9-12 AUGUST 2015
inter.noise 2015
SAN FRANCISCO, CALIFORNIA USA

Sound quality analysis of cymbals

Toshiki NAKANISHI[a)]
Graduate School of Mechanical Engineering, Hosei University
3-7-2, Kajinocho, Koganei-shi, Tokyo, 184-8584, Japan

Tatsuhito AIHARA[b)]
Mitsuo IWAHAR[c)]
Department of Mechanical Engineering, Hosei University
3-7-2, Kajinocho, Koganei-shi, Tokyo, 184-8584, Japan

Tetsuya SAKAI[d)]
Meiji Institute for Advanced Study of Mathematical Sciences, Meiji University
1-1-1, Higasi-Mita, Tama-ku, Kawasaki, Kanagawa 241-8571 Japan

Gaku MINORIKAWA[e)]
Department of Mechanical Engineering, Hosei University
3-7-2, Kajinocho, Koganei-shi, Tokyo, 184-8584, Japan

ABSTRACT

Many researches on sound quality improvement have been conducted in various musical instruments focusing on human audibility. However, current researches indicate that ultra-high-frequency over 20 kHz called human audibility limit affects sound quality. In addition, clarifying the mechanism of generating sound from the view point of manufacturing process is necessary to improve the sound quality of musical instrument. Therefore, the main purpose of this research is to clarify the effect of the cymbal shape on the sound quality by using numerical simulations and experiments including over human audibility range. The numerical simulations are carried out to calculate the sound pressure of various cymbals using the Finite Element Method and the velocity potential method by varying the length of the center part of the cymbal called cup, which is well known as important portion to generate the high frequency sound in manufacturer's experience. Recording experiments are also conducted with actual cymbals equivalent to the simulation models. As a result, the simulation results are found to correspond with the experimental ones.

[a)] email: 10x0078@stu.hosei.ac.jp
[b)] email: tatsuhito.aihara@hosei.ac.jp
[c)] email: iwahara@hosei.ac.jp
[d)] email: tetsuya_sakai@mth.biglobe.ne.jp
[e)] email: minori@hosei.ac.jp

Moreover, the numerical simulations are performed to clarify the effects of the design parameters such as the height of the center on the sound quality.

1 INTRODUCTION

Recently, lower the noise level and reducing the vibration is important matter in various industrial products. Meanwhile, sound quality improvement is essential for musical instruments in order that generating sound becomes performance. Because of this, many researches on sound quality improvement have been conducted in various musical instruments. However, these researches have some problems.

1. Conventional researches[1,2] on sound quality improvement is performed within an audible frequency range below 20 kHz. However, current researches[3,4,5] indicate that ultra-high-frequency over 20 kHz called human audibility limit affects sound quality. Therefore, considering ultra-high-frequency over 20 kHz is necessary to improve sound quality.
2. Clarifying the mechanism of generating sound from the viewpoint of manufacturing process is necessary to improve the sound quality of actual musical instrument.

Mentioned above, the subject of this study is cymbals which generate ultra-high-frequency over 20 kHz called human audibility limit and focus on the shape which is one of the elements to constitute cymbal in order to contribute to manufacturing process. Furthermore, the effect for the cymbal shape on the sound quality is clarified by using numerical simulations and experiments including over human audibility range.

2 NUMERICAL SIMULATION

2.1 Flow of numerical simulation method

The numerical simulation method[6,7] for calculating the sound pressure of cymbal is explained in this chapter. First, three dimensional of finite element models of cymbals are created and natural frequencies and natural modes are calculated by eigenvalue analysis. Secondly, natural frequencies, natural modes and modal damping ratio are inputted into the radiation sound forecast program. Modal damping ratio is identified by experimental modal analysis because it cannot be found by theoretical calculation. Based on these data, the vibration velocity of all nodes of the finite element model surface is calculated by theory modal analysis. The sound is calculated using the velocity potential method from that vibration velocity and the geometric shape of model. The surface vibration velocity and the sound are calculated in a frequency domain and frequency response function is calculated. Figure 1 shows this flowchart of numerical simulation.

