Multiplication of Displacements of the Langevin Type Piezoelectric Transducer using Various Shapes of Horns

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(Received February 5 2004, Accepted March 15 2004)

Bolt-tightened Langevin type vibrators using longitudinal mode of bar were designed and fabricated. In order to amplify the displacement of the tip of the vibrators, stacked ceramics were used and five different shapes of the horns were designed and jointed. Resonant frequencies and vibration characteristics of vibrators and horns were analyzed by ANSYS(finite element analysis computer program), and the displacements of tips of the horns were measured.

As results, when the numbers of the stacked ceramics were increased, the displacements of the tips were increased and the driving voltages were decreased. Step1 horn (BLT-St1) showed maximum displacement of 36.92 μm at 36.7 kHz with 45 V_{rms} and 0.11 A. The displacement amplification ratio was about 5.2. But, the stress of step1 horn was concentrated on intersection, where two diameters meet. To lessen the stress, step3 shaped horn is recommended.

KeyWords : Langevin type vibrator, Horn, Displacement, ANSYS

1. INTRODUCTION

P. Langevin invented Langevin type vibrator at 1922[1]. With the development of $BaTiO_3$ and PZT, Langevin type vibrator was used broadly in various application areas as SONAR and industrial processing. Recently, the bolt tightened and horn structure magnifies the displacement of the vibrator and makes more stable vibrations.

On this paper, bolt tightened Langevin type vibrator was designed using the vibration theory of a bar and a commercial finite element analysis program (ANSYS) [2,3]. Fixing the total length of the vibrator at 57 mm, 2,4,8 and 12 ceramic plates were stacked for comparing the generated displacements and the driving voltages. Also, five kinds of shapes of horns were designed and jointed on the Langevin type vibrators for magnifying the displacement of a tip. Most stable shape of horn was found by measuring stress distribution and displacements of a tip.

2. DESIGN OF THE VIBRATORS

2.1 Length and resonant frequency of the vibrators

Because the resonant frequency of the ceramic plate was 43 kHz, vibrators were designed at a same frequency using equations (1),(2) and (3).

$$c_1 = \sqrt{\frac{E_1}{\rho_1}} \qquad c_2 = \sqrt{\frac{E_2}{\rho_2}} \tag{1}$$

$$\lambda_1 = \frac{c_1}{f_n} \qquad \lambda_2 = \frac{c_2}{f_n} \tag{2}$$

$$a = \alpha\frac{\lambda_2}{4} \qquad b = \beta\frac{\lambda_1}{4} \tag{3}$$

Where, c_1: propagation velocity in ceramic, c_2: propagation velocity in aluminum, E_1: Young's modulus of ceramic, E_2: Young's modulus of aluminum, ρ_1: density of ceramic, ρ_2: density of aluminum, a: thickness of aluminum, and b: thickness of ceramic.

Table 1. Size and material properties of ceramics.

Size, property and units	Value
Inner radius ϕ_{in} [mm]	15
Outer radius ϕ_{out} [mm]	35
Contact surface area S_1 [mm^2]	785.4
Thickness of ceramic b [mm]	6
Density ρ_1 [kg/m^3]	7600
Propagation velocity c_1 [m/sec.]	3162
Young's modulus E_1 [N/m^2]	7.6×10^{10}
Resonant frequency f_r [kHz]	42.8 ~ 43.1
Relative permittivity $\varepsilon_{33} / \varepsilon_0$	1250
Piezoelectric constant d_{33} ($\times 10^{-12}$)[m/V]	290
Piezoelectric constant g_{33} d_{33} ($\times 10^{-3}$)[[V· m/N]	27
Mechanical quality factor Q_m	1800

Propagation velocity c_1 and c_2 were calculated using equation (1). The thickness of ceramic b was determined from a resonance frequency of the ceramic and using equations (2) and (3) the thickness of aluminum was determined.

Table 2. Material properties of Alloy 6061.

Property and units	Value
Modulus of elasticity E [N/m^2]	7.6×10^{10}
Poisson ratio σ	0.33
Density ρ [kg/m^3]	2700

Material properties of aluminum and the size of the vibrator were shown at Table 2 and Table 3.

Figure 1 shows the structure of the Langevin type vibrator.

Table 3. Size of the vibrator.

