inter-noise 2009
innovations in practical noise control
2009 August 23-26
Ottawa, Canada

Characteristics of the origami impulse source

Emi Toyoda[a]
Satoshi Sugie
Junichi Yoshimura
Kobayasi Institute of Physical Research
3-20-41 Higashi-Motomachi
Kokubunji, Tokyo 185-0022, Japan

ABSTRACT

The purpose of the present study is to develop a new easy-to-use impulse source that performs as well as conventional sources. The present paper introduces an innovative method of generating impulses using a new impulse source called the origami impulse source. The origami impulse source has a simple shape that is easy to produce because its design originates from a traditional paper craft. The paper is folded in such a way that its shape produces a sudden sharp cracking sound when manipulated downward. In order to identify the acoustic characteristics of the origami impulse source, such as the sound energy level, repeatability, radiation directivity, and frequency characteristics, the proposed source was examined by comparison with conventional sources. These results indicate that the origami impulse source is able to produce an impulsive sound that is sufficient for the measurement of impulse responses used in measuring reverberation time. Consequently, the origami impulse source was practically applied to the measurement of reverberation time using the integrated impulse response method. The results of the reverberation time for the origami impulse source were compared with results obtained using the interrupted noise method. The results measured by these two methods were in good agreement. Thus, the capabilities of the origami impulse source for acoustic measurements have been established.

1. INTRODUCTION

The reverberation time can be measured easily and directly by the integrated impulse response method using an impulse source such as a pistol shot or a balloon burst. However, it is difficult to obtain sound pressure level sufficient to ensure a decay curve, especially at low frequencies. An impulsive sound that is more convenient and effective than conventional sources is therefore required.

The purpose of the present study is to develop a new easy-to-use impulse source that performs as well as conventional sources. The present paper introduces an innovative method of

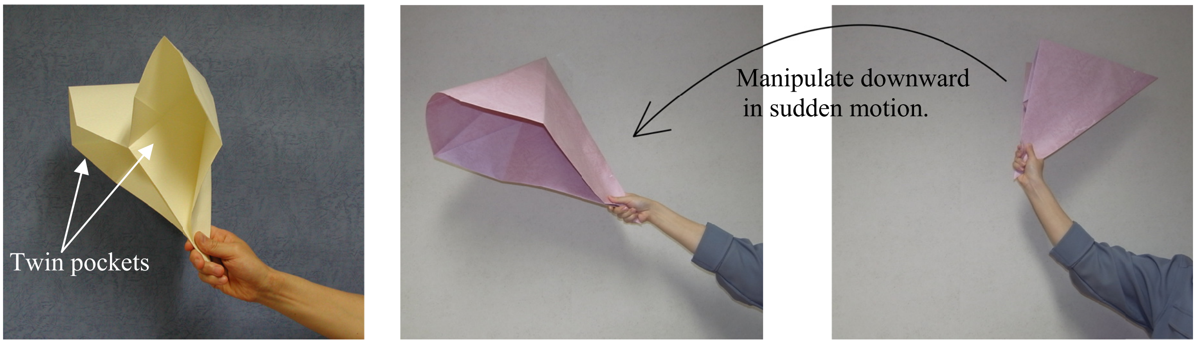
[a] Email address: toyoda@kobayasi-riken.or.jp

generating impulses, called the origami impulse source (OIS). The OIS is constructed using the Japanese paper folding craft known as “origami”.

In order to identify the acoustic characteristics of the OIS, such as the sound energy level, repeatability, radiation directivity, and frequency characteristics, the proposed source was examined by comparison with conventional sources. Moreover, in order to confirm the capabilities of the OIS, the proposed source was applied to the measurement of reverberation time in a small meeting room.

