively and the phase difference in the space between two bending vibration standing wave is $\pi/2$. When the frequency and the amplitude of two columns of standing wave are consistent and the phase difference in time is $\pi/2$, the superposition result of two columns of standing wave is that bending vibration traveling wave is generated in the cylinder of stator and it causes the vibration in elliptical orbit of the drive gear, finally, the output of the macroscopic motion is realized by friction coupling between the drive gear and rotor.

The variety of the vibration modes in a whole vibration period is shown in Fig. 2, when the amplitudes of the AC voltage excitation signals on longitudinal vibration piezoelectric ceramic plates and bending vibration piezoelectric ceramic plates are equal and their frequencies are equal to the resonance frequency of the stator and the phase difference is $\pi/2$. Where, the cylinder bending vibration is the mode of B (0,6). Figure 2 indicates that the counterclockwise rotation traveling wave which is bending vibration is caused by the alternation of longitudinal vibration and bending vibration of transducer on the cylinder.

Figure 2 shows that two basic vibration modes are used in working process of motor. Where, mode A is the mode which uses longitudinal vibration excitation cylindrical bending vibration of transducer. The realization of mode A is based on the degeneracy between longitudinal vibration mode of transducer and cylindrical bending vibration mode. Mode B is the mode which uses bending vibration excitation cylindrical bending vibration of transducer. The realization of mode B is based on the degeneracy between bending vibration mode of transducer and cylindrical bending vibration mode. One necessary condition to realize the traveling wave excitation in cylinder is the consistency of characteristic frequencies of the two basic vibration modes of stator. Therefore, there is a problem that the degeneracy of multiple modes in the design process of motor.

CHARACTERISTIC FREQUENCY DEGENERACY OF BASIC VIBRATION MODE OF THE MOTOR

Firstly, to design patch longitudinal-bending transducer, extract the one order longitudinal vibration mode and the three order bending vibration mode and analyze the sensitivity of structure parameters of the mode characteristic frequency. Secondly, to design stator cylinder whose frequency is close to the frequency of transducer. Finally, to establish the finite element model

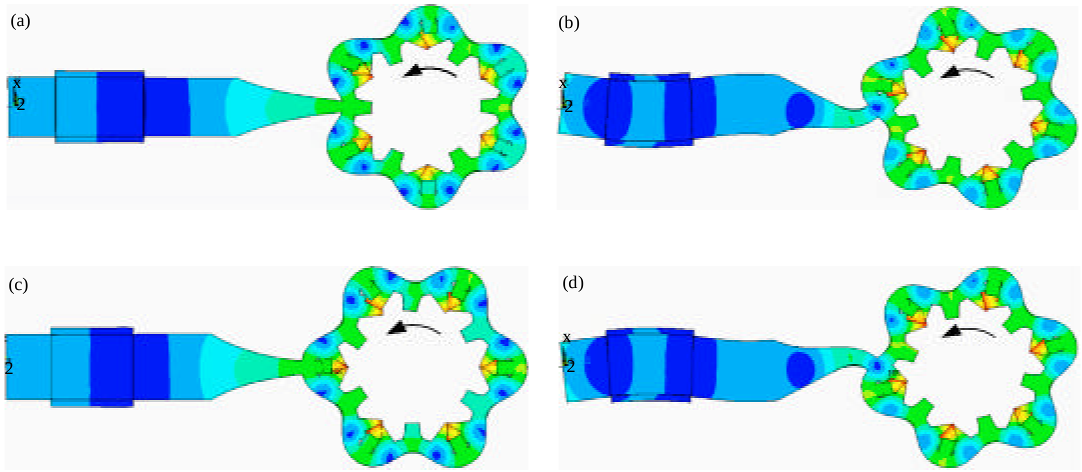

Fig. 2(a-d): Diagram of vibration modes in a vibration period of a stator, (a) Transducer elongation, (b) Transducer bending, (c) Transducer contraction and (d) Reverse bending of transducer

