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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 115-116
8-10 November, 2011

Investigation on the structure of a high-power piezoelectric transformer
大出力圧電トランスの構造の検討

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1. Introduction

The advantages of piezoelectric transformers are their high-efficiency and small size as compared with conventional electromagnetic ones. Recently, Rosen-type piezoelectric transformers have been used as low-power transforming devices, such as inverters in back-lighting systems of liquid crystal display panels.[1] However, for high-power transforming, electromagnetic transformers are still widely used. In light of potential demand for compact high-efficiency transforming devices in power electronics, high-power piezoelectric transformers have been quite desirable.

In the present study, we propose a new structure of a piezoelectric transformer. **Figure 1** shows the structure of the transformer and the vibratory displacement distribution along its length. In the structure, two bolt-clamped Langevin-type transducers (BLTs) are connected to a stepped horn with a straight extension. These transdeucers on the primary and the secondary side of the transformer enables high output power.

The ratio of the vibration velocities on the primary and secondary side is the inverse cross-sectional ratio of the stepped horn. On the other hand, the ratio of vibration forces, which detremines the voltage transformation ratio, is equal to the cross-sectional ratio. It is very difficult to design a conventional Rosen-type piezoelectric transformer which realizes a specific transformation ratio, while easy to do so with the newly-proposed transformer.

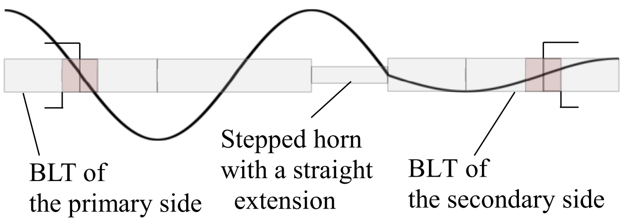

Fig. 1 Structure of a high-power piezoelectric transformer and the vibratory displacement distribution.

2. Results of finite-element analysis

We analyzed the action of the transformer using UNIFESP, a two-dimensional finite-element analysis system developed by K. Adachi.[2] In all cases of the analysis, axi-symmetry was assumed.

Figure 2 shows the configuration of the piezoelectric transformer. The dimensions of stepped horn were determined so as to make its resonance frequency the same as that of the BLTs. The cross-sectional ratio of the stepped horn is 4.

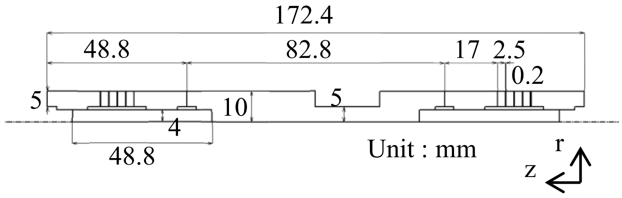

Fig. 2 Configuration of the piezoelectric transformer.

Figure 3 shows the numerical result for the case of step-up transformation by setting the left side of the transformer shown in **Fig. 2** as the primary. The transformation ratio diverges to infinity at the resonance frequency since the mechanical resistance was not taken into account in the analysis. The resonance frequency is 56.6 kHz, and the driving frequency at which transformation ratio becomes the specified value 4 is 56.7 kHz. The driving frequency is found quite near the resonance frequency.

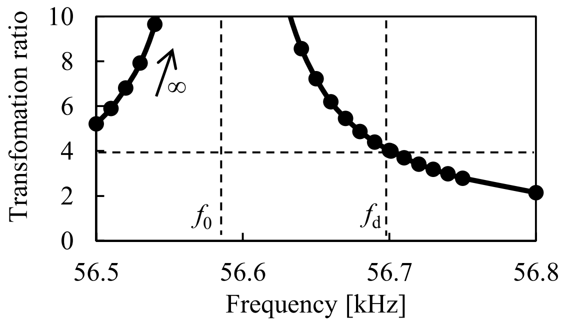

Fig. 3 Numerical result for the step-up transformation.

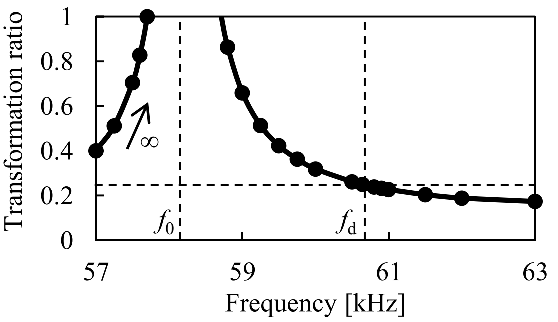

Fig. 4 Numerical result for the step-down transformation.

Figure 4 shows the numerical results for the step-down operation of the transformer by setting the right side as the primary. The transformation ratio was 0.25 accordingly. The resonance frequency is 58.2 kHz, and the driving frequency is found at 60.6 kHz. The driving frequency is far from the resonance frequency compared with the step-up case. This can be attributed to the effect of the damped capacitance of the BLT on the secondary side. Thus, realizing a step-down transformer of a specified transformation ratio is very difficult.

