Proceedings of the International Symposium on Music Acoustics
(Associated Meeting of the International Congress on Acoustics)
25-31 August 2010, Sydney and Katoomba, Australia

Percussion Instruments with Plural Sounds using Orthogonal Modes

Kojiro Nishimiya (1), Naoto Wakatsuki (1), and Koichi Mizutani (1)

(1) University of Tsukuba, Tennodai 1-1-1, Tsukuba, Ibaraki, Japan

PACS: 43.75.Kk

ABSTRACT

Percussion instruments of axisymmetry, like bell, have two degenerate modes which have an identical eigen frequency. A cup without handle is of such a case. On the other hand, a cup with handle is able to make plural sounds by selecting hitting point, because the handle behaves as a mass loading and the degenerate modes are separated. This means that we can choose the exciting eigen mode since the antinode point of one mode overlaps the node point of another mode. In our research, we aim to create a percussion instrument making plural sounds by using the principle explained above. In this paper, the shapes of such instruments are designed using finite element method (FEM). We investigated the relationship between the hitting point and the sound in the shape by the analysis results of FEM. We made the prototypes of the porcelain and examined them by impact test. As a result, the experimental and numerical results agreed with each other. The shape we designed can make more plural sounds than the cup with handle using on a daily basis. We plan to investigate the relationship between the tone and the shape, and we aim to create the new percussion instrument having abundant expression.

INTRODUCTION

Various musical instruments have been developed all over the world based on our daily life. Especially, percussion instruments have a long history. ‘Hands and foot’ and ‘wood-bar and log’ are believed to be the oldest percussion instruments since we invented the tools. Such musical instruments have been sophisticated as our technology evolved. Percussion instruments basically play single tone at the single object. However, ‘Chime-Bells’, which has double tone at the single object, existed in ancient China. In this instrument, the double pitch is caused by the separation of degenerate mode. Although, the percussion instruments have evolved with the time, double-pitched instruments, like ‘Chime-Bells’, have not become popular up to the present date. Correspondingly, we regard a cup with handle using on a daily basis. The cup also has double pitch caused by the separation of degenerate mode. Through our research, we aim to create the new percussion instrument having abundant expression.

In this paper, we analyzed the shape with plural sounds using orthogonal modes, caused by the separation of degenerate mode, by FEM. Especially, we examined the relationship between the each eigen-mode shape and selective tone. We also made a prototype by porcelain and experimented in the impact test. Hereby, we verified the validity of the result in FEM analysis.

PARAMETER MEASUREMENT OF PORCELAIN

In this paper, we use the porcelain as the material of musical instruments. It is desired that the parameters, the density, Young ratio, and Poisson’s ratio, are measured for FEM analysis [1]. We made a rectangular bar by porcelain and measured these parameters by impact test. Figures 1 and 2 show the rectangular bar for the impact test and the impact test condition, respectively. The rectangular bar is 228 mm long, 29 mm wide, and 5 mm thickness. The impact points and measurement points are selected to excite the various eigen-modes and to verify the difference between the bending vibration and the torsional vibration, respectively. A plastic ball is shot to the impact point, and the sound of collision is recorded by a microphone (WM-62PC, Panasonic). The sampling frequency is 25 kHz. The measured parameters for FEM analysis, the density, Young ratio, and Poisson’s ratio, are shown in Table 1. These parameters measured as follows: the density is obtained by the volume and the mass. Young ratio, E, is obtained by the bending vibration eigen-frequency equation in the case of the long bar as shown;

$$f_n = \frac{\alpha_n^2}{l^2}\sqrt{\frac{EI}{\rho S}} \qquad (n = 1,2,3\cdots), \tag{1}$$

$$I = \frac{bh^3}{12}, \tag{2}$$

where S, l, b, h, and ρ are the cross-section area, the length, the width, the thickness and the density of the bar, respectively. The coefficient depending on the order of the vibration mode is α. Among eigen frequencies, f_n, we use the bending vibration eigen frequency of 1st order mode obtained from the impact test, as shown in **Fig. 3**. Figure 3 shows the power spectrum of the impact sounds at each measurement point.

