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Resonance characteristics of a longitudinal-torsional complex vibration source using a transmission rod with helical slits

ヘリカルスリット付伝送棒を用いた縦-ねじり複合振動源の共振特性

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1. Introduction

Ultrasonic welding using planar vibration with a two-dimensional vibration locus improves welding performance compared with linear vibration with a one-dimensional vibration locus [1-2].

We have focused on generating planar vibration by simultaneously driving a one-dimensional vibration locus in different directions with an ultrasonic vibration source with a helical slit. In this paper, an analytical model of an ultrasonic vibration source with a helical slit was developed using the finite element method (FEM). The depth of the helical slit was selected so that the ratios of longitudinal to torsional vibration displacement at the tip of the transmission rod in the longitudinal and torsional vibration resonance modes were the same.

A transmission rod with a helical slit with the depth determined by the FEM results was fabricated, and the resonance characteristics of the ultrasonic vibration source containing the rod and the vibration locus at the tip of the transmission rod were measured.

2. Ultrasonic source with a helical slit

Figure 1 shows a schematic of the ultrasonic vibration source with a helical slit. The vibration source consists of a 40 kHz bolt-clamped Langevin transducer (HEC-3039P4B, Honda Electronics), a flange-integrated exponential horn (diameter of large end face: 30 mm; diameter of small end face: 12 mm; amplification factor: about 2.9; material: A 2017), and a transmission rod with a helical slit connected with screws. The helical slit is in the transmission rod tip and is a double-helical groove with equal spacing on the circumference of the transmission rod. The slit shape on the transmission rod surface is semicircular for all slit depths.

3. Selection of the helical slit

An analytical model was prepared with the dimensions shown in Fig. 1, and piezoelectric

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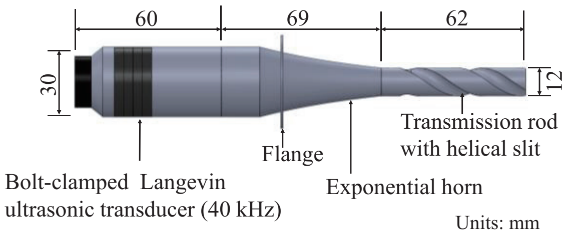

Fig. 1. Schematic of the ultrasonic source.

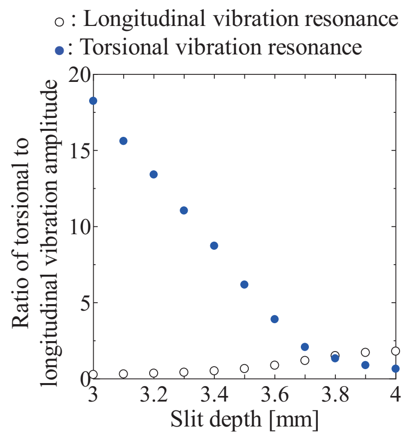

Fig. 2. Relationship between slit depth and ratio of torsional to longitudinal vibration amplitude.

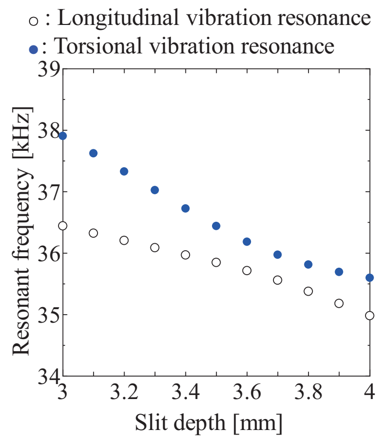

Fig. 3. Relationship between resonance frequency of longitudinal vibration and torsional vibration.

analysis was performed with COMSOL analysis software using the FEM to determine the slit depth. The analysis model also considered the connection screw inside the ultrasonic vibration source. At longitudinal and torsional vibration resonances, the slit depth (radius shape) was varied in steps of 0.1 mm in the range of 3.0–4.0 mm, and the relationship between the ratio of longitudinal to torsional vibration displacement at the tip of the transmission rod and the slit depth was determined. The flange was fixed and restrained.