2. DEVELOPMENT OF OIS

The OIS is a simple shape that is easy to produce because its design originates from a traditional paper craft called *Kami-teppo* which means paper gun in Japanese due to the sound that it produces when operated. However, the original *kami-teppo* has twin pockets as shown in Fig. 1 (a), so that they produce two impulses during the short time. For the purpose of the present study, the *kami-teppo* design has been modified in order to produce single pocket hence a single impulse. Figure 2 shows how to fold the OIS. The paper is folded in such a way that its shape produces a sudden sharp cracking sound when manipulated downward in an abrupt motion, as shown in Fig. 1 (b). Unlike pistols, which must be recharged, or balloons, which cannot be reused, the OIS can also be reset repeatedly. However, the main disadvantage of OIS is the short lifetime of its. After repeated use, the paper becomes torn. As such, the main edge of the OIS should be reinforced with plastic tape.



(a) Traditional paper craft called *kami-teppo*. **(b)** Origami impulse source.

Figure 1:.Original *kami-teppo* and the origami impulse source.

3. INVESTIGATION OF ACOUSTIC CHARACTERISTICS

A. Sound energy level

The sound energy level of the impulse source was measured by the diffuse field method.[1] As sound sources, three types of OIS made of paper of different dimensions and two types of conventional impulse sources (balloons and firecrackers) were used as shown in Table 1 and Fig. 3. The sound sources were placed in a 513-m^3 reverberation room, and the single event sound exposure level for each 1/3 octave band from 50 Hz to 5 kHz was measured at six points. From the measurement results and the equivalent sound absorption area obtained from the reverberation time measurement, the sound energy level was calculated according to the prescription in Annex 2 of JIS Z 8734[2]. (This standard is identical to ISO 3741[3].)

The measurement results are shown in Figs. 4, 5, and 6. These results show the arithmetic mean values and the standard deviation of five measurements for each impulse source. In the case of the OIS, the sound energy levels become systematically higher as the dimensions of the paper increase, and high repeatability is obtained for any dimensions, as shown in Fig. 4. Figure 5 shows that frequency characteristics of the sound energy levels of the balloon are relatively broad at frequencies above 125 Hz. However, at high frequencies, the repeatability is slightly lower than that of OIS. As shown in Fig. 6, the results for the firecracker have a wider variation at all frequencies.

