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# Development of longitudinal-torsional vibration source with a helical slits transmission rod

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## ABSTRACT

Ultrasonic welding using planar vibration with a two-dimensional vibration locus shows improved joining performance, including increased joining area and welding strength. Therefore, we have focused on generating planar vibration by simultaneously driving one-dimensional vibration loci with different directions using an ultrasonic vibration source containing a transmission rod with a helical slit. In this study, an analysis model of the ultrasonic vibration source with a helical slit transmission rod was created using the finite element method. The slit depth at which the ratio of the longitudinal and torsional vibration displacement at the tip of the transmission rod were the same in the longitudinal and torsional vibration modes was calculated. Based on these results, a transmission rod with helical slits of the selected depth was prototyped, and the resonance characteristics of an ultrasonic vibration source containing the transmission rod and the vibration trajectory at the tip of the transmission rod were measured. We confirmed that a planar vibration was generated by the ultrasonic vibration source containing the transmission rod with helical slits.

Keywords: Ultrasonic, Planar vibration, Helical slit, Vibration loci

## 1. INTRODUCTION

Ultrasonic welding using planar vibration with a two-dimensional vibration locus improves the welding performance by increasing the welding area and welding strength compared with welding using linear vibration with a one-dimensional vibration locus (1- 3).

To generate planar vibration, we have examined an ultrasonic complex vibration source using a diagonal slit in the transmission rod of a vibration source that consisted of a longitudinal vibrator, a horn, and a transmission rod (4, 5). The diagonal slit is formed from several straight slits with an angle at the position of a longitudinal vibration node of the transmission rod at equal intervals on the circumference of the transmission rod. The longitudinal vibration is converted to the torsional vibration at the diagonal slits. The planar vibration is generated by simultaneously driving the sum of the longitudinal and torsional vibration in one dimension in different directions at two resonance frequencies. However, the impedance is higher at the torsional vibration resonance than at the longitudinal vibration resonance, and therefore it is difficult to obtain a sufficient torsional vibration amplitude. To tackle this problem, 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 created by using the finite element method (FEM). The depth of the helical slit was selected by changing the depth of the slit so that the ratios of the 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.

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## 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 has 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. The helical slit is applied to the transmission rod tip.

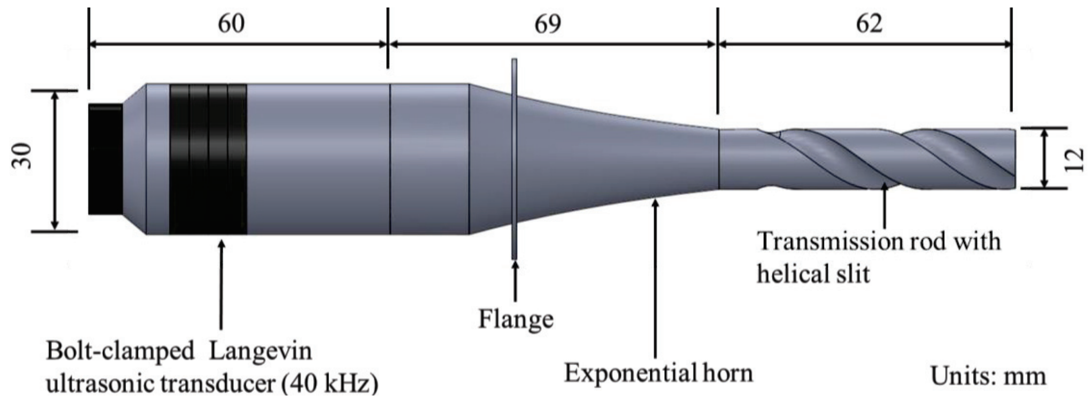



Figure 1 – Schematic of the ultrasonic source.

## 3. SELECTION OF THE HELICAL SLIT

An analytical model was prepared with the dimensions shown in Fig. 1, and piezoelectric analysis was performed with COMSOL analysis software using the FEM to determine the slit depth. At the longitudinal and torsional vibration resonances, the slit depth (radius shape) was varied in steps of 0.1 mm in the range of 1.0–3.0 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.

