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Study of longitudinal–torsional vibration source using stepped horn with hollow part
中空部を有するステップホーンを用いた縦－ねじり振動源

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1. Introduction

We have previously studied ultrasonic machining using ultrasonic longitudinal–torsional vibration and vibration sources used for ultrasonic machining.[1-3] Additionally, we have proposed the use of a planar vibration locus composed of longitudinal–torsional vibration in ultrasonic welding, which is an ultrasonic vibration-assisted manufacturing technology.[3] To date, stepped horns with variations in only the outer diameter have been used as vibration sources when generating a planar vibration locus. However, the difference between the amplitude amplification ratio of longitudinal vibration and that of torsional vibration is large in such horns, which leads to problems in terms of vibration control. Therefore, we propose a stepped horn with a varying outside diameter that includes a hollow part to allow the amplitude amplification ratio of longitudinal vibration and torsional vibration to be individually designed.

In this paper, we examined the vibration mode and vibration distribution of the proposed stepped horn with a hollow part by finite element method analysis using COMSOL software, to determine whether the amplitude amplification ratios can be individually designed.

2. Longitudinal–torsional vibration source

Figure 1 outlines the longitudinal–torsional source proposed in this study. The vibration source is composed of a bolt-clamped Langevin-type longitudinal transducer (rated frequency, 26.9 kHz; D4427PC; NGK SPARK PLUG), a bolt-clamped Langevin-type torsional transducer (rated frequency, 18.1 kHz; DAN 4419; NGK SPARK PLUG), and a stepped horn (material, A2017) with a hollow part. The structure of the vibration source is designed to obtain the vibration displacement amplitude corresponding to each transducer by inputting the signal to each transducer. While not shown in the figure, a flange is also present for stable placement.

As shown in **Fig. 2**, the stepped horn used in this study had half of its total length hollowed out from the thin end of the horn, starting from the point of change in outer diameter. The wider portion of the horn had an outer diameter of 40.0 mm, and the thinner portion had an outer diameter of 29.6 mm and an inner diameter of 22.0 mm. The total length of the horn was 88.2 mm, and R machining with a radius of 3.0 mm was used for the part where the cross-sectional area changed. The coordinate axes in Figs. 1 and 2 are Cartesian coordinate systems, and the *z*-axis coincides with the central axis of the stepped horn along the longitudinal direction.

3. Examination of the vibration mode by finite-element method analysis

Using the finite element analysis software COMSOL Multiphysics 5.5, the vibration mode and vibration distribution when the longitudinal vibration and torsional vibration of the stepped horn shown in Fig. 2 were half the wavelength resonance were obtained by eigenvalue analysis.

Figure 3 shows the vibration modes as determined by eigenvalue analysis. Figure 3(a) shows the results for a frequency of 17.690 kHz and Fig. 3(b) shows those for a frequency of 28.349 kHz. In the figure, the magnitude of vibration displacement amplitude is shown in grayscale, with white representing the maximum value and black

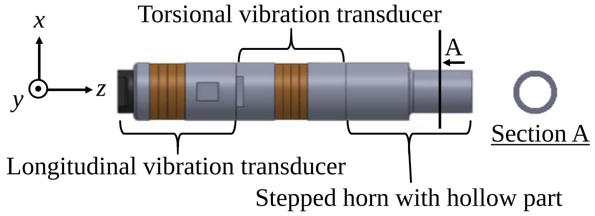

Fig. 1. Longitudinal–torsional vibration source.

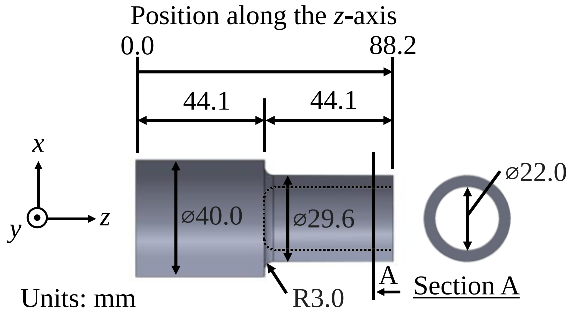

Fig. 2. Stepped horn with a hollow part.

