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Study of ultrasonic longitudinal and flexural vibration source using a slit

切り込みを用いた縦―たわみ振動する超音波振動源の検討

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1. Introduction

We study ultrasonic applied processing by using certain vibration sources to generate complex ultrasonic vibration. To date, we have focused on complex ultrasonic vibration comprising longitudinal and torsional vibrations, and we have developed vibration sources to generate such vibrations.[1-3] Specifically, we have examined a vibration source that uses diagonal slits as a vibration converter[2], and a vibration source that uses one longitudinal and one torsional vibration transducer[3].

However, in the vibration source that uses diagonal slits as a vibration converter, it was difficult to select the flange fixing position because the node positions of each vibration displacement do not match. Meanwhile, the drawback with the vibration source that uses two vibration transducers (one longitudinal and one torsional) is that it is consequently relatively large.

To solve the aforementioned problems, we considered developing a source of complex ultrasonic vibration that is both easy to fix and uses only one small transducer. Specifically, the source generates complex ultrasonic vibration in the form of longitudinal and flexural vibrations. This is done by using a notch at the tip of the vibration source using a single longitudinal vibration transducer; then, by adopting a plane-symmetric structure, the phase of the generated flexural vibration is reversed, and the flexural vibration other than that at the tip is cancelled. In this paper, we report a basic study of the vibration source using the finite-element analysis software COMSOL Multiphysics 5.5. We examined whether the vibration source with the above structure could produce complex vibration in the form of longitudinal and flexural vibrations, and whether it is possible to cancel the propagation of the flexural vibration.[4]

2. Longitudinal–flexural vibration source

Figure 1 is an outline of the longitudinal–flexural vibration source under consideration. The vibration source consists of a 60-kHz bolt-clamped Langevin-type longitudinal vibration transducer (HEC-1560P4B, Honda Electronics) and a horn with a plane-symmetric structure (material: A2017) using a notch with a flange. The transducer and horn are fastened with a threaded rod. The plane-symmetric horn has a notch of width 0.2 mm extending a distance b [mm] back from its tip. In addition, the horn cross section is basically a 15 mm × 15 mm square; the width of one side is a [mm] from the tip to the position of 20 mm, and the R connection is applied to position of 20 mm from the tip. In this study, we used $a = 3.7$ mm. We made the structure plane-symmetric with respect to the notch, thereby making it easier to induce flexural vibration. The horn flange was 1.0 mm thick, and the width on one side was 5.0 mm. The total length of the vibration source was 119 mm, and the position in the length direction is defined as L [mm]. Also, the length direction of the vibration source and the displacement direction of the longitudinal vibration correspond to the z direction, and the displacement direction of the flexural vibration corresponds to the x direction; the coordinate system is defined in the lower left of Fig. 1.

3. Examination by finite-element method

Using COMSOL Multiphysics 5.5, we investigated whether the longitudinal–flexural vibration source in Fig. 1 can produce complex vibration in the form of longitudinal and flexural vibrations at the tip. We also examined whether the propagation of the flexural vibration can be canceled by using a plane-symmetric structure. In the study, an eigenvalue analysis was performed to

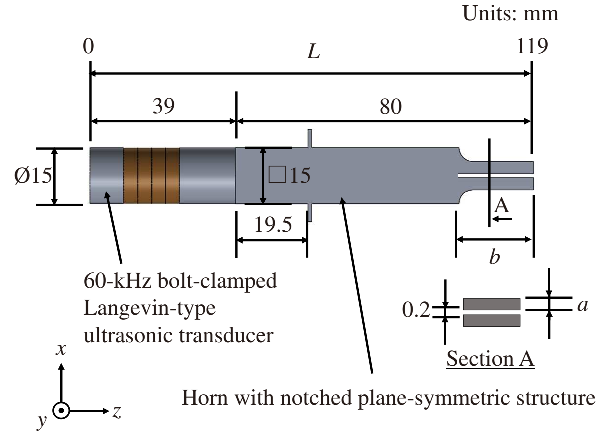

Fig. 1 Longitudinal–flexural vibration source.[4]

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find the resonant frequency of the longitudinal vibration for a notch depth $b = 0$ to 40 mm. The material of the vibration source was A2017, the piezoelectric element was PZT4, and the bolts were iron alloy. Also, the flange of the longitudinal–flexural vibration source imposes the fixed constraint of zero displacement in the *x*, *y*, and *z* directions within 3 mm on either side.