2.2 Calculation of the sound by velocity potential method

The radiation sound forecast program calculates the direct sound, reflected sound and diffracted sound. Here, influence of the reflected sound and the diffracted sound are little in this case. Each calculation methods are described as follows.

2.2.1 Calculation of the direct sound

Equation (1) shows the velocity potential of the sound field in the half-space of the wall surface forward in case point sound source exists on the surface of rigid wall.

$$\Phi = \frac{A_0}{2\pi r} e^{j(\omega t - kr)} \tag{1}$$

where

Φ : Velocity potential of the sound field
r : Distance from point sound source
A_0 : Strength of point sound source
k : Wavenumber
j : Imaginary number

Expanding eqn. (1), following equation can be obtained.

$$p = \rho \frac{\partial \Phi}{\partial t} = j\omega\rho\Phi \tag{2}$$

where

p : Sound Pressure
ρ : Density of medium

From eqn. (2), sound pressure can be calculated. The vibration surface is divided into micro area elements in case vibration surface emits the sound. Direct sound by its surface is solved by considering the each micro area element emitting sound as new point sound source. Figure 2 shows calculation method of the direct sound.

2.2.2 Calculation of the reflected sound and the diffracted sound

Figure 3 and 4 show each calculation method of sound. Reflected sound and diffracted sound are calculated by using Huygens' principle. In this calculation method, the sound from sound source is caused to diffuse reflection with reflection surface. Wave front expanded from sound source to the edge is divided into micro area elements, and reflected sound by the vibration of the surface is solved by considering the each micro area element emitting sound as new point sound source. The calculation method of diffracted sound is also performed similarly, too

3 EXPERIMENT

3.1 Vibration examination

The modal damping ratio is necessary in numerical simulation. However, the formulation of the damping in theory is impossible to interact with various causes such as friction. Therefore, value of damping is identified by analyzing the experimental data which was measured in the vibration examination. The method to clarify vibration characteristic for object by analyzing the experimental data is called as experimental modal analysis. However, identifying modal damping ratio by the nonlinear optimization method is difficult in this case because the cymbals have much number of the natural mode. Therefore, modal damping ratio is manipulated to correspond with experiment in this study.

3.1.1 Experimental method

The cymbal is vibrated with the impulse hammer to measure the surface vibration velocity in the Laser doppler vibrometer which installed 0.15m from the cymbal. The measurement with laser is possible to obtain high reliability because it is not affect to the cymbal to be unnecessary to touch it. Figure 5 shows experiment environment.

3.1.2 Identifying modal damping ratio

Figure 6 shows comparison result of the surface vibration velocity between experimental result and numerical simulation one. As shown in Fig.6, the result of the calculation using manipulated modal damping ratio is a tendency similar to the experimental results. However, it is difficult to identify the modal damping ratio because the cymbals have natural frequency more than 3500 in the frequency domain to 40kHz. Therefore, the modal damping ratio is not adjusted at each natural frequency, but it is manipulated that the graph tendency of the calculation in all frequency band is similar to experimental result shown in Fig.7 in this study.

3.2 Sound recording

Sound recording is conducted in actual cymbals equivalent to analytical models to compare with numerical analytical results and experimental ones. Figure 8 and Table 1 show the dimensions of each cymbal. As shown in Table 1 and Fig.8, the length of the center part of the cymbal called as cup are mainly different. This difference may affect the frequency response characteristics including the ultra-high-frequency sound. Figure 9 shows recording position and beating point. The recording conditions are as follows. Analysis frequency is 50kHz which is limit of the sound level meter unit and measurement time is 0.64 sec due to be early damping of the ultra-high-frequency. In addition, the frequency response function was calculated by the sound recording results and the measurement of the exciting force results to make a condition same as the numerical results.

4 RESULTS

4.1 Experimental results

Figure 10 show the spectrogram of each cymbal in experiment. The horizontal axis of the spectrogram is time and the vertical axis is frequency. As shown in Fig.10, ultra-high-frequency over human audibility damps instantly. Figure 11 shows the frequency analysis result of experiment. However, Fig.10 and Fig.11 are difficult to detect the difference of the high frequency sound. Therefore, 1/1 octave band analysis are conducted to clearly compare the sound pressure. This analysis is most suitable for the sound evaluation in considering acoustic sense because frequency response characteristic to feel in human ear are like equal ratio. In addition, the calculation of the sound pressure level for measured sound in each band is possible through a band filter determined in a standard.

