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RESEARCH ON LARGE TORQUE TRAVELING WAVE ULTRASONIC MOTOR

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ABSTRACT

To increase the torque of a travelling wave type ultrasonic motor (USM), a special G-shaped support structure is proposed and studied. Its effect on the transverse amplitude and the contact area of the stator and rotor has been studied by FEM. In addition, to enhance the motor torque further, a twin-vibrator structure is equipped. Experimental results indicate that some significant improvement in the torque performance characteristic can be achieved.

Keywords: ultrasonic motor, travelling-wave, large torque.

1. INTRODUCTION

As a novel motor, USMs have many notable features compared with conventional electric ones[1]. For example, they can produce a relative high torque at a low speed with a high efficiency and the torque produced per unit weight is high. It would therefor appear that USMs have the huge potential for uses as actuators for functional automotive parts. However, applications in the large torque field are limited at present because most of the currently available USM can not provide sufficiently absolute high torque yet.

To solve the above problem, a special Γ-shaped support structure for travelling wave type USM is proposed and studied. We expect that it can reduce the undesired vibration component. As a result, the improved type of motor should also increases the transverse amplitude and the contact area between the stator and rotor evidently compared to most of the present ones, which employ thin-metal support structure.

In addition, as a trial, we use two identical vibrators to combine a stator to make the torque higher, although it is difficult to produce pure twice as high maximum torque compared to single one. Finally, experimental results obtained from a prototype motor indicate evidently that some improvement in the torque performance characteristic can be achieved.

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2. MOTOR CONSTRUCTION

Fig. 1 shows the construction of the single-vibrator motor. The torus-shaped vibrator, which combines a stator and a piezoelectric ceramic (PZT), produces flexural vibration. Unlike the conventional travelling wave type USM, in which support structure is a thin metal plate connected to the inner periphery of the stator (Fig. 2), a special Γ-shape support structure is adopted (Fig. 3). A nylon-made rotor is pressed against the stator directly, and the resulting revolution is utilized via a drive shaft. The improved type of support structure has remarkable features as follows:

1) it reduces undesired vibration component, i.e. the radial vibration.
2) it increases the transverse amplitude of the vibrator.

it increases the contact area of the stator and rotor, so as to improve the motor's torque.

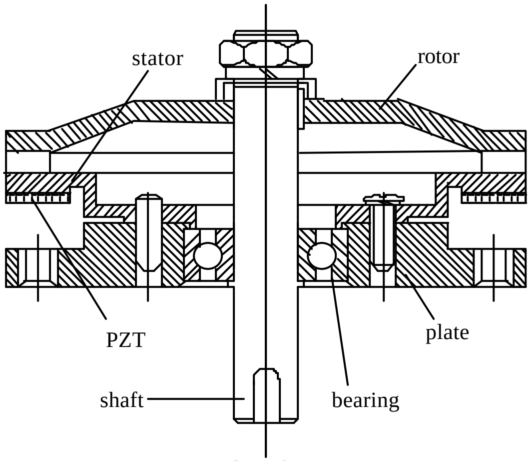

Fig. 1. single-vibrator motor

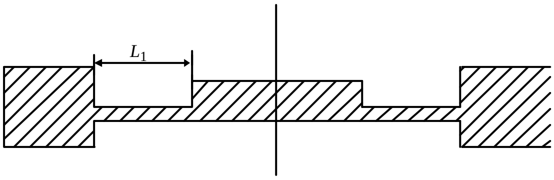

Fig. 2. thin-metal support structure (conventional)

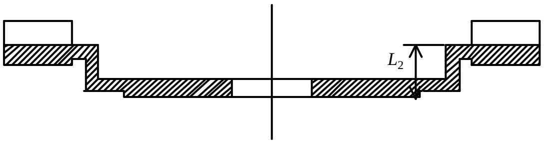

Fig. 3. Γ-shaped support structure (proposed by authors)

3. STATOR DESIGN

3.1 SUPPORT STRUCTURE

As known, travelling waves have no stationary nodes along the stator ring, which makes the supporting somewhat difficult. A support structure for the stator should ideally satisfy [2]:

1) it does not affect the stator's oscillation.
2) no oscillations leak through the support.

As known also, the vibrations of the PZT are in three dimensions, while the available energy are transformed only by transverse and circumferential vibration components for travelling wave type USM. That is the radial component should be null. To reduce this component, we use a Γ-shaped transition extending from the ring to the support frame of the stator (Fig. 3). Since the ring's vibration and the frame's one are not in the same level, the Γ-shaped structure can be regarded as a isolation mounting. Thus, its effect on the ring's oscillation is smaller, and less oscillation can be leaked through the support. From the point of conversation of energy, it should therefore increase the efficiency of electromechanical energy in any case.

3.2 FEM ANALYSIS

If the lose of USM is zero, the torque can be written as [2]:

$$T = \frac{2\pi R D \nu}{pN} \oint f\,du \qquad (1)$$

Where f = tangential force.
u = displacement in the circumferential direction of particles on the stator surface, which is proportional to the transverse amplitude.
P = wavenumber
N = the rotor's speed.
R = the stator's radius.
D = the contact width of the stator and rotor.
ν = driven frequency.