3-1. Longitudinal–flexural vibration ratio at tip

Figure 2 shows the finite-element results for the longitudinal–flexural ratio of the tip at the longitudinal-vibration resonant frequency for different values of the notch depth *b*. The longitudinal–flexural ratio is the absolute value obtained by dividing the vibration source tip displacement in the *x* direction by that in the *z* direction. The results show that the longitudinal–flexural ratio increases gradually with increasing *b* and has local maxima at $b = 14$, 26, and 40 mm. We consider these local maxima to be caused by the coupling of the vibration modes of longitudinal and flexural vibration resonance in the part in which the notch was machined.

3-2. Vibration displacement distributions

Figure 3 shows the vibration displacement distributions in *x*, *y*, and *z* directions of the longitudinal–flexural vibration source for $b = 14$ mm, namely the first of the maxima. In Fig. 3, the horizontal axis is the vibration source position *L*, and the vertical axis is the vibration displacement normalized by the maximum value of the *z*-direction vibration. The vibration distributions show the results near the central axis of the vibration source, avoiding the notches. The results show the following. As the longitudinal vibration, the vibration displacement in the *z* direction has a distribution of 1.5 wavelengths and has its maximum value at the tip. As the flexural vibration, the vibration displacement in the *x* direction has a distribution of ~0.625 wavelengths, is distributed only in the range of $L = 105$–119 mm, and is almost zero elsewhere. This shows that the plane-symmetric structure causes flexural vibration only in the notch portion and cancels it in the other portions. Also, the vibration displacement in the y direction was almost zero everywhere.

4. Conclusion

In this paper, we used finite-element analysis software to investigate how a source of complex ultrasonic vibration using a notch generates longitudinal–flexural vibration, and how a

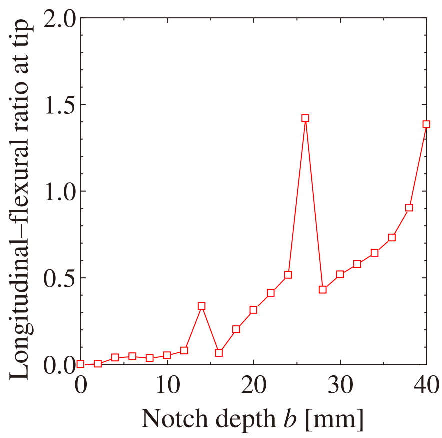

Fig. 2 Longitudinal–flexural ratio at tip versus notch depth *b*.

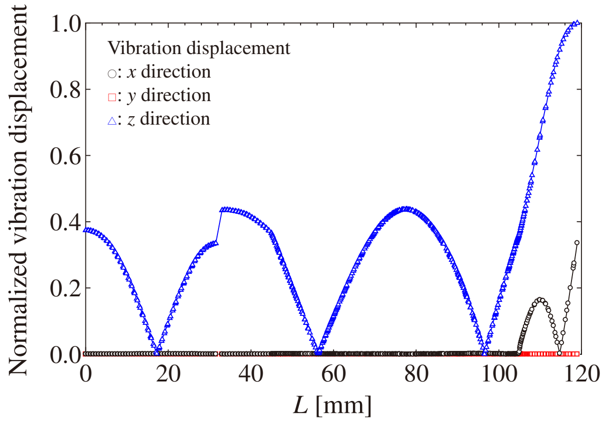

Fig. 3 Vibration displacement distributions of longitudinal–flexural vibration source for $b = 14$ mm.

plane-symmetric structure cancels the flexural vibration other than that at the notch part. The results showed that the longitudinal–flexural vibration source with the proposed structure can deliver longitudinal–flexural vibration at the notch part as the tip of the vibration source, and that the vibration source cancels the flexural vibration everywhere except at the notch part. As such, we have the prospect of realizing a source of complex ultrasonic vibration with a single oscillator that is both easy to fix and compact.

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