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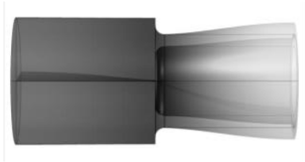
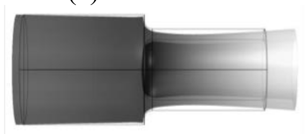
representing the minimum value. As can be seen in Fig. 3(a), at a frequency of 17.690 kHz, the vibration mode of the outer diameter was amplified at both end faces. This is because the torsional vibration is expressed as the combination of the vibration displacement along both the x- and y-axes, owing to the calculation being carried out in a Cartesian coordinate system. As a result, the vibration mode of the stepped horn with a hollow part at a frequency of 17.690 kHz is considered to be half the wavelength resonance of torsional vibration. Next, as seen in Fig. 3(b), it was found that the vibration displacement along the z-axis was the dominant vibration mode at a frequency of 28.349 kHz, and that vibration along the z-axis was the longitudinal vibration. This suggests that the vibration mode of the stepped horn with a hollow part at a frequency of 28.349 kHz was half the wavelength resonance of the longitudinal vibration.

Figure 4 shows the vibration distribution obtained from the results shown in Fig. 3. Figure 4(a) and shows the results at a frequency of 17.690 kHz and Fig. 4(b) shows those at a frequency of 28.349 kHz. Each vibration displacement amplitude is normalized by the value of the maximum displacement amplitude at each frequency. As Fig. 4(a) shows, the vibration distribution at a frequency of 17.690 kHz was along the x-axis only. This vibration corresponds to the torsional vibration as shown in Fig. 3(a). This demonstrates that the torsional vibration was distributed at the half wavelength, with an amplitude amplification ratio of 3.55. Next, as seen in Fig. 4(b), the vibration distribution at a frequency of 28.349 kHz consisted mainly of vibration along the z-axis. This corresponds to the longitudinal vibration as shown in Fig. 3(b). This demonstrates that the longitudinal vibration was also distributed at the half wavelength, with an amplitude expansion ratio of 4.19.

The above results show that the amplitude amplification ratio of torsional vibration and that of longitudinal vibration could be made nearly equal using a stepped horn with a hollow part.

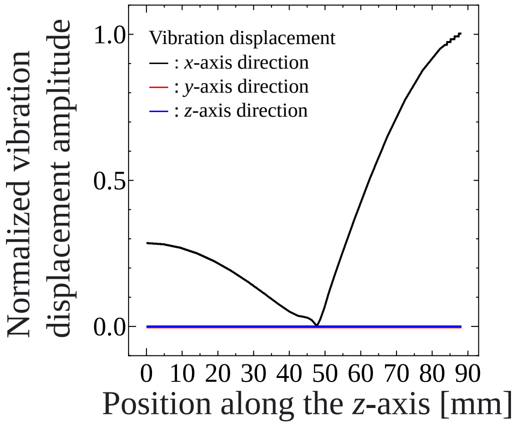


(a) 17.690 kHz

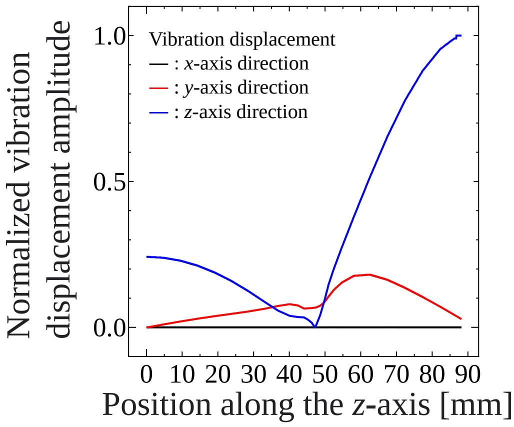


(b) 28.349 kHz

Fig. 3. Vibration modes.



(a) 17.690 kHz



(b) 28.349 kHz

Fig. 4. Vibration distributions.

4. Conclusion

In this paper, the vibration mode and vibration distribution of a stepped horn with a hollow part were examined to determine whether the amplitude amplification ratio of torsional vibration and that of longitudinal vibration can be individually designed. It was found that amplitude amplification ratio of longitudinal and torsional vibration was 4.19 and 3.55, respectively, and the two vibration amplitude amplification ratios could be made nearly equal. This suggests that a stepped horn with a hollow part may allow for the individual design of each amplitude amplification ratio.

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References

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