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An Amplification Method of Ultrasonic Monopole Pulse without Reverberation for Precision Ultrasonic Machining

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1. Introduction

Ultrasonic-assisted machining is widely used in the field of precision machining such as cutting, grinding and polishing. In this field, resonant phenomenon of ultrasonic oscillation system is used, in general, in order to obtain large vibration amplitude. However utilizing the resonance phenomenon causes the hopping[1)], reverberation and slippage at the tool end, so that machining accuracy is reduced.

In order to resolve this problem, we advocate utilizing ultrasonic monopole pulse by non-resonance driving. Machining by monopole pulse without reverberation will be able to avoid hopping and slipping when the tool end contacts to work surface. However, electrical energy of ultrasonic monopole pulse is so small compared with resonance driving, so that large kinetic energy cannot be applied to work surface .

In this study, we tried to develop an amplifier method of ultrasonic monopole pulse by concentration of pulse energy by controlling the shape of propagation path of ultrasonic pulse.

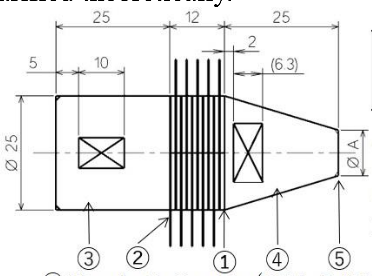
2. Generation and amplification method of ultrasonic monopole pulse

2.1 Generation of ultrasonic monopole pulse without reverberation

An ultrasonic monopole pulse source in this study has similar structure of Bolt-clamped Langevin-type Transducer (hereafter, BLT) which is composed of multilayered piezoelectric ceramic plates. This structure makes lower resonance sharpness Q (quality factor) , and it means higher followability of deformation to supplied voltage. Furthermore, it can be driven by lower voltage. The thickness of every piezoelectric ceramic plates is 1mm with 25mm diameter. Fig. 1 shows outside drawing of experimental BLT and its components.

A piezoelectric ceramic is roughly divided into hard and soft materials by mechanical quality factor (hereafter, Q_m). To obtain a large displacement, soft material with high-piezoelectric stain constant and low value of Q_m are adopted. Table I shows specification of C201(Fuji ceramic).

To overcome reverberation, the driving method of ultrasonic monopole pulse[2)] is purposed applying a driving voltage waveform which doesn't contains a resonance frequency of experimental BLT. Furthermore, a half-sine waveform with gently tapered rising and falling is utilized. This indicates that purposed method is proved effective against reverberation from the result of experimental. Fig.2 indicates the driving voltage waveform and a pulse cycle T_p related to resonance frequency of experimental BLT f_0. In addition, we calculated reverberation state via displacement of driving voltage waveform in experimental BLT using a Laplace transform[3)]. Consequently, pulse cycle related to resonance frequency of experiment BLT is clarified theoretically.



The shapes of BLT for experimental	φA (mm)
Straight	25
Taper_a	15
Taper_b	10
Taper_c	5
Reverse Taper_d	30

① Piezoelectric Ceramics (C201 : Fuji Ceramic)
② Electrode plate (Beryllium Copper)
③ Front plate (Duralumin : A2017)
④ Lined plate (Duralumin : A2017)
⑤ Tip

Fig. 1 An outside drawing of experimental BLT.

Table I Specification of Piezoelectric ceramics.

Material Properties	C201 (Piezoelectric ceramics)	
Equivalent piezoelectric constants	$\times 10^{-12}$m/V	330
Elastic constants $Y_{33}^E = 1/S_{33}^E$	$\times 10^{10}$N/m^2	6.4
Poisson ratio σ		0.3
Mechanical quality factor Q_m		900
Dielectric loss: tanδ	%	0.29
Density: ρ	$\times 10^3$kg/m^3	7.8

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2.2 Ultrasonic monopole pulse amplification method without reverberation

By virtue of the output side of the shape of propagation path of ultrasonic pulse is made tapered it goes forward, then oscillation energy is concentrated compared to straight shape. Using this idea is expected to amplify the vibration velocity. Conversely, we assume that the velocity of sound is accelerated by virtue of shape whose outside diameter becomes smaller toward the tip end. For this reason, we put forward a new shape of experimental BLT which is designed different diameter of input and output side and its shapes and specification are shown as tapered shapes in Fig.1. Regarding layer number of piezoelectric ceramics is fixed six and ten for comparison and evaluation through experimental data of vibration velocity. The displacement of multilayer actuator at no-load as shown in Fig.3 and it is related to equation (1).a indicates Nonlinear correction coefficient ≅ 1.5. When number of layers n is increased from six to ten, displacement is obtained approximately times 1.67.