Therefore, the motor's torque is proportional to the transverse and the contact width of the stator and the rotor.

Unlike the vibration of beam, the amplitudes of particles on one tooth of the stator are not the same while vibrating. To make the motor run stable, the contact width of the stator and the rotor must be less than the width of the torus. Consequently, if the difference of transverse amplitude of one tooth can be reduced, the contact width will increase, which leads to the increase of torque.

Let ε be the maximum difference of transverse amplitude of one tooth:

$$\varepsilon = A_{zmax} - A_{zmin} \tag{2}$$

where A_{zmax} and A_{zmin} are the maximum and minimum transverse amplitudes respectively. To make a comparison between the two kinds of support structure, a FE code designed by our group is used to calculate ε and A_{zmax} with different support structure. Fig. 4 shows the finite-element model of the stator. It has 9288 nodes and 5616 solid elements. The materials constants and main specifications of the stator are listed in Table 1, and Fig. 5 illustrates the cross-section scheme of the stator.

Table 1. The materials constants and main specifications of the stator

Dimensions of the stator:	
Outer diameter	80mm
Inner diameter	60mm
Height of copper h_m	6mm
Thickness of PZT h_p	1mm
Width of PZT b	10mm
Vibration mode	9
Resonant frequency	31.8±3% (kHz)
Materials constants:	
An annular plate of copper:	
Young's modulus	10.5×10^{10}N/m^2
Shear modulus	3.8×10^{10}N/m^2
Poisson' ratio	0.32
Density	8500kg/m^3
An annular plate of PZT:	
Young's modulus	7.5×10^{10}N/m^2
Shear modulus	2.8×10^{10}N/m^2
Poisson's ratio	0.3
Density	7500kg/m^3
Piezoelectric strain constant d_{31}	-150×10^{-12}C/N

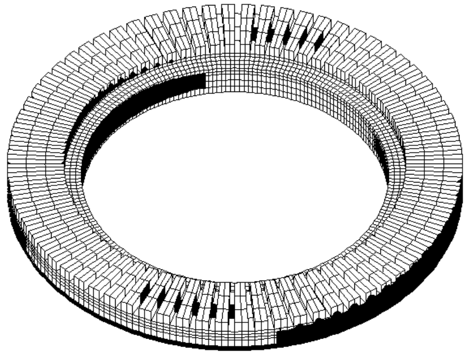

Fig. 4. Finite-element model of the stator

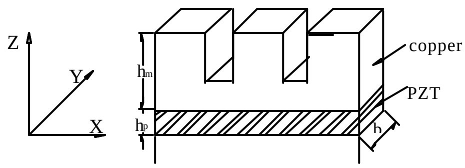

Fig. 5. Cross-section scheme of the stator

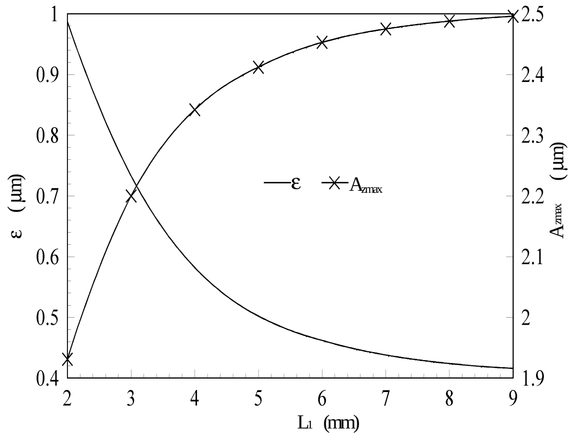

Fig. 6. relations of e and A_{zmax} to L_1 (defined in Fig. 2)

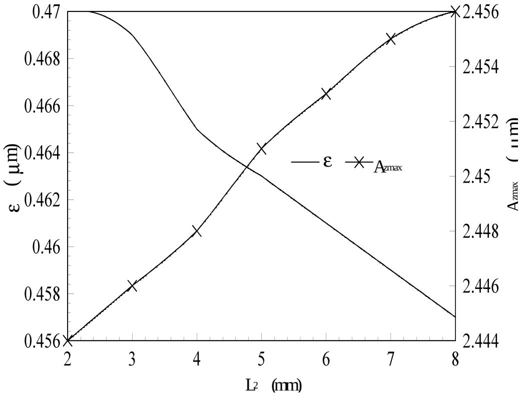

Fig. 7. relations of e and A_{zmax} to L_2 (defined in Fig. 3)

Fig. 6 and 7 show the relations of ε and A_{zmax} to L_1 and L_2 respectively. In Fig. 6, which support structure is thin metal as shown in Fig. 2, A_{zmax} increases with L_1, while ε decreases. When L_1 increases from 2 mm to 9 mm, A_{zmax} increases from 1.931 μm to 2.496 μm, and ε decreases from 0.9837 μm to 0.416 μm. However, when a Γ-shaped support structure is added on this basis (shown in Fig.3), although A_{zmax} and ε have the same tendency with those of Fig.6 (shown in Fig.7), the A_{zmax} is much bigger and ε smaller. For example, when L_1=2 mm, A_{zmax}=1.931 μm, ε=0.9837 μm. Next, a Γ-shaped support structure is added on this basis, in this case, A_{zmax}=2.444 μm and ε=0.47 μm. That is, A_{zmax} increases by a factor of 26.5% and ε decreases 52%. The decrease of ε means the enlargement of contact width. Assuming that others parameters in eqn.1 remain the same value in the two kinds of support structure, the torque will increase by a factor of 50%.