4.2 Comparing experimental results and numerical calculation ones

It is possible to detect the difference of the frequency response characteristics by using octave band analysis. Therefore, comparison of experimental results and numerical calculation ones are conducted to verify the analysis method. Figures 12(a) and (b) show the numerical results and the experimental ones. As shown in Fig.12, the tendency of the graph and relative merit of the sound pressure level in two cymbals of numerical calculation results correspond with experimental ones and the effectiveness of the numerical analysis is clarified. In addition, the length of the center mainly affects the high frequency band.

4.3 Effect of the design parameter

The influence on high frequency sound by the other design parameters is examined by numerical calculation. Here, influence of the height of the cup is confirmed by using radiation sound forecast program. Table 2 shows that the model dimensions changed only height on the basis of Model 2. As sown in Table 2, the height of the cup is fluctuated from Model 2 by 20%. Figure 13 shows the results of numerical analysis of three models. As shown in Fig.13, Model B generates sound higher than Model A in all frequencies band. However, Model C generates sound lower than Model B in the high frequency band.

5 CONCLUSIONS

The main purpose of this research is to clarify the effect of the cymbal shape on the sound quality by using numerical simulations and experiments including over human audibility range. This study can be summarized as follows:

1. Simulation method for calculating the sound pressure of cymbals by using the Finite Element Method and the velocity potential method is proposed.
2. The experiments are carried out using the actual variant cymbals. The experimental result shows the difference in the shape of the cymbal affects the frequency response characteristics including the ultra-high-frequency sound.
3. The effectiveness of the numerical analysis is clarified by comparing the experimental results with the numerical ones. As a result, it is possible to connect to the development of products improvement by clarifying the mechanism of generating sound from the view point of manufacturing process.
4. The numerical simulations are performed to clarify the effects of the height of the center on the sound quality. The height of the center is proved to affect in the sound pressure level in all frequency band.

6 ACKNOWLEDGEMENTS

We would like to express our gratitude to Koide company cooperated to make cymbal samples

7 REFERENCES

1. Tsuji K, Kobayashi A, Ishiwata T, Iwahara M, Minorikawa G and Nagamatsu A, "Research for the improvement of cymbal sound quality", JSME annual meeting, vol.5, 125-126(2003) in Japanese

2. Fujitsuka K, Kokubun K, Oe K, Iwahara M, Tanaka Y and Minorikawa G, Vibration analyses of a Japanese traditional stringed instrument called shamisen, internoise (2012)

3. Oohashi T, Nishina E, Honda M, Yonekura Y, Fuwamoto Y, Kawai N, Maekawa T, Nakamura S, Fukuyama H and Shibasaki H, "Inaudible high-frequency sounds affect brain activity: hypersonic effect", Journal of Neurophysiology, vol. 83: 3548-3558 (2000)

4. Yagi R, Nishina E, Honda M and Oohashi T, "Modulatory effect of inaudible high-frequency sounds on human acoustic perception", Neuroscience Letter, vol. 351: 191-195 (2003)

5. Yagi R, Nishina E and Oohashi T, "A method for behavioral evaluation of the "hypersonic effect"", Acoustical Science and Technology, vol. 24: 197-200 (2003) in Japanese

6. Iwahara M, Kubota Y, Kubota K and Nagamatsu A "Accuracy Improvement of FEM Model for Impact Sound Prediction of Golf Clubs", Japan Society of Sports Industry vol.23, No.1 1-10 (2013) in Japanese

7. Saitou Y, Iwahara M, Kubota K and Nagamatsu A, "Accuracy Improvement of Batted Ball Sound Prediction for Golf Clubs", Japan Society of Sports Industry vol.21, No2, 97-110 (2011) in Japanese