3. Results of experiment

Figure 5 shows the experimental results of the step-up transformation. When the load resistance on the secondary side is greater than 1kΩ, it could realize the specified transformation ratio in the design. The influence of the load resistance on the deviation of the driving frequency from the resonance is less than 50Hz.

As shown in **Fig. 6**, we also determined the constants of the equivalent circuit of the transformer at the frequency near its resonance from the admittance loop measured by NF5087 Frequency Response Analyzer. **Figure 7** shows the loop in the step-up case with no load at the output on the secondary side. **Table I** shows the equivalent circuit constants of the transformer. The F-parameters of the circuit are given by

$$\mathrm{F}_1 = \begin{pmatrix} -0.74 + \mathrm{j}0.263 & 10.23 + \mathrm{j}67.46 \\ -0.0004 + \mathrm{j}0.025 & 0.89 + \mathrm{j}0.017 \end{pmatrix}. \quad (1)$$

We also determined the F parameters of the transformer by direct measurement of the input and output voltages and currents as,

$$\mathrm{F}_2 = \begin{pmatrix} -0.91 + \mathrm{j}0.325 & 11.43 + \mathrm{j}62.01 \\ -0.0002 + \mathrm{j}0.025 & 0.66 + \mathrm{j}0.038 \end{pmatrix}. \quad (2)$$

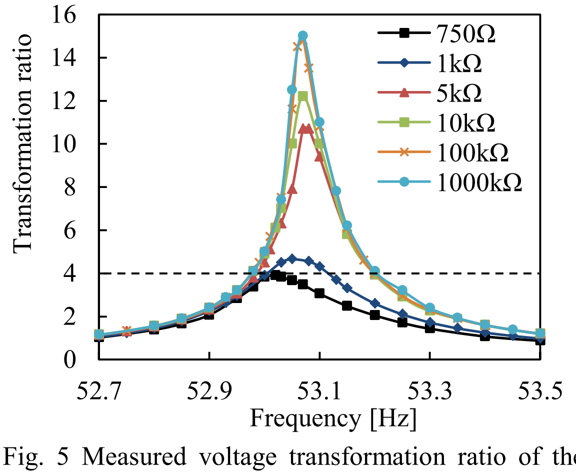

Fig. 5 Measured voltage transformation ratio of the step-up transformer versus the driving frequency.

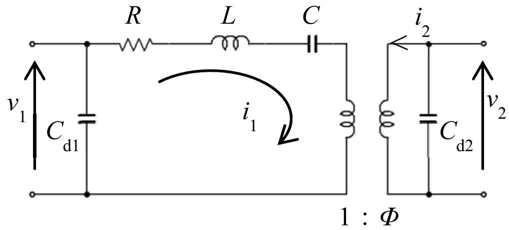

Fig. 6 Equivalent circuit of the piezoelectric transformer at the frequency near its resonance.

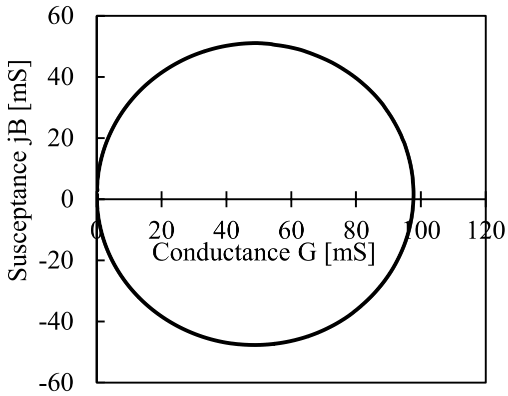

Fig. 7 Admittance loop of the piezoelectric transformer without load resistance

Table I Equivalent circuit constants of the piezoelectric transformer.

Q	787.3	C[nF]	0.375
f_0[Hz]	53118	C_{d1}[nF]	4.89
R[Ω]	10.23	C_{d2}[nF]	4.81
L[mH]	24.14	k_{vn}[%]	26.60

4. Conclusion

We carried out the experiments with a trial-made piezoelectric transformer which was composed of two BLTs connected to a stepped horn. Its step-up operation as designed has been experimentally verified. Actually, the driving frequency which realizes the specified voltage transformation ratio is quite near the resonance frequency both in the simulations and experiments. On the other hand, the step-down operation is very difficult because of the large effect of the damped capacitance of the BLT on the secondary side. Though small-size BLTs were used for convenience of the experiments, we can realize a piezoelectric transformer with high output power theoretically in the same manner.

References

1. I. Tomonaga: Ricoh Technical Report, 31, (2005) 59-66 [in Japanese].

2. T. Takahashi and K. Adachi: Nihonn Onkyo Gakkai-shi (J. Acoust. Soc. Jpn.) Vol. 60 (8) (2004) 441-450 [in Japanese].