Therefore, we can draw a conclusion from above analysis that Γ-shaped support structure can increase the transverse amplitude and enlarge the contact width of the stator and rotor evidently, and then increase the torque significantly.

4 GLOBAL DESIGN

To enhance the motor torque, some researchers have ever used a so-called twin-rotor structure [3]. Though it can provide greater torque, the efficiency of PZT is somewhat low for it is nearly full adhered to the inner disk plate, and much vibration is consumed by the support structure. For this reason, a novel twin-vibrator motor is proposed by authors, shown in Fig.8. We expect that it can produce almost twice as high torque compared to the single-vibrator one.

However, since the two vibrators are difficult to be made full alike, and the pressure against the two rotors are not ideally equal, the torque will be greater than that of single vibrator only when the two rotors have the same speed. This makes the motor run unstably. Therefore, the torque of a twin-vibrator motor is unable to obtain the highest target of itself, pure twice the single one as expected. The torque of the prototype motor can reach 1.2N.m sometime.

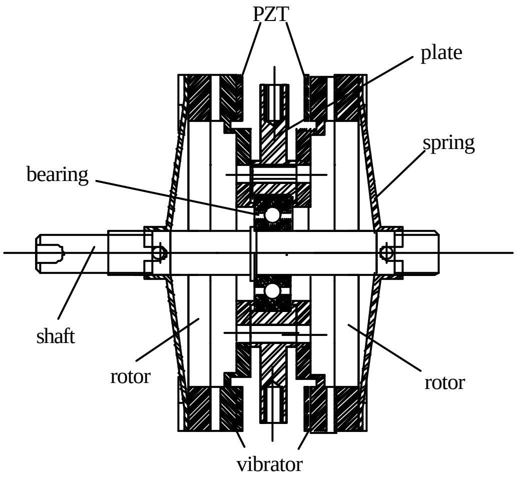

Fig. 8. twin-vibrator motor

5 EXPERIMENTAL RESULTS

Fig. 9 is the torque performance characteristic obtained from a single-vibrator motor only. The maximum torque is near 1 N.m. The maximum torque of USR-60 of ShinSei Co. Ltd, which diameter is 60mm, is 0.6 N.m. When its diameter is 80mm, the torque would be around 1N.m[3], which is nearly equal to that of the improved type of motor. But a fact must be mentioned that the frictional material employed in the prototype motor is not suitable compared with USR-60, and this is a very important parameter for the torque. It can be predicted that the torque will be greater if the frictional material is better. Thus, we can draw a conclusion that the improved type of support structure can improve the torque performance characteristic.

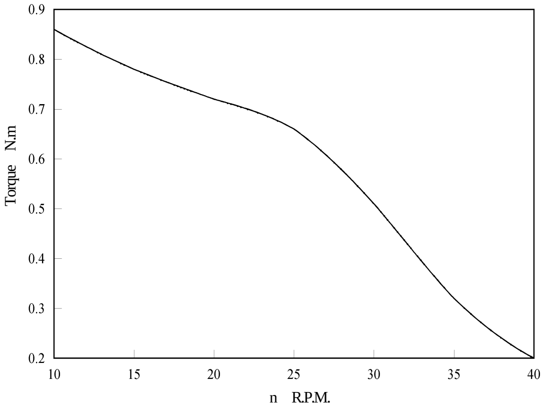

Fig. 9. torque performance characteristic

6. CONCLUSION

We have attempted to increase the torque of travelling-wave type ultrasonic motor as far as possible. To reduce the undesired vibration component, a special Γ-shaped support structure is investigated. Its effect on the transverse amplitude and the contact area of the stator and rotor has been studied by FEM. A prototype motor is built. Experimental results indicate that the improved support structure can increase the torque compared to the conventional one, although the frictional material employed is not ideal yet. To make the torque higher more, a twin-vibrator motor is equipped. However, since the two vibrators can not be made full alike, the results raised from a prototype motor show that the real torque is less than the maximum one as expected.

REFERENCES

1. Ueha.S, Tomikawa.Y, Kurosawa.m, Nakamura.N, Ultrasonic motors: theory and applications. Oxford, 1993
2. Sashida.T, Kenjo.T, An introduction to ultrasonic motor. Oxford, 1993
3. Yasuaki.K, Kiyokazu.A. “High power travelling-wave type ultra-sonic motor”. Jpn J. Appl. Phys, vol. 34, 1995, pp. 2711-2714

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