The spectrum of d1, d2, and d3 are closely related with the bending vibration mode. The spectrums of d1, d4, and d5 are also closely related with the torsional vibration mode. The bending vibration of 1st order mode has the antinode point at the edge and the center and has the node point in the middle of the center and the edge of the bar. The torsional vibration of 1st order mode has the antinode point at the edge and has the node point at the center of the bar, diagonally. Therefore we can distinguish the bending mode and torsional mode using the difference between the tendencies of the group of d1, d4, and d5 and the group of d1, d2, and d3. The Poisson's ratio is associated with the rigidity. Because the torsional vibration in the bar is dependent on the Poisson's ratio, we regard the torsional vibration in the bar. The torsional vibration eigen frequency is obtained by using the experimental results in Fig. 3.

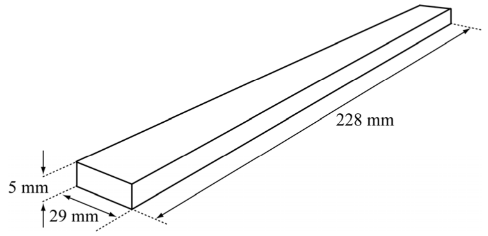

Figure 1. Rectangular bar made of porcelain for the measurement of parameters.

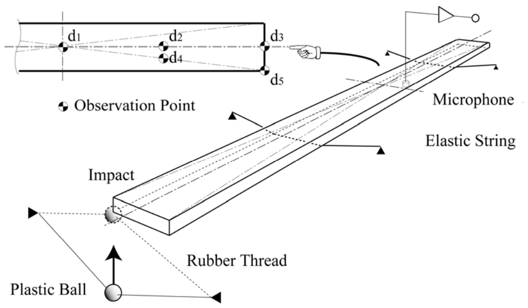

Figure 2. Condition of impact test; measurement points and hitting point.

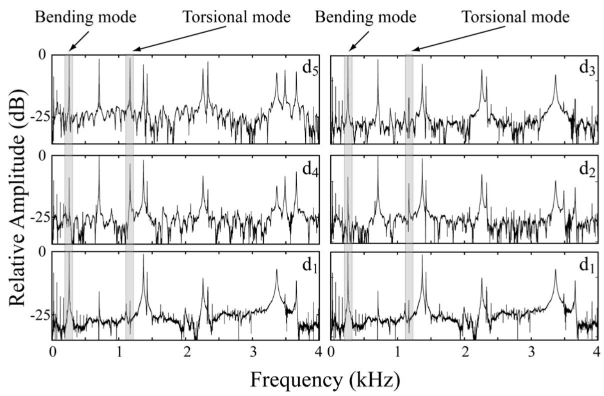

Figure 3. Sound power spectrum at measurement points.

Table 1. Parameters of porcelain sample

Young ratio E	15.7 GPa
Poisson's ratio	0.253
Density ρ	2294 kg/m^3

FEM ANALYSIS FOR PROPOSAL MUSICAL INSTRUMENTS

Separation of degenerate mode

We aim to make plural sounds with one structure in the percussion instruments. In this research, we regard the separation of the degenerate mode [2]. One of such examples is a cup with handle [3]. The cup is able to make plural sounds by selecting hitting point, because the handle behave as a mass loading and the degenerate modes are separated. This means that we can choose the excited eigen mode since the antinode point of one mode overlaps the node point of another mode. In fact, the two modes are orthogonal. The vibration modes in the cup are shown in **Fig. 4.**

Design of Musical Instruments with Plural Sounds by FEM

We analyzed the shape that has more sounds than the cup with handle using FEM (COMSOL Multiphysics). The designed shape is shown in **Fig. 5**. Two cups are attached to each other sharing their bottoms and handles. We calculated the eigen-modes of the designed shape using FEM. The vibration mode shapes are shown in **Fig. 6**. The vibrations of the upper and lower cups are shown as U and L, respectively. The obtained results show that the separation of degenerate modes occurs in both the upper and lower cups. Therefore, we found out the possibility that the four tones can be generated by selecting the hitting points. The hitting points assumed are indicated as h1 ~ h4 as shown in Fig. 5. These hitting points are selected to overlap the antinode and node point of each 1st order mode.