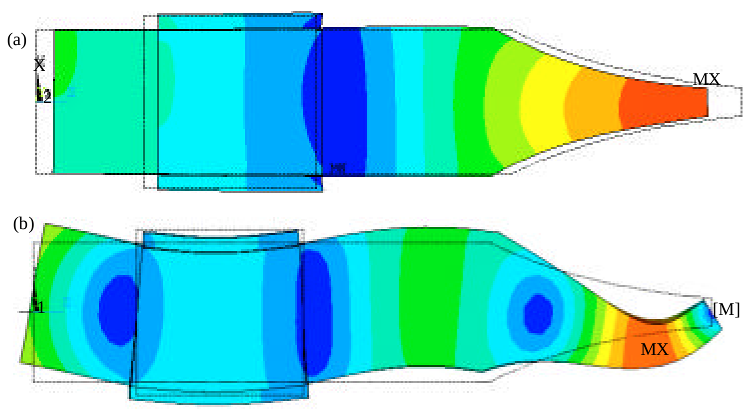

Fig. 3(a-b): Vibration modes of transducer (a) First order longitudinal vibration and (b) Third order bending vibration

of the stator, adjust the structure parameters on the basis of the analysis results of parameter sensitivity and the degeneracy of characteristic frequencies of the two basic vibration modes is realized.

Parametric finite elment model is established in ANSYS. The voltages on the surface of all the electrodes are zero. The mode of first order longitudinal vibration and the mode of third order bending vibration are obtained according to the mode analysis. Figure 2 illustrates that the small end surface of transducer's front end cap which connected with the cylinder should be near the nodal section of transducer's bending vibration, when the cylinder bending vibration is caused by bending vibration of transducer. Therefore, all the nodes on the central line of the front end cap's small end surface are added constraint of translational degrees of freedom in X direction during the analysis process of the mode of the transducer. The vibration modes of first order longitudinal vibration and third order bending vibration are shown in Fig. 3.

TEST AND ANALYSIS OF THE MOTOR

The initial structure parameters of transducer is shown in Table 1, the corresponding modal characteristic frequencies of first order longitudinal vibration and third order bending vibration are 58.463 and 58.646 kHz. The parameter sensitivity curves of modal characteristic frequencies of transducer's first order longitudinal vibration and third order bending vibration obtained by adjusting the structure parameters (matrix section is square, the height H = B of cylinder and