Table 1 – Dimension of the cymbals used in experiment

Name	t, (mm)	D_b , (mm)	D_c , (mm)	h, (mm)	r, (mm)	h_1, (mm)
Model 1	1.55	144.0	58.5	36.8	6.2	20.1
Model 2	1.45	131.7	70.8	39.5	6.2	21.6

Table 2 - Dimension of the cymbals used in numerical simulation

Name	t, (mm)	D_b , (mm)	D_c , (mm)	h, (mm)	r, (mm)	h_1, (mm)
Model A	0.88	131.7	70.8	39.5	6.2	17.3
Model B	0.88	131.7	70.8	39.5	6.2	21.6
Model C	0.88	131.7	70.8	39.5	6.2	26.0

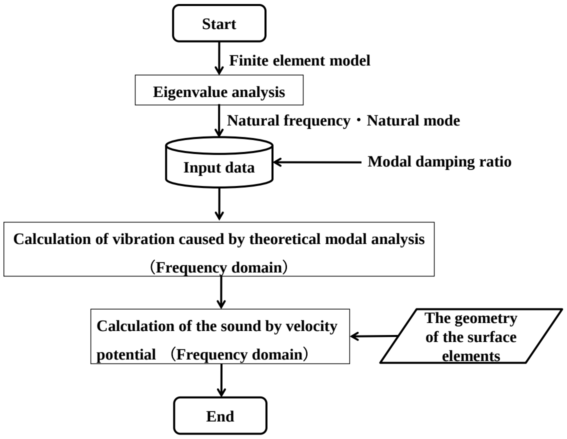


Fig.1 – Flowchart of the numerical simulation

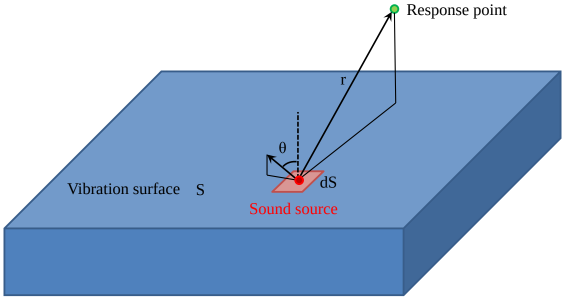


Fig.2 - Calculation method of direct sound