Size	Value
Inner radius ϕ_{in} [mm]	15
Outer radius ϕ_{out} [mm]	35
Thickness of aluminum a [mm]	22.5
Thickness of ceramic b [mm]	6
Thickness of electrode [mm]	0.15
Total length l [mm]	57

2.2 Design of the horn

The displacement of the Langevin type vibrator is very small. For magnifying the displacement, a horn whose cross-areas decrease exponentially to the tip is normally jointed to the Langevin type vibrator. On this paper, five kinds of horns were designed and made as Fig. 2. The lengths of these five horns were determined for resonating at 43 kHz. The cross-areas of the bottom surfaces of the five horns had same diameter of 35 mm and, the diameter of the top surface (tip) was also same as 10 mm. Names of these horns are conical, exponential, step1, step2 and step3 and their size and shape were shown in Fig. 2.

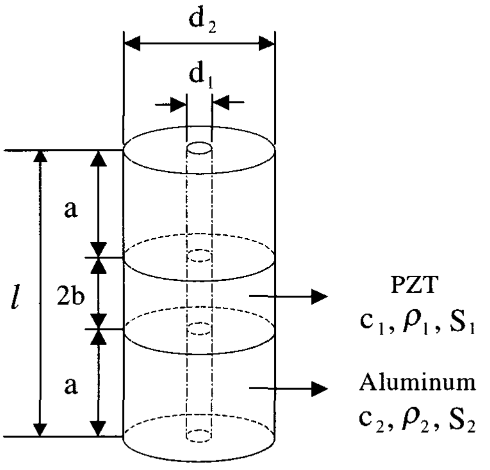

Fig. 1. Structure of the Llangevin vibrator.

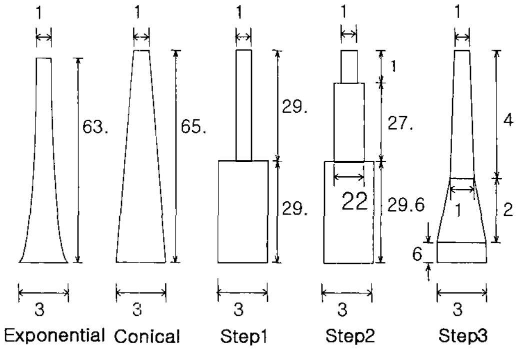

Fig. 2. Size and shape of the horns.

3. FINITE ELEMENT ANALYSIS AND MEASUREMENT

3.1 Mode analysis of the vibrator

Dynamic behavior characteristic of the Langevin vibrator that was designed by the size of Table 3 was simulated using a commercial finite element analysis program (ANSYS). As conditions of the analysis, the vibrator was considered as free-free state and the potential of the electrode is zero V. Figure 3 shows that the vibrator is vibrating at 43.67 kHz as the first longitudinal mode. This frequency is almost same with the designed frequency of 43 kHz.

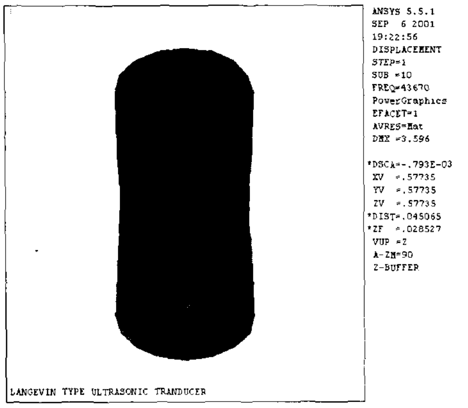

Fig. 3. Mode analysis of the vibrator.

3.2 Mode analysis of the horns

According to the designed size and shape of horns as in Figure 2, mode analysis of the horns were performed using an axis symmetric two dimensional model. As a material, duralumin (6061), whose elastic coefficient, density and Poisson's ratio were 7.6×10^{10} N/m^2, 2700 kg/m^3 and 0.3, respectively, was used. Figure 4 shows the vibrating mode at the resonant frequencies. Each frequency had some differences from the designed frequency of 43 kHz as in Table 4.

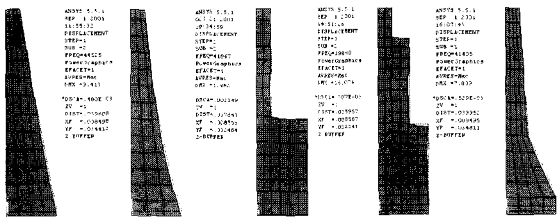

Fig. 4. Modal analysis of horns.

3.3 Displacement analysis of the horn jointed vibrator

The five kinds of horns were separately jointed to the vibrator. Both of the vibrator and horns were designed to have the first longitudinal vibration at 43 kHz, for the jointed vibrator having the second vibration at same frequency.