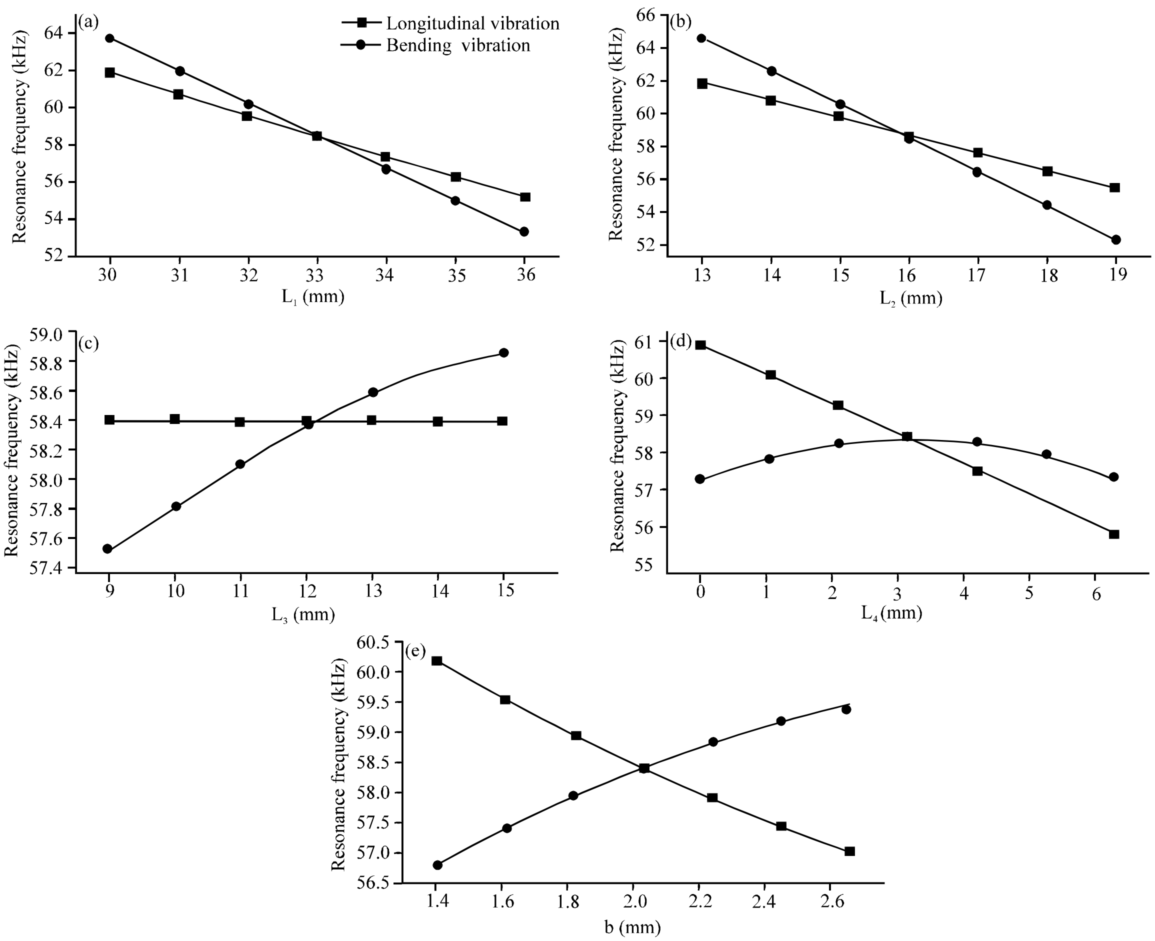

Fig. 4(a-e): Parameter sensitivity curve of transducer's modal characteristic frequency, (a) Relationship of the length L_1 of rectangular section and modal characteristic frequency, (b) Relationship between the length L_2 of amplitude transformer and modal characteristic frequency, (c) Relationship between the length L_3 of ceramic piece and modal characteristic frequency, (d) Relation of eccentricity L_4 and modal characteristic frequency and (e) Relationship between tip end face width b of amplitude transformer and modal characteristic frequency

Table 1: Initial structure parameters of transducer

L_1	L_2	L_3	L_4	B	b	d	H
33	16	12	3	10	2	1	10

the thickness d of piezoelectric ceramic is unchanged) are shown in Fig. 4.

Figure 4a and b show that the influence of L1 and L2 to the longitudinal resonant frequency and bending resonant frequency of transducer are consistent. But the influence to the modal frequency of bending vibration is notable. Figure 4c shows that the influence of L3 to the modal frequency of bending vibration approximate to linearity, but the influence to the modal frequency of longitudinal vibration remains unchanged. Figure 4d shows that the influence of L4 to the modal frequency of longitudinal vibration approximate to linearity but the modal frequency of bending vibration increases along with the size, when L4 = 3 mm, the modal frequency of bending vibration begin to decrease. Figure 4e shows that the influence trend of b to the longitudinal resonant frequency and bending resonant frequency of transducer is opposite. The above figures show that L1 and L2 have great influence on the longitudinal resonant frequency and bending resonant frequency of transducer, which can be used to adjust the structure frequency by a large margin. And L3 and L4 have little influence on the longitudinal resonant frequency and bending resonant frequency of transducer which can be used to adjust the structure frequency by a small margin. b is limited by cumulative effect of the amplitude transformer, so large size is not suitable for it,