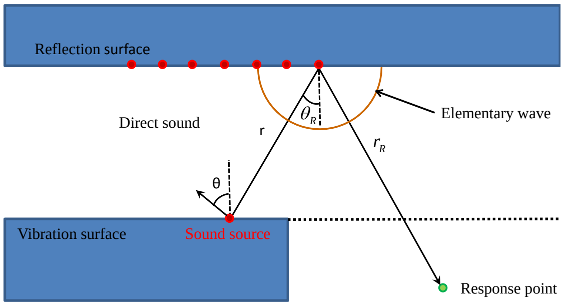


Fig.3 - Calculation method of reflected sound

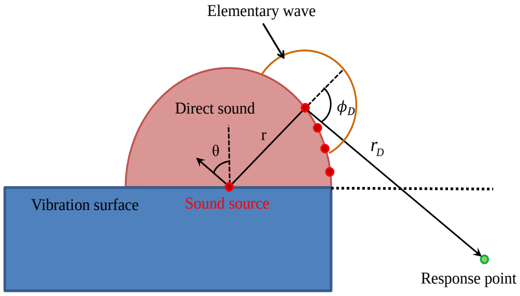


Fig.4 - Calculation method of diffracted sound

Fig.5 - Measure the surface vibration velocity

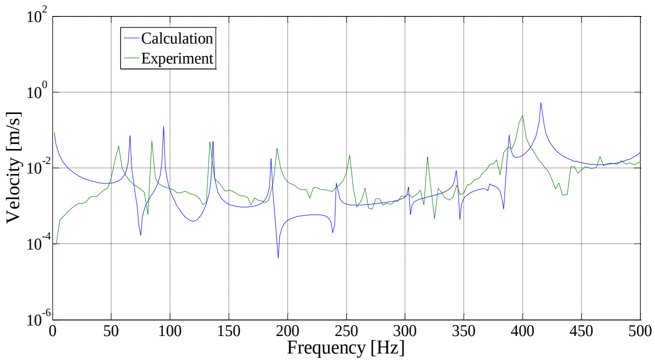


Fig.6 - Comparison result of the surface vibration velocity to 500Hz

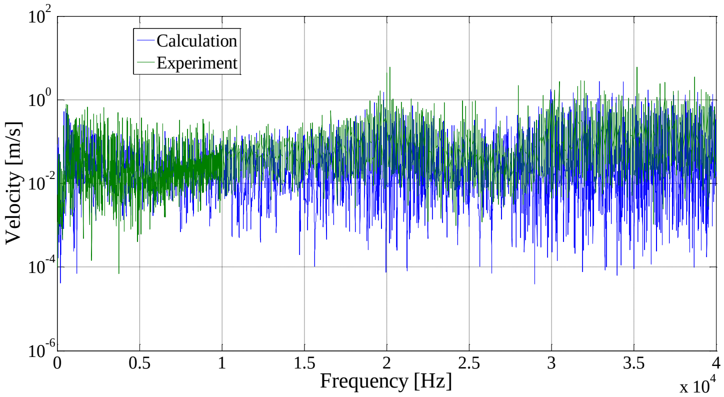


Fig.7 - Comparison result of the surface vibration velocity to 40kHz

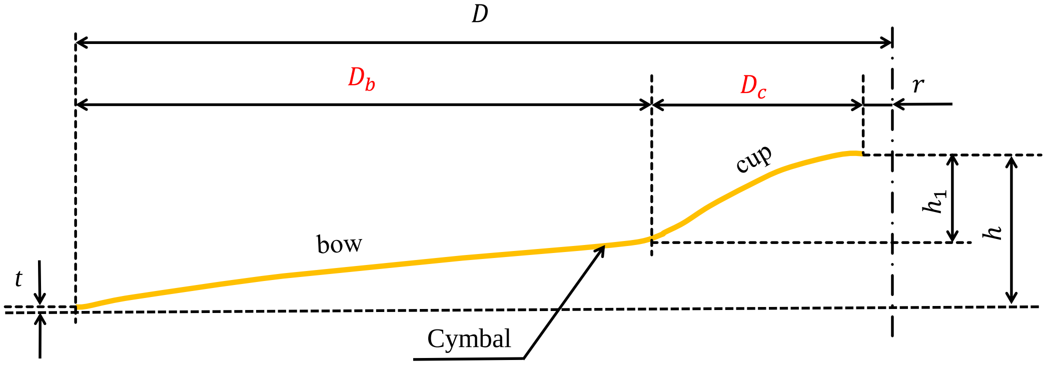


Fig.8 – Cymbal shapes

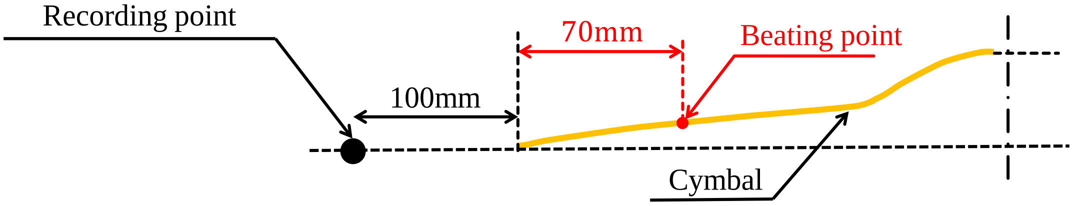
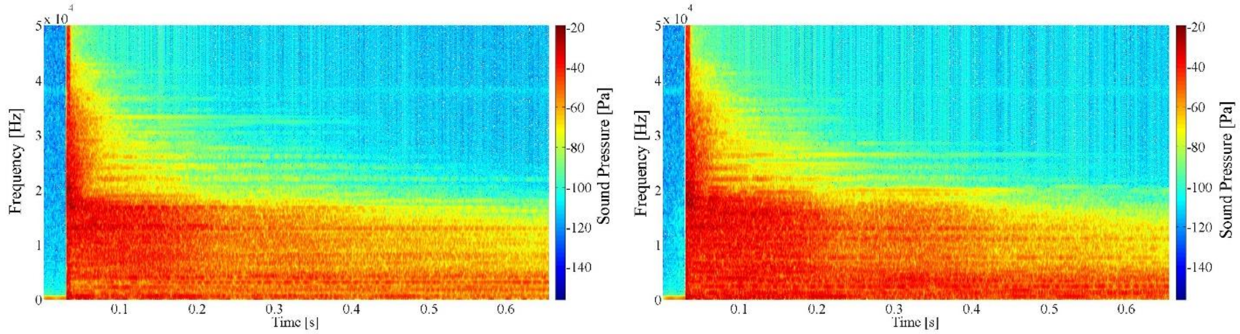


