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# The consideration of effect of bending vibrations on ultrasonically forced insertion process
超音波圧入加工における曲げ振動効果の検討

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## 1. Introduction

At a forced insertion process, there are troubles of insufficient holding power and rod inclination caused by a partial plastic deformaition on the contact surface of rod and hole. The solution of these troubles and reducing the amount of insertion force necessary can be obtained by adding ultrasonic vibration. This technique has been well known, however, a report concering this technique is few, because this technique has been developed according to the specification at each site[1~5].

The purpose of this study is to develop an ultrasonically forced insertion (USFI) device with good performance and also to quantitatively estimate the effect of the ultrasonic vibration to the process[6~8]. In this paper, two types of horns with grooves on side faces of their tops to excite bending vibrations at USFI process were proposed and the effect of bending vibration to correct inclination of a rod was considered.

## 2. Processing materials

Samples for USFI experiments are shown in Fig.1. They were a metal rod 12mm with tolerance in diameter and a metal plate with a hole 12mm in diameter. A fit tolerance coresponded to the strong pressing in JIS defined grade.

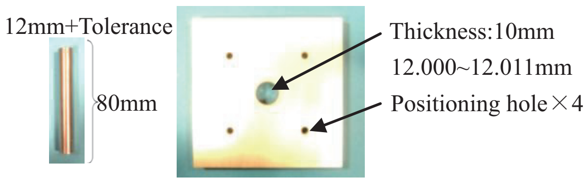



Fig.1Samples used for forced USFI experiments. (Left:Metal rod, Right:Metal plate)

## 3. Horn characteristics

### 3.1 Straight-grooved horn

The generation of a rotational vibration displacement at the top of the horn was tried to correct an inclined rod. **Figure 2** shows the top of a straight-grooved horn. Two pair of pararell straight grooves which are orthogonal to each other are formed at the side face near the top of the horn. When the top of the horn is pressed to an inclined rod, a rotational vibration will be generated by two bending vibration modes with different resonance frequencies.

Figures 2 and **3** show modal analysis results of longitudinal mode (L-mode) in Z-axis direction and bending ones (B-modes) X- and Y-axis directions, respectively, by using a finete element method analysis (ANSYS). From the analysis results, resonance frequencies of vibrations modes in Z-, X- and Y-axis directions are 26.7kHz, 32.9kHz and 32.5kHz, respectively. This horn may be tuned more for good performance.

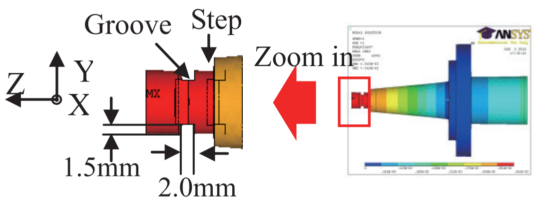
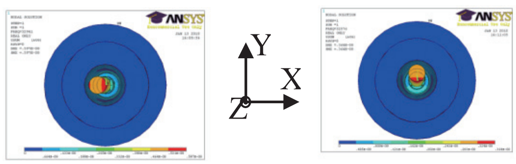



Fig.2 Modal analysis result of L-mode.




(a) X-axis. (b) Y-axis.

Fig.3 Modal analysis results of B-modes.

### 3.2 Circle-grooved horn

A circle-grooved horn with a concentric groove formed on the side face near its top was examined to confirm the effect of simple bending vibrations for corercting the inclinated rod. The horn was designed to make resonance frequencies of longitudinal vibration and bending ones close to each other.

**Figures 4 and 5** show modal analysis results of longitudinal vibration mode, bending ones of which resonance frequencies were 27.7kHz and 28.0kHz, respectively.

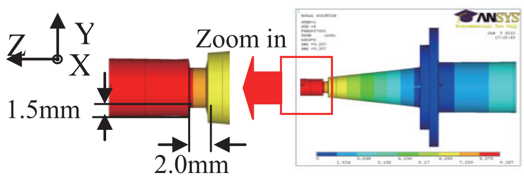
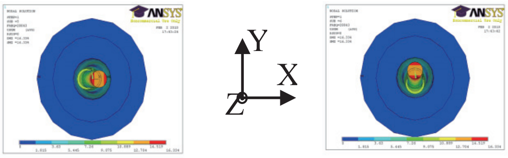



Fig.4 Modal analysis result of L-mode.