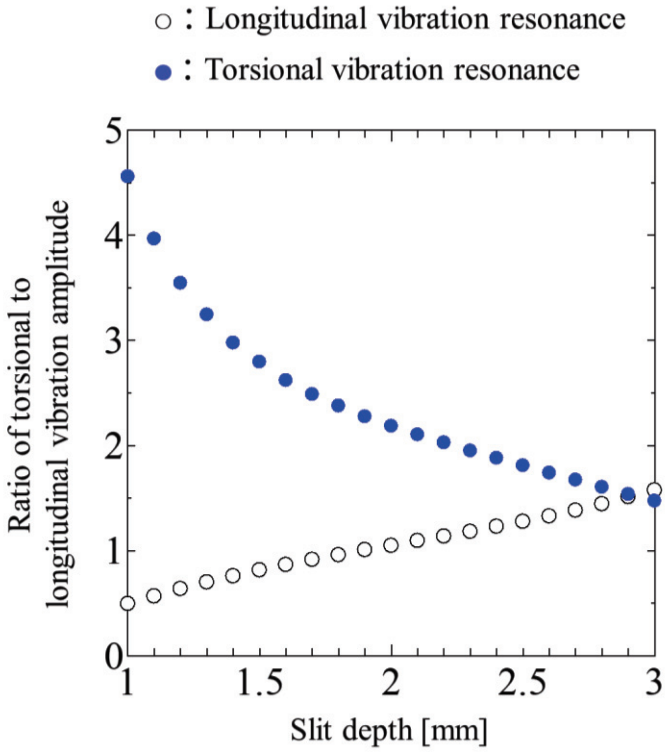


Figure 2 – Relationship between slit depth and ratio of torsional to longitudinal vibration amplitude.

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 the blue circles indicate the ratio at the torsional vibration resonance frequency. The ratios were both about 1.5 at a slit depth of 3.0 mm. A larger planar vibrational area was obtained when the ratios agreed with values close to 1.0. Thus, the dimensions of the helical slit were selected as a slit depth of 3.0 mm and a pitch (straight distance of slit from start to end) of 54 mm.

Figure 3 shows the longitudinal and torsional vibration resonance frequencies as a function of the helical slit depth. The analytical model for a slit depth of 3.0 mm has a longitudinal vibration resonance frequency of 37.4 kHz and a torsional vibration resonance frequency of 38.1 kHz.

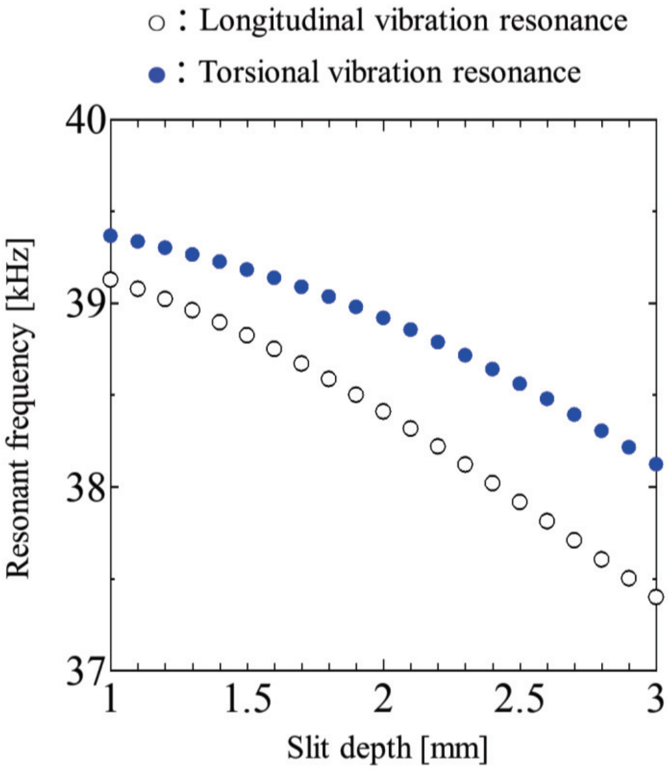
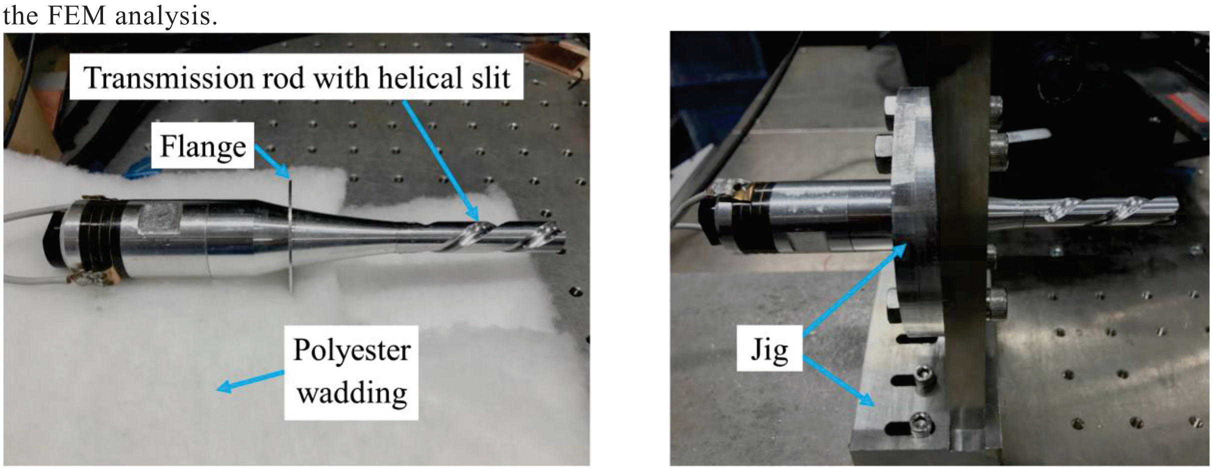