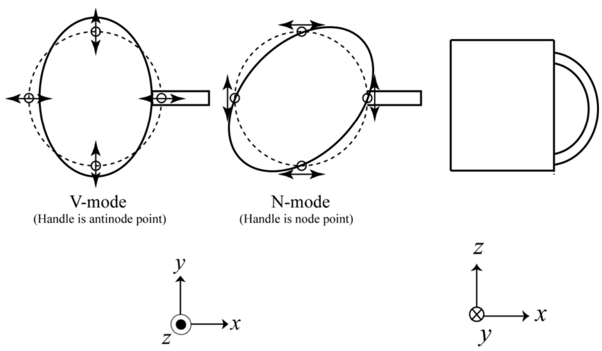

Figure 4. Separation of degenerate modes in cup with handle.

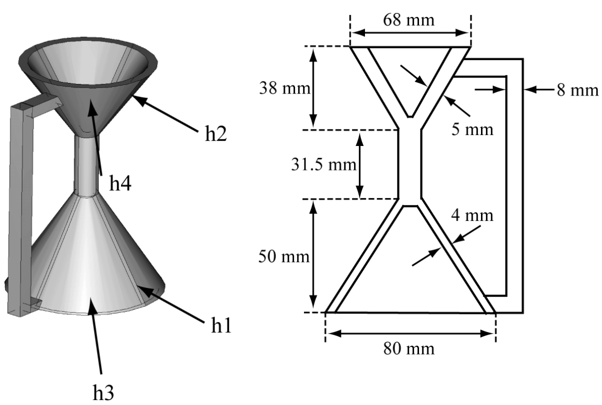

Figure 5. Design of musical instrument with plural sounds.

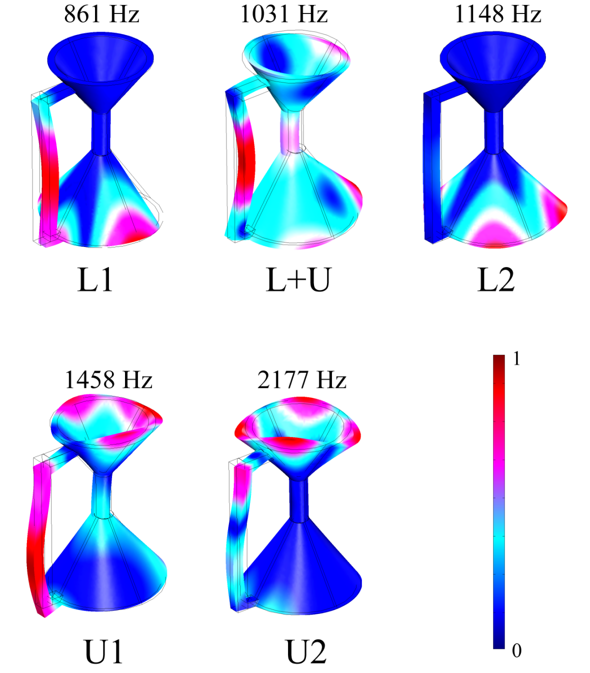

Figure 6. Eigen mode frequency and shape of the designed structure.

EXPERIMENTS FOR PROPOSAL MUSICAL INSTRUMENTS

Proposal musical instruments made of porcelain

We made a prototype by porcelain and performed the impact test. The photograph of the prototype by porcelain is shown in **Fig. 7**. The structure is designed almost the same as the object for the FEM analysis.