Figure 2 shows the results of the piezoelectric analysis. The vertical axis represents the ratio of torsional to longitudinal vibration displacement amplitude at the tip of the transmission rod and the horizontal axis represents the slit depth. Open circles indicate the ratio at the longitudinal vibration resonance frequency, and blue circles indicate the ratio at the torsional vibration resonance frequency. The ratios were both about 1.5 at a slit depth of 3.8 mm. A larger planar vibrational area was obtained when the ratios agreed with values being close to 1.0. Thus, the dimensions of the helical slit were selected as a slit depth of 3.8 mm and a pitch (straight distance of slit from start to end) of 54 mm. From the analytical results, the dimensions of the helical slit were selected to be a slit depth of 3.8 mm and a pitch of 54 mm (straight distance of slit from start to end).

Figure 3 shows the resonance frequency at as a function of slit depth. The analytical model slit depth of 3.8 mm had a longitudinal vibration resonance frequency of 35.4 kHz and a torsional vibration resonance frequency of 35.8 kHz.

4. Resonance characteristics of ultrasonic vibration source

Based on the piezoelectric analysis, a transmission rod with a helical slit of slit depth of 3.8 mm was fabricated. The resonance characteristics of an ultrasonic vibration source containing the rod were measured. The resonance characteristics were measured considering the frequency of the electricity supplied using an impedance analyzer (ZGA 5920, NF). The driving voltage of the ultrasonic vibrator was 1.0 Vrms. As in the analytical conditions, the ultrasonic vibration source flange was fixed with a duralumin jig 1 mm away.

Figure 4 shows the resonance characteristics of the vibration source. The vertical axis represents conductance and the horizontal axis represents frequency. The resonance occurred at frequencies of 36.1 and 36.5 kHz.

5. Vibration locus of the ultrasonic vibration source

To examine the vibration loci obtained from the ultrasonic vibration source, the vibration loci at the tip of the transmission rod were measured with two laser Doppler vibrometers at the resonance frequency obtained from the resonance characteristics.

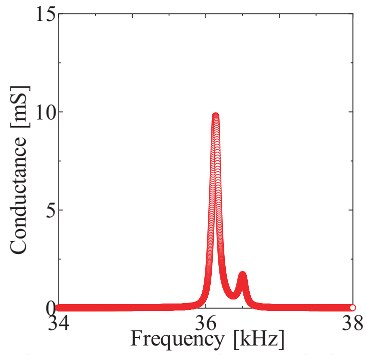

Fig. 4. Frequency characteristics.

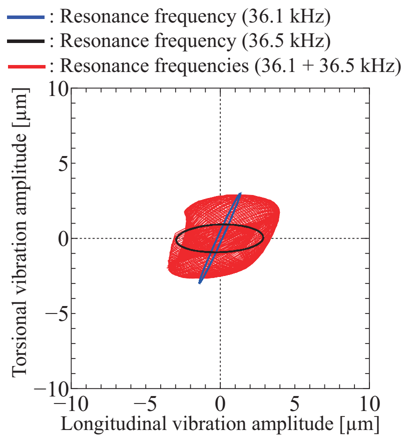

Fig. 5. Vibration loci.

Figure 5 shows the vibration loci. The longitudinal vibration displacement amplitude is shown on the horizontal axis and the torsional vibration displacement amplitude is shown on the vertical axis. An almost straight vibration locus was obtained at the frequency of 36.1 kHz and an elliptical vibration locus was obtained at the frequency of 36.5 kHz. A planar vibration locus with a vibration amplitude of 6 μm_{p-p} was obtained when both resonant frequencies were driven simultaneously.

6. Conclusions

A transmission rod with a helical slit was fabricated based on FEM calculations, and the resonance characteristics and vibration loci of the ultrasonic vibration source containing the transmission rod were investigated. The vibration occurred at frequencies of 36.1 and 36.5 kHz. A planar vibration locus was obtained by driving both resonant frequencies simultaneously.

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References

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