Table 4. Resonance frequencies of horns.

Horn Type	Conical	Exponential	Step1	Step2	Step3
Resonance Frequency	44525	41867	39840	41405	37978

Figure 5 shows the displacements of the tip of the jointed vibrators when alternating voltages of 45 V_{rms} were applied. Displacement of a tip of the step 1 vibrator was the biggest among the five kinds.

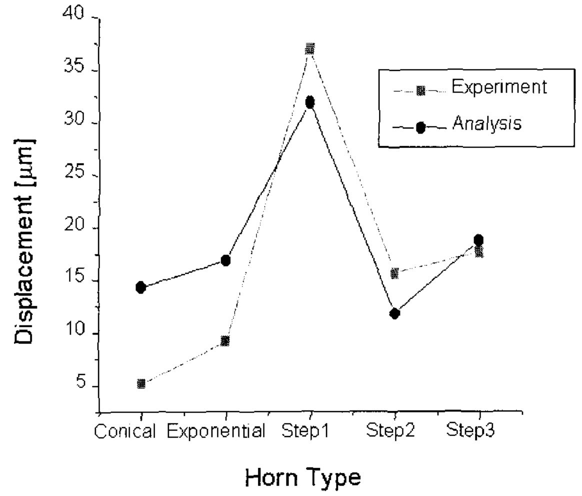

Fig. 5. Comparison of displacements of the jointed vibrator.

Figure 6 shows displacements of the points on the central line of BLT-step 1 vibrator. Displacements of the thicker part of the vibrator were small, but it was rapidly increased at a tip of the horn.

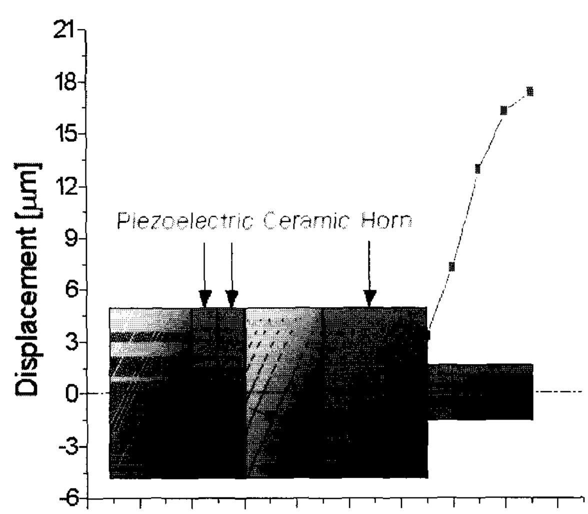

Fig. 6. Variation of displacements on a central line of BLT-st1.

Figure 7 shows distribution of the equivalent stresses when BLT-st1 was driven by 45 V_{rms} at 37.6 kHz. High stress was concentrated at the points where the cross-areas of horn were abruptly changed.

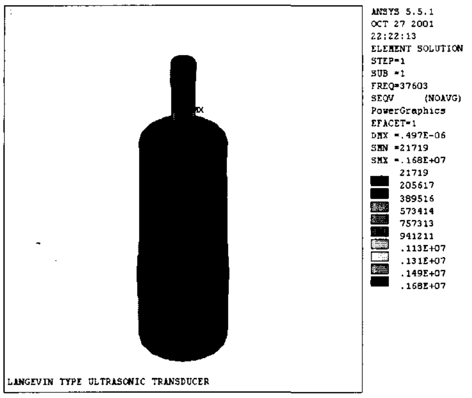

Fig. 7. Distribution of the stresses of BLT-st1.

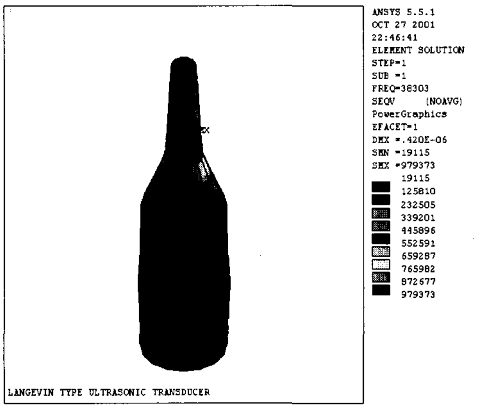

Fig. 8. Distribution of stresses of BLT-st3.

