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Examination of complex vibration source with convex ring attached to step horn with hollow part

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1. Introduction

Using a planar vibration mode for ultrasonic welding shortens the welding time and increases the welding strength[1)]. The welding tip should be easy to attach, increase the vibration energy propagation, and have a robust structure. Here, we examined whether a vibration source with a structure in which a circular ring with a convex part was incorporated in the step horn would meet these requirements, and simulated the vibration distribution generated when the step horn was attached to a complex vibration source.

2. Study of step horn with ring

The dimensions of a step horn with a convex ring were investigated by calculating the longitudinal and torsional vibration amplitude magnification ratios using COMSOL finite element method analysis software. Figure 1 shows the structure of the step horn with a hollow part attached to a convex ring (called thereferred to hereafter as the ring). The step horn consisted of the step horn body (black rectangle), the ring (blue rectangle), and the nut for fixing the ring (red rectangle). The inner diameter of the ring was set to be half the thickness of the narrow end of the step horn. The ring and nut were connected via tightening the ring and the nut on a screw thread in the corresponding part of the horn. The step horn and nut were made of A2017, and the ring was made of SUS303. D_2 was the outer diameter of the narrow end of the step horn and the ring, and D_3 was the inner diameter of the narrow end of the step horn. Positions P_1 and P_2 of both ends of the step horn were set as points for extracting displacement. An analysis model with the structure shown in Fig. 1 was created, and the values of D_2 and D_3 at which the amplitude expansion ratios of the longitudinal and torsional vibrations were both tripled were examined. Natural frequency analysis was performed using the analysis model. The ratio of the displacement in each vibration direction at point P_2 and the displacement in each vibration direction at point P_1 were calculated from the analysis results at the longitudinal and torsional vibration resonance frequencies, and a color map was created.

Figures 2(a) and (b) show the results for the torsional and longitudinal vibration resonances, respectively. The color bar indicates the amplitude expansion ratio of each vibration. The range enclosed by black squares is the dimension where each vibration amplification ratio is 2.9 to 3.1. From the ranges in Fig. 2, D_2 = 26.6 mm and D_3 = 16.6 mm were selected as the dimensions that made the two

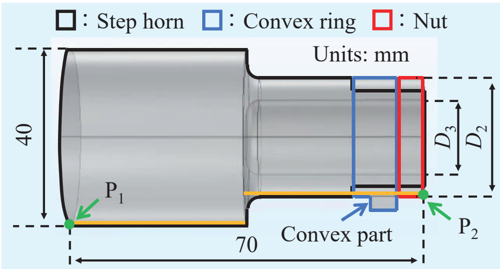
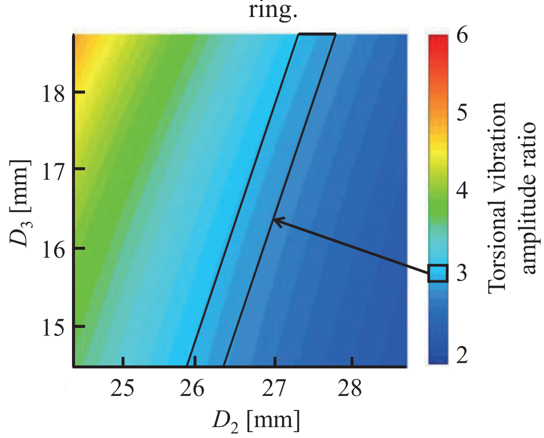
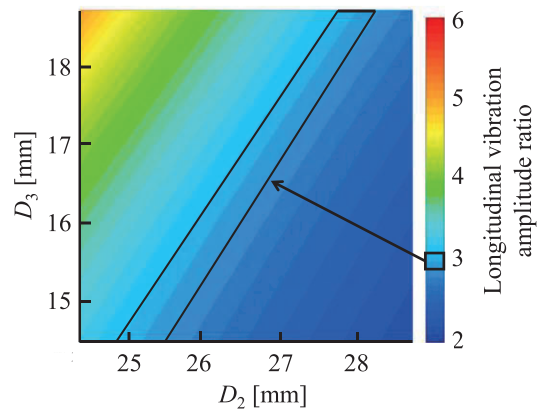


Fig. 1. Step horn with hollow part attached to convex ring.



(a) Torsional vibration amplitude ratio.



(b) Longitudinal vibration amplitude ratio.

Fig. 2. Relationship between D_2 and D_3 for each vibration amplitude ratio.

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vibration amplification ratios close to 3.

Figure 3 shows the vibration displacement distribution at the outside diameter of the step horn (yellow line in Fig. 1). The horizontal axis indicates the distance of the outside of the step horn in the central axis direction with the thick end side being 0 (original point). In the legend, the red line indicates longitudinal vibration, and the blue line indicates torsional vibration. The expansion ratio of each vibration was close to 3.