3. Experimental

We produced five types of BLT with different taper angle as shown in Fig. 1. It is included a straight shape of BLT for comparison with taper angle shapes.

A half-sine voltage waveform from a multifunction generator (WF1974, NF) is applied to transmitting BLT through a power amplifier (HSA4052, NF). Regarding of vibration velocity is transmitted by digital oscilloscope(DSOX1204A, Keysight) via obtained voltage of Laser the doppler vibrometer (VibroOne, Polytech Japan).

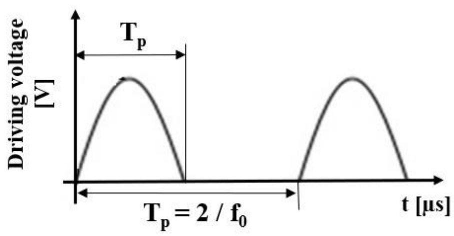

Fig. 2 A half-sine voltage waveform and relational expression of pulse cycle and resonance frequency of experimental BLT.

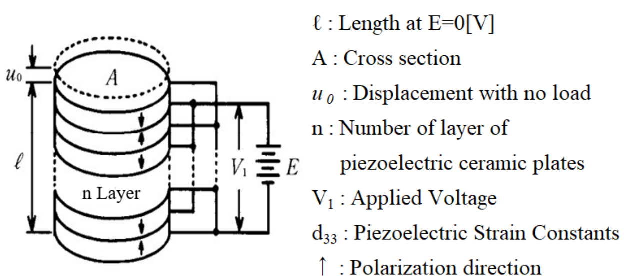

Fig. 3 Displacement of multilayered actuator with no load.

$$u_0 = nV_1 d_{33} \alpha \cdots (1)$$

4. Results and Discussion

Table II shows as an obtained result and applied voltage 165[V_{0p}] is a maximum value to supress reverberation. Taper_c is obtained largest vibration velocity 0.029[$m/s_{0\text{-}p}$] with layered number six in tapered shapes. Therefor, we manufactured and measured a shape Taper_c BLT with ten piesoelectric ceramics layered. The consequence of Taper_c with layered number ten is 0.046[$m/s_{0\text{-}p}$] which is times 1.59 approximate to based on design value through equetion (1). Hence, in layered number twenty with Taper_c can be expected to nealy 0.1[$m/s_{0\text{-}p}$]. A suppresed reverbation are presented using this amplification method via expelimental, as shown in Fig.4. The proposed amplification method is found to be effective for ultrasonic monopole pulse amplification and also suppressing reverberation.

Table II Result of each type of experimental BLT and its experimental conditions.

The shapes of BLT for experimental	Number of Piezoelectric ceramics plates	Applied Voltage [$V_{0\text{-}p}$]	Pulse Width [μs]	Vibration Velocity [$m/s_{0\text{-}p}$]
Straight	6	165	38.00	0.020
Taper_a	6	165	36.25	0.025
Taper_b	6	165	35.65	0.026
Taper_c	6	165	30.10	0.029
Reverse Taper_d	6	165	53.60	0.016
Straight	10	165	44.75	0.033
Taper_c	10	165	34.84	0.046

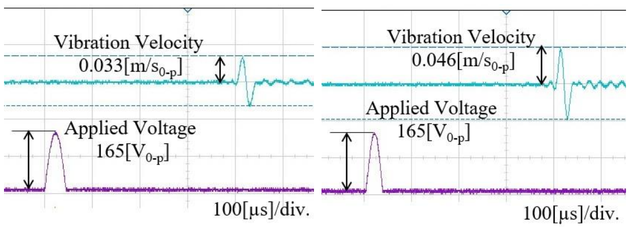

Fig.4 Result of data of Straight (left) and Taper_c (right).

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number JP22K03846.

References

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