Figure 3 – Resonant frequency of longitudinal and torsional vibration as a function of slit depth.

## 4. RESONANCE CHARACTERISTICS OF ULTRASONIC VIBRATION SOURCES

Based on the piezoelectric analysis, a transmission rod with a helical slit of slit depth of 3.0 mm was fabricated. The resonance characteristics of an ultrasonic vibration source containing the rod were measured. The admittance was 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 $V_{rms}$. The ultrasonic vibration source was placed on polyester wadding 5 mm thick (unfixed flange, Fig. 4 (a)) or the flange was fixed with a duralumin jig (fixed flange, Fig. 4 (b)).

Figure 5 shows the resonance characteristics for the unfixed (black circles) and fixed flange (red circles). The vertical axis represents conductance and the horizontal axis represents frequency. The unfixed flange produced two resonances at 37.7 and 36.8 kHz, whereas the fixed flange produced one resonance at 37.5 kHz. The resonance frequency around 37.5 kHz was similar to that obtained from the FEM analysis.



(a) Unfixed flange (b) Fixed flange

Figure 4 – Photographs showing the unfixed and fixed flange conditions.

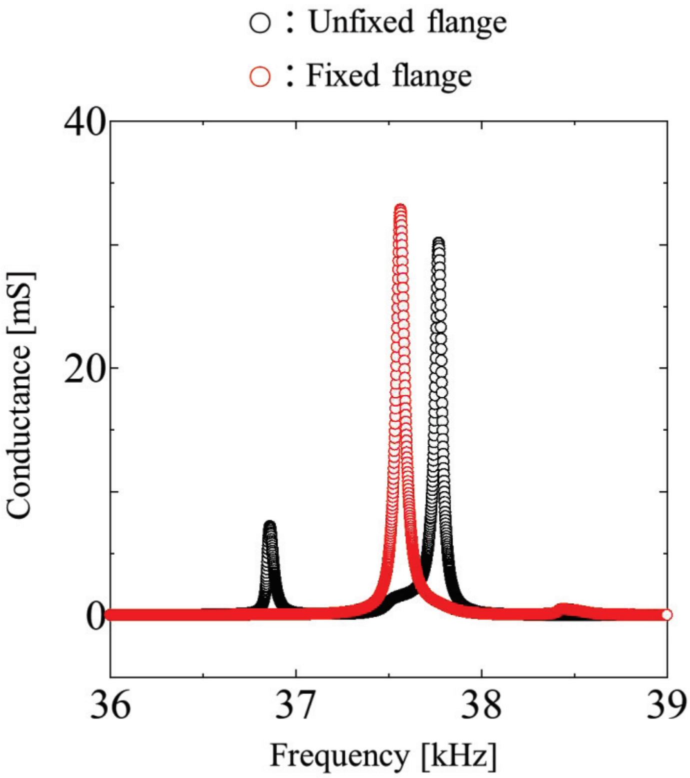



Figure 5 – Frequency characteristics for the unfixed and fixed flange conditions.

## 5. VIBRATION LOCUS OF THE ULTRASONIC VIBRATION SOURCE

To examine the locus of the vibration obtained from the ultrasonic vibration source, the vibration locus at the tip of the transmission rod was measured with two laser Doppler vibrometers at the resonance frequency obtained from the resonance characteristics. The driving voltage was 10 $V_{rms}$. Figure 6 (a) and (b) show the vibration loci for the unfixed and fixed flange conditions, respectively. The longitudinal vibration displacement amplitude is shown on the horizontal axis and the torsional vibration displacement amplitude is shown on the vertical axis. For driving frequencies of 37.7 and 36.8 kHz, the vibration loci each had a linear locus (Fig. 6 (a)). A planar vibration locus was obtained when the source was driven simultaneously at both resonance frequencies. The ratio of torsional vibration displacement to longitudinal vibration displacement was similar to the analytical result. On the other hand, the vibration locus at a driving frequency of 37.5 kHz was a linear locus (Fig. 6 (b)), and the torsional vibration amplitude was smaller than that in Fig. 6 (a). Therefore, fixing the flange suppressed the torsional vibration amplitude.

