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RECONSTRUCTION OF THE SPATIAL RADIATION CHARACTERISTICS OF LARGE KOREAN BELL

Wan-Ho Cho[1*] **In-Jee Jung**[1] **Jung-Han Woo**[2]
Bong-Ki Kim[3] **Jeong-Guon Ih**[3]
[1] Division of Physical Metrology, Korea Research Institute of Standards & Science, Republic of Korea
[2] Department of System Dynamics, Korea Institute of Machinery & Materials, Republic of Korea
[3] Department of Mechanical Engineering, Korea Advance Institute of Science & Technology, Republic of Korea

ABSTRACT

The conventional recording of sounds radiating from a specific source provides limited information at the measurement positions and it is not possible to obtain the sound at other positions. Hence, an approach based on model construction is required to reproduce the sound at any arbitrary position, radiating from the source. In this study, the spatial radiation characteristics of the large Korean bell named "Divine Bell of King Seongdeok" were reconstructed using the near-field acoustic holography based on the equivalent source method. The "Divine Bell of King Seongdeok" is famous for its unique sound characteristics, including a beating sound produced by two dominant modes at close frequencies. It is also known that its radiation characteristics depend on the direction, even the main frequency component around 60 Hz. The measurement was conducted using 120 microphones in the near field, and the equivalent source model was constructed with a spherical radiation function. The directional dependency of the radiated sound field including the beating characteristics was accurately reproduced by this model through the superposition of each mode frequency.

Keywords: *bell, spatial radiation characteristic, acoustic holography*

[*]***Corresponding author***: *chowanho@kriss.re.kr.*

1. INTRODUCTION

The "Divine Bell of King Seongdeok" is the traditional type of large Korean bell and it is famous for its unique sound characteristics, including a long-lasting beating sound produced by two dominant modes at close frequencies. From this reason, many research works have been conducted to investigate the characteristics and principle of the generated sound [1-3].
Recently, activities to record these cultural heritages and preserve them in digital media have been actively carried out. However, since the perceived sound is dependent on the listening position, a model-based approach [4-8] is required to preserve and reproduce the sound in all positions, including those not measured. In this study, the near-field acoustic holography based on the equivalent source method (ESM) [7, 8] is applied to preserve the spatial radiation characteristics of "Divine Bell of King Seongdeok" and the feasibility of approach is investigated.

2. MEASUREMENT

2.1 Measurement setup

In order to reconstruct the spatial radiation characteristics of the bell, a measurement system using a multi-channel microphone array was constructed. An important consideration in the configuration of the measurement system is to perform simultaneous measurements on the measurement plane that surrounds the entire surface of bell under near-field conditions.
In most of practical situation, there are limits of the resources of microphones and data collection systems. Nowadays, this problem has been greatly improved by the

advances of measurement instruments, but there are still practical limitations in measuring large structures of several meters with sufficiently small spacing. In addition, when the structure of the measurement system is enlarged and the density is increased, the influence of scattering by this increases, which can act as a cause of error.
For this reason, in the past, a method of measuring sequentially by moving the microphone array position was applied [9]. The basic assumption of this approach is that the response of the system is repeated identically. However, it is very difficult to hit accurately and repetitively in case of excitation as in the real situation. This is due to the instability of hitting, the non-uniformity of the surface of the bell, and its own movement. A generally applied method to solve this problem is to directly measure the input force by attaching a sensor capable of measuring the force to the excitation surface. However, if a sensor is directly attached to a hammer or bell surface, the system response can be changed and it also can make damage on the surface. Therefore, it is desirable to obtain complete radiated sound field data with one simultaneous measurement.

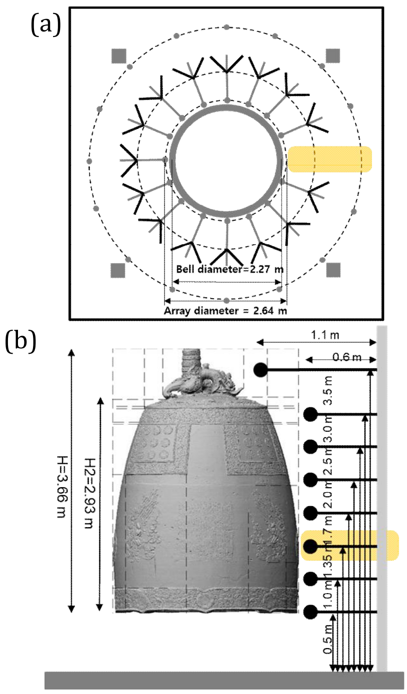

Figure 1. Configuration of the measurement setup: (a) horizontal plane at the height of hammer, (b) vertical plane.

