1P4-8

A Designing Method of Ringing Suppression for Ultrasonic Sound Source and its Application to Ultrasonic Machining

残留振動抑制を考慮した超音波パルス音源の設計と超音波加工への応用

Sayuri Tarvainen[1†], Guangyuan Wang[1], and Yuji Watanabe[1] ([1]Graduate school of Eng., Takushoku University)
ターヴァイネン さゆり [1†]，王 光遠 [1]，渡辺 裕二 [1]（[1]拓殖大学大学院 機械·電子システム工学）

1. Introduction

High-Power Ultrasonics are known for high frequency vibration with large-amplitude, utilizing the resonance effect of material, and it is widely applied in various industrial fields such as welding, cleaning and machining.

However, it is used in resonance state thus, followability of vibration amplitude is declined by load, and constant tracking of resonance frequency against load fluctuation in driving voltage is required. The other restriction on use is operation by fixed working condition or constant vibration amplitude.

In this study we investigate the voltage waveform in order to generate high-power ultrasonics with improved properties and ringing suppression by utilizing the referring generation method of pulse sound source in ultrasonic signal application. Furthermore, we provide and design a bolt-clamped Langevin type transducer (hereafter written as BLT) as a suitable pulse driving method and demonstrate its application by using this generated ultrasonic sound source[1].

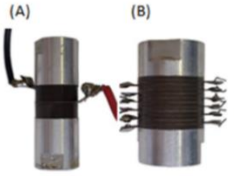
2. Summary of principles of ultrasonic monopole pulse generation and its method

In order to generate an ultrasonic monopole pulse with ringing suppression for driving voltage, we utilized a voltage waveform with inclination at the rise time. Our experimenation has revealed that half-sine has a constant inclination of voltage waveform resulting in diminished ringing when compared to rectangular waveform[2].

Figure 1 shows 2 types of BLT for ultrasonic monopole pulse generating experimentation.The obtained data of (A) in last experimental, vibration amplitude is small to apply to high-power ultrasonic applications and therefore we considered to generate a larger amplitude by using multilayer BLT instead of (A)[3]. The structure of this transducer shows (B) in Fig.1[4].

Figure 2 shows a round disk of piezoelectric ceramic for analysis in order to demonstrate longitudinal vibrating mode and its related equation[5].

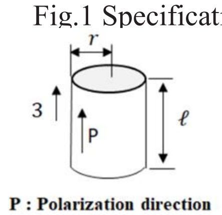
E-mail: u2watana@es.takushoku-u.ac.jp



Specification of BLT

Item		(A)	(B)
Size [mm]	:	φ15-L42	φ20-L34
Resonance Freq. [kHz]	:	60.5	59.3
Number of Layer	:	2	12
Model No.	:	DA21560A	C201
Manufacture	:	NGK	Fujicera

Fig.1 Specification of an experimental BLT



$$\Delta\ell = n \cdot d_{33} \cdot \mathrm{v} \qquad (1)$$

$$\mathrm{Fs} = n \cdot \frac{\pi \cdot r^2}{\ell_0} \cdot \frac{d_{33}}{S_{33}^{E}} \qquad (2)$$

Fig.2 A sample of longitudinal effect vibration and its related equation (1) and (2)

By changing the number of layers of piezoelectric ceramics and its thickness, it can inclease electric field intensity so that amplitude can be increased[3]. The displacement of multilayered piezoelectric ceramics is as shown in equation (1), where d_{33} is the piezoelectric constant d, n is the number of sheet of piezoelectric ceramics, and v is applied voltage. The equation of generative force F_s is as shown in equation (2). The r is radius of a sample, $\Delta\ell$ is total displacement, ℓ_0 is the displacement of a sample by applied voltage and S_{33}^{E} is compliance.

Our experimentation reveals that transducer (B) in Fig.1 could provided approximately six times the amplitude of transducer (A).

We describe here our analysis on a longitudinal vibrating mode of a round plate sample for simplicity in understanding the driving voltage waveform, its cycle and generation of ringing.

A kinetic equation for the longitudinal mode of a piezoelectric ceramics is represented as follows[5].

$$\rho\left(\frac{\partial^2 \nu}{\partial t^2}\right) = \frac{1}{S_{33}^{D}} \cdot \left(\frac{\partial^2 \nu}{\partial z^2}\right) \qquad (3)$$

Where ρ is the density of piezoelectric ceramics, ν is the displacement in 3 direction and S_{33}^{D} is discribed as equation (4)[5].

$$S_{33}^{D} = s_{33}^{E} \cdot \frac{1}{\left(1 + \frac{d_{33}^2}{S_{33}^{E} \cdot \varepsilon_3}\right)} \qquad (4)$$

According to the piezoelectric equation we need to solve equation (3) by using the Laplace transform method and initial conditions are given in (6) and (7).

$$\rho \cdot s_{33}^{D} \cdot S^2 \cdot V(s,z) = \partial^2 V(s,z)/\partial z^2 \qquad (5)$$

$$\upsilon = (t=0, Z) = 0 \qquad (6)$$

$$\partial\upsilon = (t=0, z)/\partial t = 0 \qquad (7)$$

A boundary condition at x=0, ℓ leads X_3 as

$$X_3 = \frac{1}{s_{33}^{E}}(x_3 - d_{33} \cdot E_z) \qquad (8)$$

The following equation is derived from equation (5), resulting in equation (9). Where υ means sound velocity of piezoelectric ceramics as shown in (10).

$$\mathrm{V}(s, z=\ell) = d_{33} \cdot \tilde{E} \cdot \frac{\upsilon}{s} \cdot \frac{1-e^{-\frac{s\ell}{\upsilon}}}{1+e^{-\frac{s\ell}{\upsilon}}} \qquad (9)$$

$$\upsilon = \frac{1}{\sqrt{\rho \cdot s_{33}^{d}}} \qquad (10)$$

When a half-sine function is used and the Laplace transform of field E(z), $\tilde{E}(s)$ is represented by equation (11) then V in (9) is calculated by equation (12). An applied half-sine voltage waveform, as shown in Fig.3, and its conditions follow as $n\ell/\upsilon = T/2$.