Fig.9 – Sound recording point



(a) Model 1

(b) Model 2

Fig.10 - Spectrogram of cymbals sound

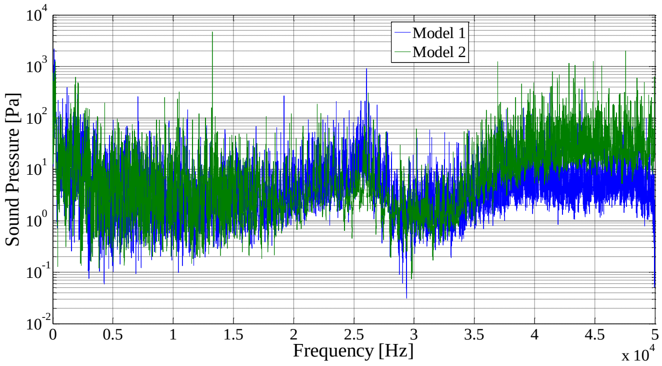
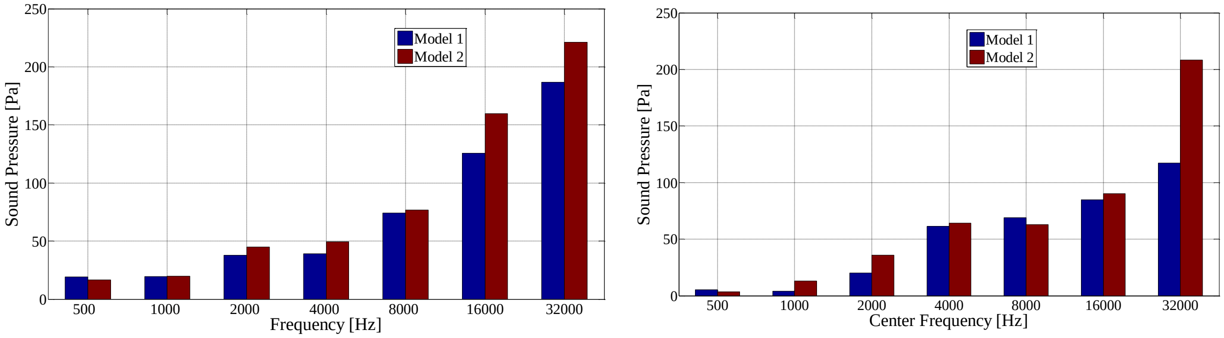


Fig.11 - Frequency domain Sound Pressure of two Cymbals



(a) Numerical result *(b) Experimental result*

Fig.12 - Frequency domain Sound Pressure of two Cymbals

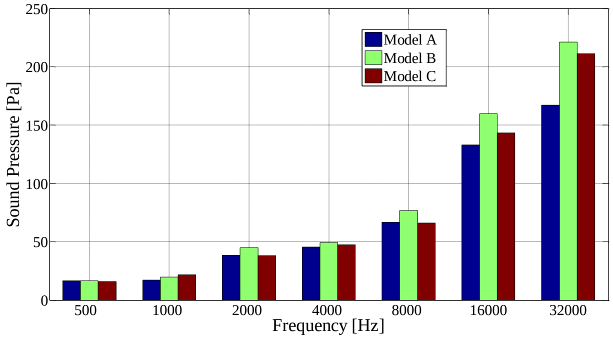


Fig.13 - Frequency domain Sound Pressure of three models