Figure 1 shows the configuration of measurement setup. On the horizontal plane, the microphones were placed at equal intervals of 22.5° on the circumference except for the hammer position, and the distance between the microphones was about 0.52 m. In the case of the uppermost part, it was placed 0.5 m inward in the radial direction. Figure 2 shows the photo of the measurement system after installation was complete with 120 channels of microphones.

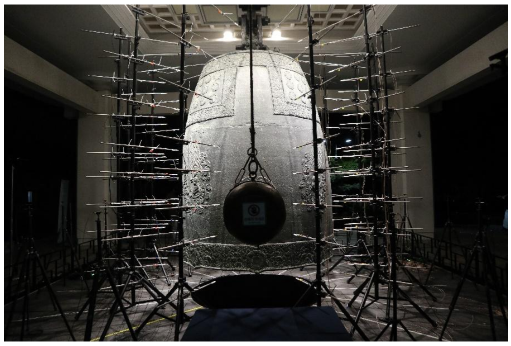

Figure 2. Photo of the measurement setup.

2.2 Result

Figure 3 shows an example of the signal measured at the nearest microphone from hitting point. The distinct beating characteristic can be observed in the time domain signal (Fig. 3(a)). The major mode frequencies are listed in Table 1. Figure 4 shows the distribution of time domain signal on the plane at the height of hammer. It is observed that the modulation amplitude of beating is different according to direction. To investigate the reason of directional dependency, the distribution of mode shape at beating frequencies were observed.

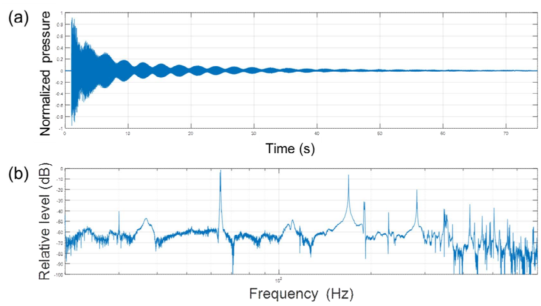

Figure 3. Example of the measured signal: (a) time domain, (b) frequency domain.

Table 1. Measured mode frequencies.

Mode frequency (Hz)	Beat frequency (Hz)	Beat interval (s)
64.18	0.34	2.94
64.52		
168.72	0.08	12.5
168.8		
189.5	1.26	0.79
190.76		
228.18	0.32	3.13
228.5		
282.22	0.66	1.51
282.88		
346.24	1.44	0.69
347.68	1.46	0.68
349.14	0.8	1.25
349.94		

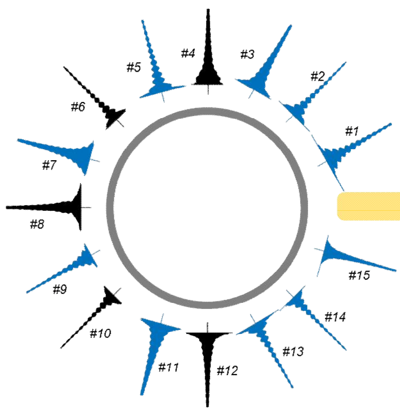

Figure 4. Distribution of signal on the plane at the height of hammer.

Figure 5 shows the relative distribution of radiated pressure measured at near field microphones for two model frequencies of 64.18 Hz and 64.52 Hz, inducing dominant beating. It is observed that the (0, 2) mode is formed at these two frequencies. However, the positions of the nodal line at the two frequencies are different, which leads to different amount of modulation in each direction. For example, the direction #4 in Fig. 4 the ratio of amplitude between two frequencies is about 10. In contrast, the relative ratio was about 2 in direction #2, where beating occurred relatively noticeably.