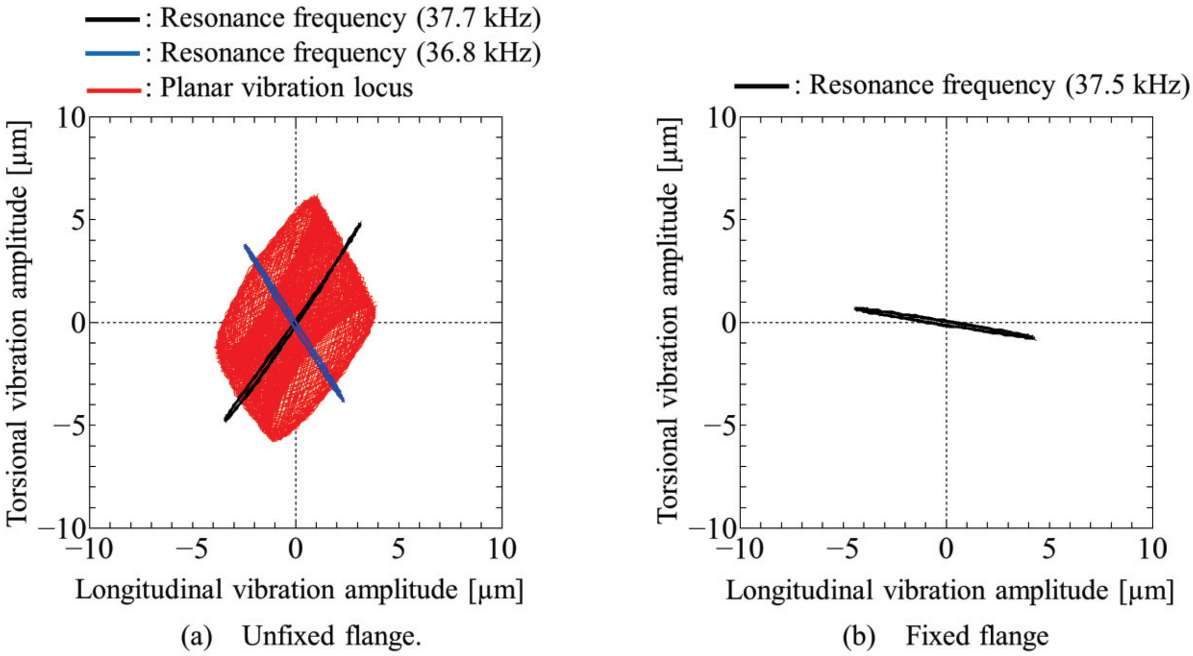



Figure 6 – Vibration loci for the unfixed and fixed flange conditions.

## 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 FEM analysis results showed that the ratios of torsional to longitudinal vibration displacement amplitude at the longitudinal and torsional vibration resonances were both about 1.5 at the tip of the transmission rod for a helical slit depth of 3.0 mm. A transmission rod with a helical slit with a depth of 3.0 mm was fabricated and the resonance characteristics were measured. For the unfixed flange conditions, two resonances were obtained at 37.7 and 36.8 kHz, whereas for the fixed flange conditions, one resonance was obtained at 37.5 kHz. The transmission rod tip only had a planar vibration locus with the unfixed flange. This result indicated that the torsional vibration was suppressed by fixing the flange. In addition, the discrepancy between the analysis results and the measurements arose because the coupling screws connecting the vibrator, horn, and transmission rod were not considered in the analytical model. Therefore, a more realistic analytical model is required.

## REFERENCES

1. Y. Tamada, T. Asami, and H. Miura, Jpn. J. Appl. Phys., vol.57, 07LE12 (2018).
2. Jiroumaru TUJINO, Takahiro MORI, Takashi ONOZATO and Koichi HASEGAWA. Jpn. J. Appl. Phys., vol.32, (1993) pp2435-2440.
3. Jiroumaru TUJINO, Tetsugi UEOKA. Jpn. J. Appl. Phys., vol.32, (1999) pp3307-3311.
4. T. Asami and H. Miura, Acoust. Sci. Technol. 36, 232 (2015).
5. Jiroumaru TUJINO, Kentaro NAKAI, Kazuhide SAKO, Noritada IKEGAMI, Kohsuke NODA and Ryo SUZUKI. Jpn. J. Appl. Phys., vol.37, (1998) pp2960-2965.