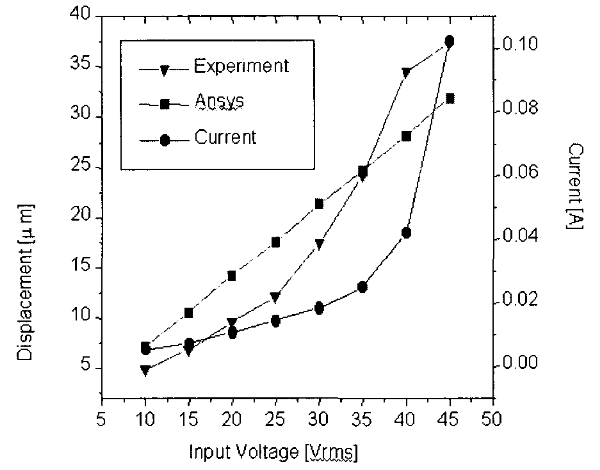

Fig. 9. Displacement of BLT-st1 due to the input voltages.

By lessen the changing rate of the cross-areas using BLT-st3 vibrator as Fig. 8, the high stresses could be lessen.

Figure 9 shows a change of displacements of the tip of BLT-st1 and a change of driving currents. By increasing the driving voltage, higher displacement could be obtained.

Figure 10 shows a frequency dependence of the displacements of BLT-st1. At a resonant frequency of 37.6 kHz the maximum displacement was obtained and the maximum current of 0.114 A was flown.

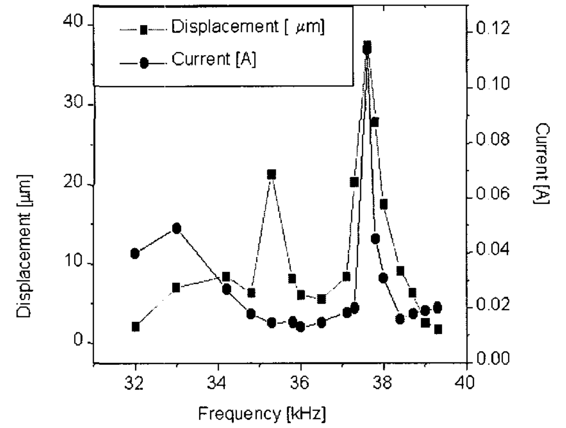

Fig. 10. Displacement of BLT-st1 due to the frequency.

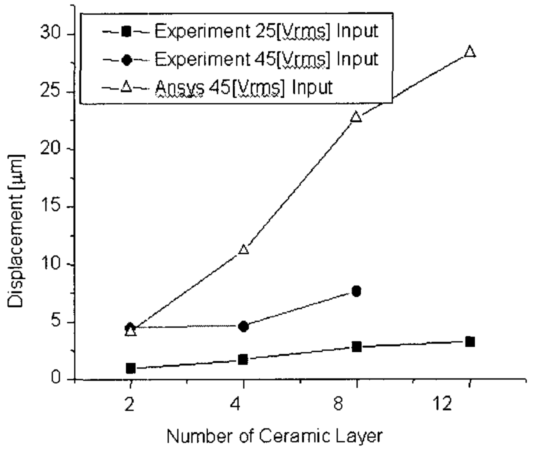

Fig. 11. Displacement of BLT-st1 due to the number of ceramics.

3.4 Effect of the stacked ceramics

With fixing the total thickness of ceramics of BLT, changes of displacements of the tip of BLT-st1 were measured, when the numbers of ceramic plates were increased from 2 to 12.

As in Figure 11, increasing the number of ceramic plates could increase displacement. For example, when driving voltage was 25 V_{rms}, displacement of 0.9 -m could be increased to 3.24 -m by using 12 ceramics instead of 2.

RESULTS

The vibration characteristics of bolt jointed Langevin type vibrators were measured. Five kinds of horns were designed and were jointed to the Langevin type vibrators to magnify the displacements.

As result, using st-1 horn, a high displacement could be obtained, but stresses were concentrated at small area of the horn that can make cracks by fatigue. For alternative of st-1, st-3 can be proposed for a practical usage.

At same thickness of ceramic layer, by increasing the number of stacked ceramics, the displacement could be increased. For obtaining a high displacement from the Langevin type vibrator, multi-layered ceramic is recommended.

REFERENCES

[1] P. Langevin, "French Patent", 505, 703, 1920.
[2] T. G. Park, C. Y. Park, and D. Y. Han, "A study on the Langevin type vibrator", J. of KIEE(in Korean), Vol. 30, No. 1-2, p. 47, 1980.
[3] Singiresu S. Rao, "Mechanical Vibrations", Addison-Wesley, p. 523, 1999.