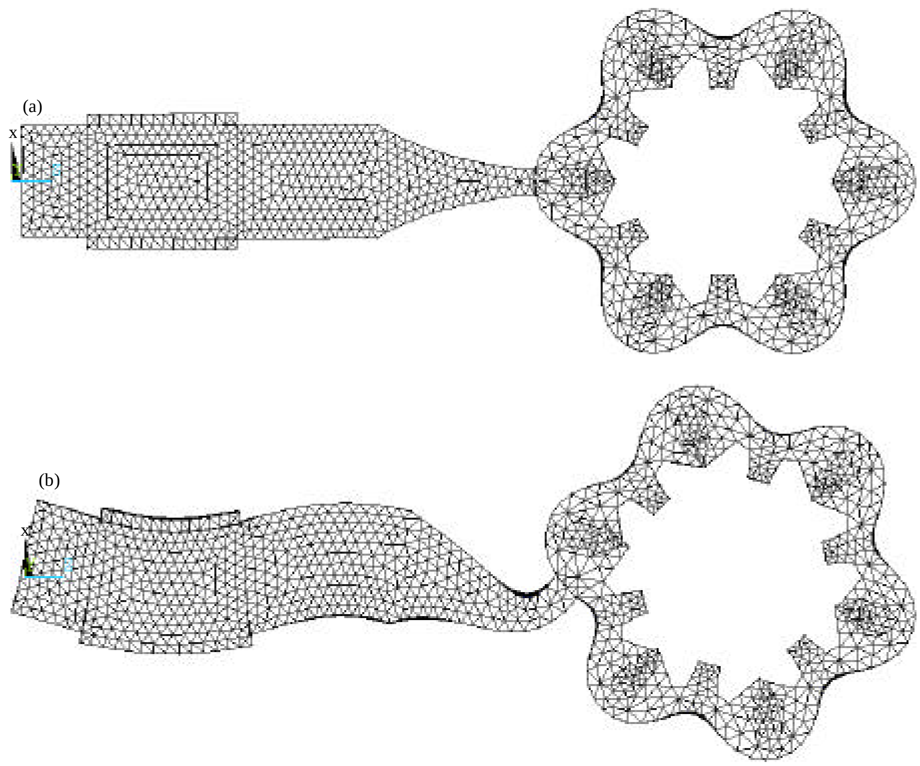

Fig. 5(a-b): Basic vibration mode of stator (a) Mode A and (b) Mode B

Table 2: Structural parameters of cylinder

D_1(mm)	D_2(mm)	D_3(mm)	α(°)	H(mm)
30	26	21	11	10

but the structure inflexibility will be affected, if the size is too small. Let b = 2 mm, since its adjustable range is small.

The finite element model of the cylinder with drive gear is built and the radial bending vibration mode of B(0,6) is selected in this design. The characteristic frequency of B(0,6) is obtained based on the analysis of mode. The radial size of cylinder is adjusted in terms of the analysis results of the parameter sensitivity of cylinder, so the modal characteristic frequencies of B(0,6) is close to the modal characteristic frequencies of transducer. The structure parameters adjusted are shown in Table 2, the modal characteristic frequencies of B(0,6) is 56.46 (56.493) kHz.

The finite element model of the stator is established according to the initial structure parameters of transducer and cylinder. Two basic vibration modes are got based on the analysis for the mode, the corresponding modes are shown in Fig. 5. The degeneracy of characteristic frequencies of the two basic vibration of stator is realized based on the adjustment to the structure parameters of stator according to the analysis results of parameter sensitivity of transducer.

The characteristic frequencies of mode A and mode B are 57.377 and 57.14 kHz, respectively. The difference of the two characteristic frequencies is 0.237 kHz which is lower than 0.5% modal characteristic frequencies of stator. It illustrates that the degeneracy of the two vibration mode is great. In addition, the characteristic frequencies of the two basic vibration mode of stator is close to the characteristic frequency of cylinder B(0,6) mode which indicates that the mode of longitudinal vibration, the mode of bending vibration of transducer and the mode of cylindrical bending vibration well matched.

CONCLUSION

A miniature patch longitudinal bending composite excitation cylindrical traveling wave ultrasonic motor is designed in the study. The degeneracy of characteristic frequencies of the two basic vibration modes is realized by using finite element method to design the motor based on the analysis of the working principle of the proposed motor. The mode of vibration and the vibration test results indicate that the vibration state of the transducer is longitudinal bending vibration, in which longitudinal vibration is an active vibration caused by d33 mode excitation of piezoelectric ceramic and the bending vibration is passive vibration caused by d31 mode coupling. The difference between the two basic vibration mode resonance frequencies of the proposed motor is 0.237 kHz. The horizontal vibration and vertical vibration of the drive foot in the practical work can not achieve the optimum at the same time since the difference which affects the improvement of the mechanical output performance of the motor in a certain extent. How to enhance the consistency of the two resonance frequencies of the prototype further will be the key point in future research.

ACKNOWLEDGMENTS

This study is supported by the National Nature Science Foundation of China (61271180) and the Science and Technology Research Project of the Education Department of Heilongjiang Province (12521462).

REFERENCES

Liu, Y.X., J.K. Liu, W.S. Chen and S.J. Shi, 2009. Cylindrical traveling wave ultrasonic motor using longitudinal sandwich transducers. Proc. CSEE, 29: 83-88.

Park, T.G., D.S. Jeong, M.H. Kim and T.K. Song, 2006. A study on the rotary-type ultrasonic motor using a longitudinal-torsional vibration converter. Mater. Chem. Phys., 98: 1-4.

Zhao, C., 2002. Ultrasonic motor techniques for 21st century. Eng. Sci., 4: 86-91.

Zhao, C., 2007. Ultrasonic Motors Technologies and Applications. Science Press, Beijing, China, pp: 89-159.

Zheng, W., C.L. Zhu, D. Lu, Q.J. Ding and C.S. Zhao, 2008. Research on characteristic of traveling wave type rotary ultrasonic motors under high temperature. Proc. CSEE, 28: 85-89.