3. RECONSTRUCTION OF RADIATION PATTERN

To reconstruct the radiation characteristics, the equivalent source method [6] is applied. Figure 6 shows the reconstructed sound field with 15 equivalent sources distributed on the bell surface at the height of hammer. The synthesized sound field with the beating modes is shown in Fig. 7 and it is observed that the directional dependency shown in the measured data is well reproduced.

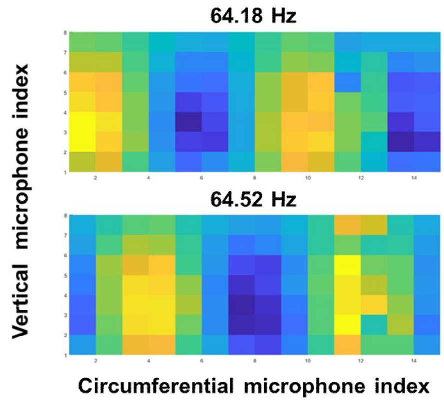

Figure 5. Near field pressure distribution of (0, 2) mode frequency.

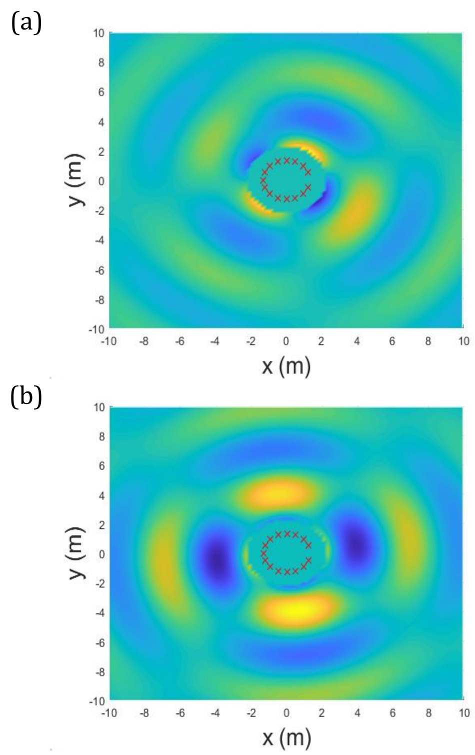

Figure 6. Reconstruction radiated sound field: (a) 64.18 Hz, (b) 64.52 Hz

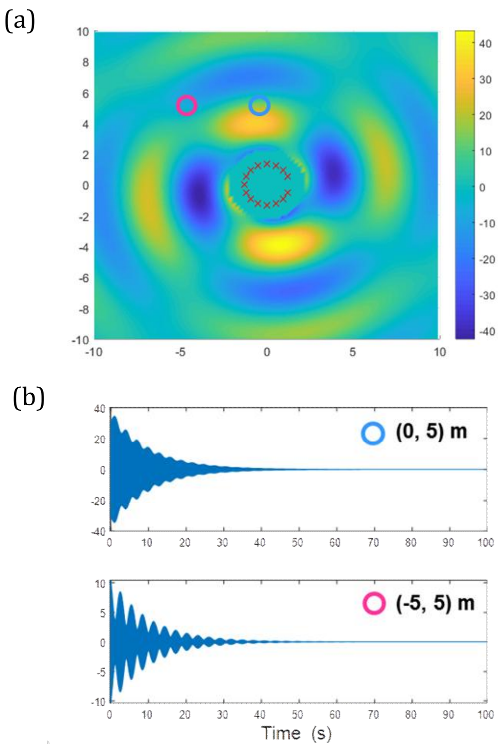

Figure 7. (a) Combined radiated sound field of two modes (64.18 Hz, 64.52 Hz), (b) synthesized time domain signal.

4. CONCLUSION

In this study, the spatial radiation characteristics of the "Divine Bell of King Seongdeok" were reconstructed using the near-field acoustic holography based on the equivalent source method. The measurement was conducted using 120 microphones in the near field, and the equivalent source model was conducted with a spherical radiation function. The directional dependency of the radiated sound field including the beating characteristics was accurately reproduced by this model through the superposition of each mode frequency.

5. ACKNOWLEDGMENTS

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