(a) X-axis. (b) Y-axis.

Fig.5 Modal analysis results of B-modes.

## 4. Vibration characteristics

Velocities of bendnig vibrations at the top of the horn were measured by two Laser Dopple Vibrometers(LDVs), as shown in **Fig.6.**

**Figures 7 and 8** show measurement results of vibration velocities and their Lissajous figures on the straight-grooved horn and circle-grooved one. Measured conditions were that pressing force was 800N and applied voltage to bolt-tightend longitudinal transduser (BLT) was 180V$_{rms}$. A large difference was not in the amplitude of vibration velocities of both horns. From Lissajous figures, a rotational vibration were generated on the straight-grooved horn, but the top of the circle-grooved one vibrated almost straight .

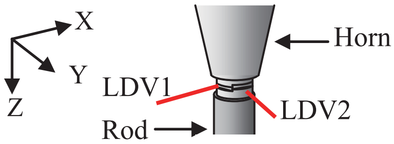
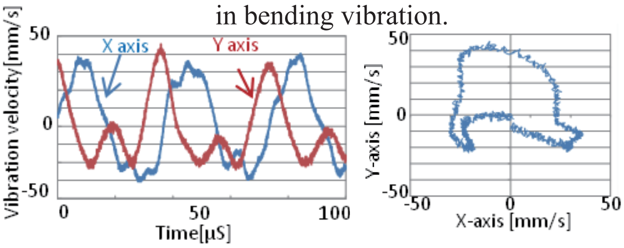
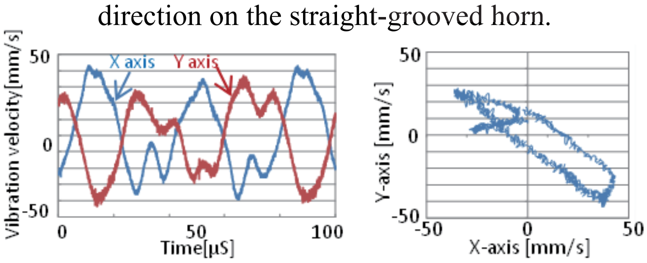



Fig.6 Measurement method of velocity in bending vibration.




(a) Measured at 26.9kHz. (b) Lissajous figure.

Fig.7 Vibration velocities in the bending direction on the straight-grooved horn.




(a) Measured at 26.9kHz. (b) Lissajous figure.

Fig.8 Vibration velocities in the bending direction on the circle-grooved horn.

## 6. Correction of inclination of rod

USFI processes using the both types of horns were examined by the same processing sample. **Table 1** show results of USFI experiments, which were carried out until it becomes impossible to plunge.

An inclined metal rod was able to be corrected by both horns. Therefore, the circle-grooved horn has also the function of inclination correction as well as the straight-grooved one. Hence, bending vibrations in one direction might be enough for correction of an inclined rod. Moreover, the design of the circle-grooved horn is easier than that of the straight-grooved one.

Table 1 Results of USFI experiments.

| Horn type | Straight-grooved | Circle-grooved |
|---|---|---|
| Rod diameter [mm] | 12.025 | 12.025 |
| Hole diameter [mm] | 12.000 | 12.000 |
| Pressing force [N] | 800 | 800 |
| Depth [mm] | 3.56 | 3.74 |
| Inclination [deg] | 0.40 | 0.20 |

## 5. Conclusion

The straight-grooved horn and the circle-grooved one were developed for exciting the bending vibration modes at forced insertion process. The effect of bending vibrations on USFI process was considered by different types of grooves.

Amplitudes of the bending vibration velocities at the top of both horns were almost the same. A rotational vibration was hardly generated on the circle-grooved horn. However the horn corrected an inclined rod. Hence, it was found that rotational vibration is not necessary to correct an inclination of a rod, and that a single bending vibration might be enough for the inclination correction in USFI process.

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