Impact test

In this experiment, we performed the impact test in the same conditions of FEM analysis. Obtained results in experimental impact test are shown in **Fig. 8**. The microphone (H2, ZOOM) is placed at 200 mm distant from the object. The sampling frequency of the microphone is 44.1 kHz. Figure 8 shows power spectrum distribution of collision sounds in each hitting points, h1 ~ h4. The grey-colored bars show the peak of dominant eigen-mode. We can confirm that the laegest peak differs depending on the hitting point. We also confirmed that the pitches of the object under each hitting conditions are also different. The hitting points, h1 and h3 and other points, h2 and h4 excite the vibrations of upper cups, U1 and U2, and lower cups, L1 and L2, respectively. Compared to the results of the FEM analysis, the experimental results are coincided with regard to the vibrations of the lower cup, L. However, regarding to the upper cup, U, the desirable results cannot be obtained. One of the reasons is considered that the vibration of the small cup becomes harder to hear and the vibration mode shape become deformative when the size of two cups are too different. In FEM analysis, the vibrations of upper cup U are obtained at 1458 and 2177 Hz. However, when we hit the points, h2 and h4, the vibration of the both cup, L+U, and that of the upper cup, U1, are obtained, respectively, although these points are expected to excite the vibration of upper cup, U.

In this analysis and experiment, we verified that we could make more plural sound than the cups with handle. However, we also found a problem like above the difference of the size of two cups.

Figure 7. Prototype made of porcelain.

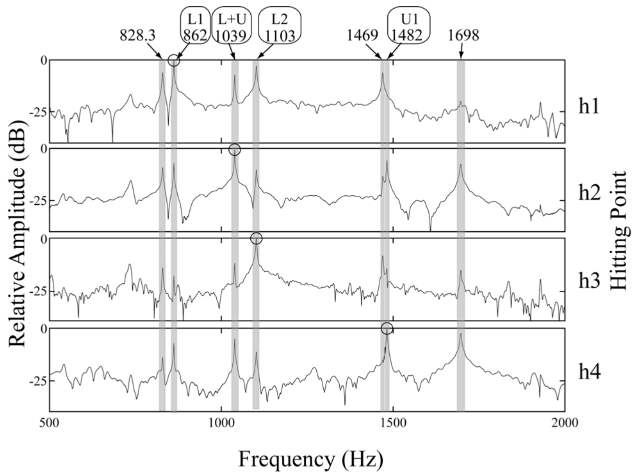

Figure 8. Power spectrums of vibration displacement in the proposal musical instruments at hitting points.

CONCLUSIONS

We aim to make plural sounds with the single object like 'Chime-Bells', regarding the cup with handle. The cup also has plural sounds with slightly different pitches caused by the separation of degenerate mode. In this paper, we designed the shape which makes more sounds than the cup with handle using FEM. We consider the porcelain as the material of the object. We measured the parameters, the density, Young ratio, and Poisson's ratio, to analyze using FEM. Each eigen-mode shape is obtained by using the parameters. Furthermore, to confirm the validity, we made a prototype by porcelain and carried the impact test. As a result, we verified that we could make more plural sound than the cups with handle. However, the obtained results suggest the possibilities that the vibration of the smaller cup become harder to hear and the vibration mode shape become deformative when two cups are too different in size. As one of the further works, we will investigate the relationship between the shapes of two cups, quantitatively. Additionally, we will not only consider the pitch but also the tone of the instruments.

REFERENCES

1 Kojiro Nishimiya, Koichi Mizutani, Naoto Wakatsuki and Shigeru Tokoyoda, "Sound Estimation of Porcelain Percussion Instruments Based on FEM", *Proc. of the Technical Committee on Musical Acousics.*, MA2006-43, 91-94 (2006)[in Japanese]

2 Kojiro Nishimiya, Naoto Wakatsuki and Koichi Mizutani, "Sound Estimation of Percussion Instruments with Plural Tones Using Multimode", *Proc. Spring Meet. Acoust. Soc. Jpn.*, 887-888 (2008)[in Japanese]

3 Kojiro Nishimiya, Koichi Mizutani, and Naoto Wakatsuki, "Control of Acoustic Characteristics of Porcelain Dishes Used for Musical Instruments Based on FEM Modal Analysis", *Int. Symp. on Music Acoust.*, (2007)