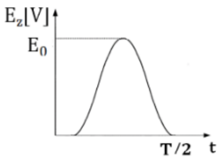


Fig.3 A half-sine voltage waveform

$$\tilde{E}(s) = E_0 \cdot \frac{\omega}{s^2+\omega^2} \cdot \left(1 + e^{-n\ell s/\upsilon}\right) \qquad (11)$$

If an input number to n (n=1,2,3…) is supplied, then equations (12), (13) and (14) are obtained.

at n=1

$$\mathrm{V}(s,\ell) = d_{33} \cdot E_0 \cdot \frac{\upsilon}{s} \cdot \frac{\omega}{s^2+\omega^2} \cdot \left(1 - e^{-\frac{\ell s}{\upsilon}}\right) \qquad (12)$$

at n=2

$$\mathrm{V}(s,\ell) = d_{33} \cdot E_0 \cdot \frac{\upsilon}{s} \cdot \frac{\omega}{s^2+\omega^2} \cdot \frac{1+e^{-2\ell s/\upsilon} - e^{-\ell s/\upsilon} - e^{-3\ell s/\upsilon}}{1+e^{-\ell s/\upsilon}} \qquad (13)$$

at n=3

$$\mathrm{V}(s,\ell) = d_{33} \cdot E_0 \cdot \frac{\upsilon}{s} \cdot \frac{\omega}{s^2+\omega^2} \cdot \frac{1+e^{-3\ell s/\upsilon} - e^{-\ell s/\upsilon} - e^{-4\ell s/\upsilon}}{1+e^{-\ell s/\upsilon}} \qquad (14)$$

By using a half-sine waveform, if the denominator is obtained for equation $1+e^{-\ell s/\upsilon}$, it leads ringing by not 1 pulse response. The relation of ringing and T, which is resonance freq. of piezoelectric ceramics, if applied as T/2 as generating frequency by using a half-sine voltage waveform, it could generate ultrasonic monopole pulse with ringing suppression.

3. Experiment

A half-sine voltage waveform from a multifunction generator (WF1974, NF) is applied to transmitting BLT through a power amplifer (HSA4011, NF). Regarding of vibration velocity is transmitted by digital oscilloscope (DSO1004A, Agilent) via obtained voltage of Laser doppler vibrometer (LV1600, Onosokki).

4. Results and discussion

We provided approximately 4.5 times larger vibration velocity in BLT (B) compare to (A) by experiment, as shown in Fig.4. From the above, converted amplitude of (B) is 0.13[μm] which is 5.4 times larger than (A), as shown in table 1. To utilize in high-power ultrasonic machining application, it is required to amplify 10 times the obtained amplitude in conventional application, such as ultrasonic fine drilling, and cutting as used in continuous wave.

As future work, we continue to design a horn in order to amplify a 10 times larger ultrasonic monopole pulse and aim for machining experiment by using this method.

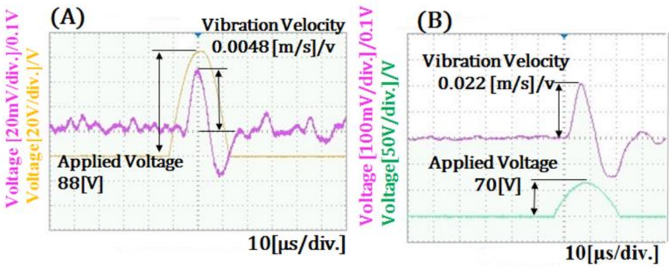


Fig.4 Result of data of BLT (A) and (B)

Table 1 Experimental conditions and result of amplitude of BLT (A) and (B)

Item	(A)	(B)
Resonance Freq. (f0) [kHz]	61.5	59.3
Freq. of pulse (f0/2) [kHz]	31.29	29.6
Amplitude [μm]	0.024	0.13

References

[1] K. Imano and H. Inoue: Technique for Generating Monopole Ultrasonic Pulse, Electron Lett.,30, pp.1551-1552(1994).

[2] S. Tarvainen, G. Wang and Y. Watanabe: Generation of High-Power Ultrasonic Monopole Pulse for Application Ultrasonic Machining, 3P4-4, USE2017

[3] Examination of the form of bolt-clamped Langevin-type transducer with stacked structure by the finite element method: J. Acoust. Soc. Vol.60, No.8 (2004) pp.441-450

[4] K. Adachi et al.: Analysis of Screw Pitch Effect on the performance of Bolt-clamped Langevin-type Transducers, JASA. Vol.116, No.9(2004) 1544.

[5] K. Uchino: Atsuden /Denwai Actuator Kiso kara ouyou made (in Japanese), Morikita publishing, pp.103-133, July,1988