3. Vibration displacement in complex vibration sources

A uniform rod with a flange and a longitudinal and torsional vibration transducer were attached to the step horn discussed in Section 2, and the vibration displacement distribution of the entire complex vibration source was investigated.

Figure 4 shows the analysis model. From the left, the longitudinal vibration transducer and torsional vibration transducer formed the complex vibration source, to which the uniform rod with flange and the step horn were connected. In this analytical model, length H of the step horn, length L of the uniform rod, and position A of the flange in the axial direction were varied. Each value at which the node positions of the longitudinal vibration and torsional vibration generated in the complex vibration source coincided within the uniform rod was examined. Figure 5 shows the results. The horizontal axis of the figure shows the distance on the central axis of the complex vibration source with the longitudinal vibration transducer side set to 0 (original point). The figure shows the vibration displacement at the outside position of the vibration source indicated by the yellow line in Fig. 4 in the vibration mode at the torsional vibration resonance frequency of 18.28 kHz and the longitudinal vibration resonance frequency of 29.52 kHz. When the length of the step horn was $H = 70$ mm, the length of the uniform rod was $L = 90.5$ mm, and the position of the flange was $A = 200$ mm. The legend is the same as in Fig. 3. The longitudinal and torsional vibrations of the entire complex vibration source consisted of two wavelengths, and the positions of the nodes of the longitudinal and torsional vibrations coincided at the position where the flange was placed on the uniform rod. In addition, the effect of inserting the ring on the vibration distribution was small at the narrow end of the step horn.

4. Conclusion

From above results, the dimensions at which the amplitude expansion ratio of longitudinal and torsional vibration approached 3 when the ring was incorporated in the step horn were determined. In addition, the analysis model of the complex vibration source showed that the nodes of both vibrations could coincide at the flange position in the uniform bar where the flange was installed.

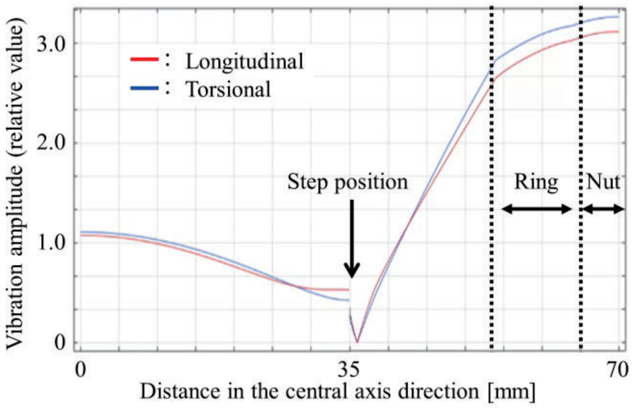

Fig. 3. Relationship between vibration displacement and the distance in the central axis direction of the step horn.

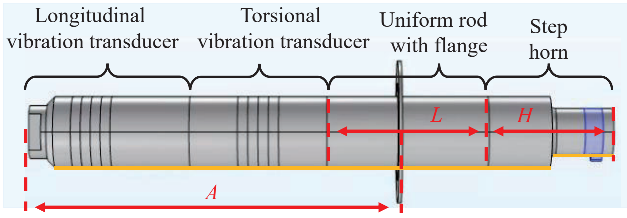

Fig. 4. Complex vibration source.

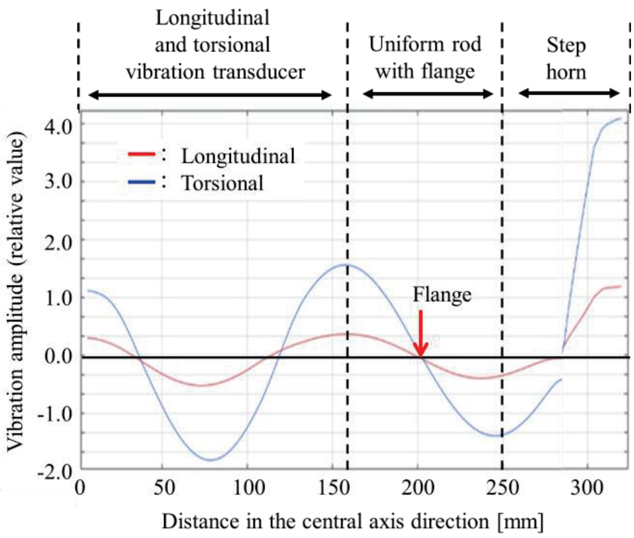

Fig. 5. Relationship between vibration displacement and the distance in the central axis direction of the complex vibration source.

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References

1) Y. Tamada, H. Sakuma, T. Asami and H. Miura, Acoust. Sci. & Tech., 41, 645–653 (2020).