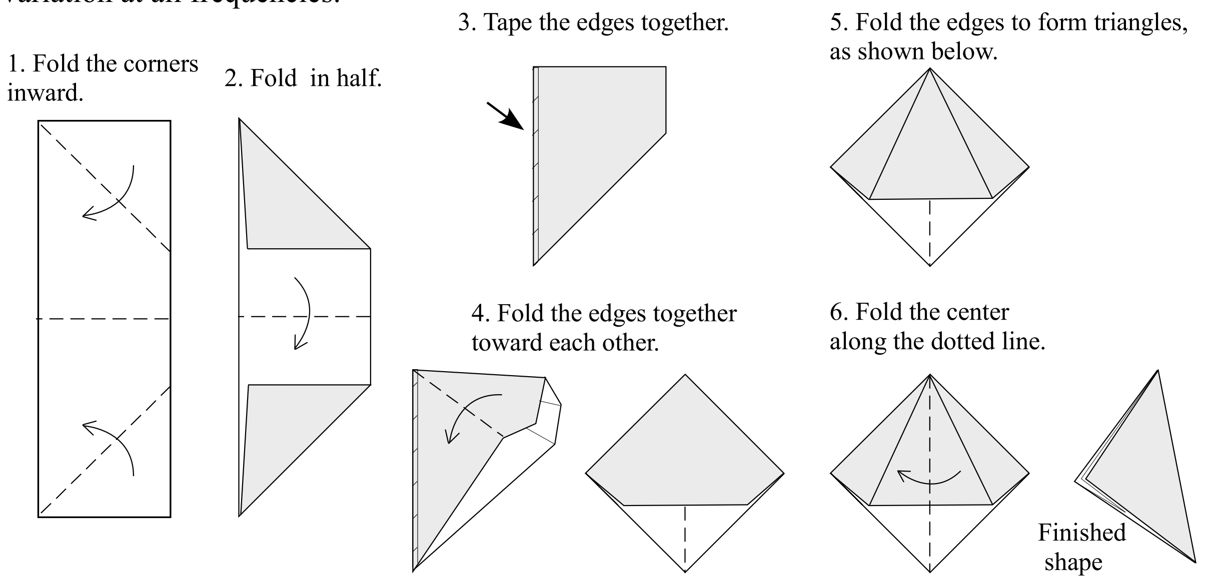


Figure 2: How to fold the origami impulse source.

Table 1: Impulse sound sources

		Dimensions of paper (mm)	Other
Origami impulse source	Type S	594 × 210	Thickness of paper: 0.19 mm
	Type M	854 × 302	
	Type L	1091 × 394	
Conventional impulse source	Balloon	—	The balloon is punctured with a needle.
	Firecracker	—	Quantity of gunpowder: 0.013 g

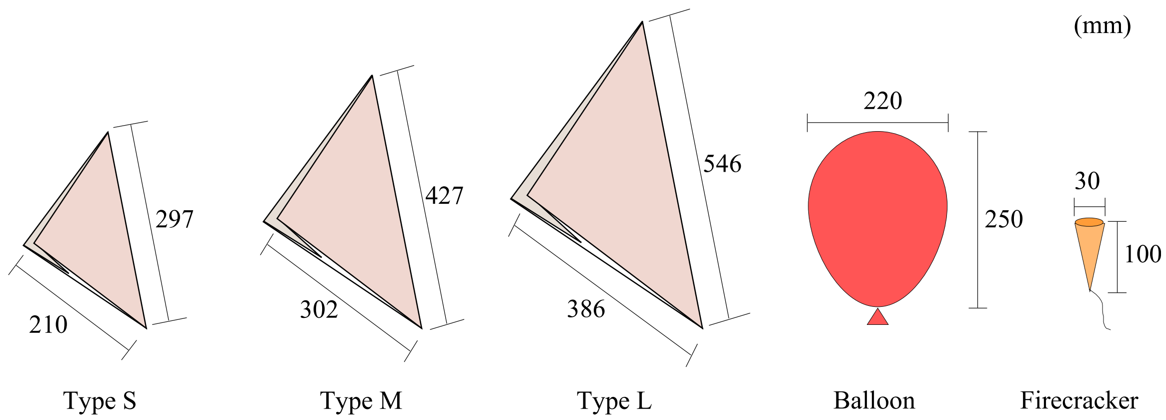


Figure 3: Dimensions of impulse sound sources investigated in the present study.

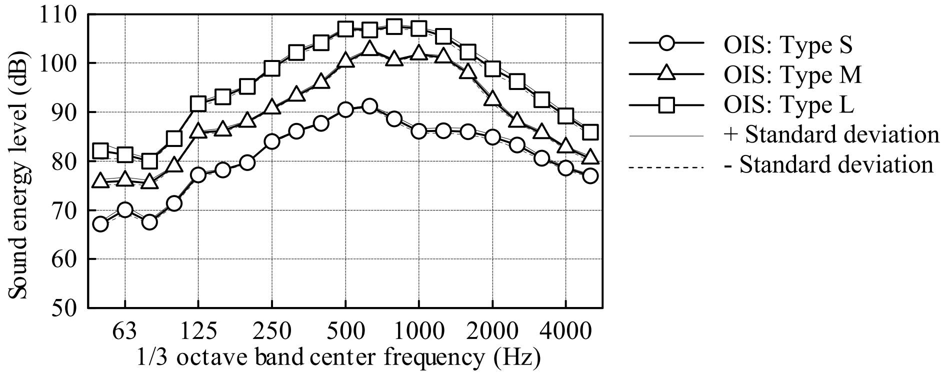


Figure 4: Measurement results of the sound energy levels of the origami impulse source.

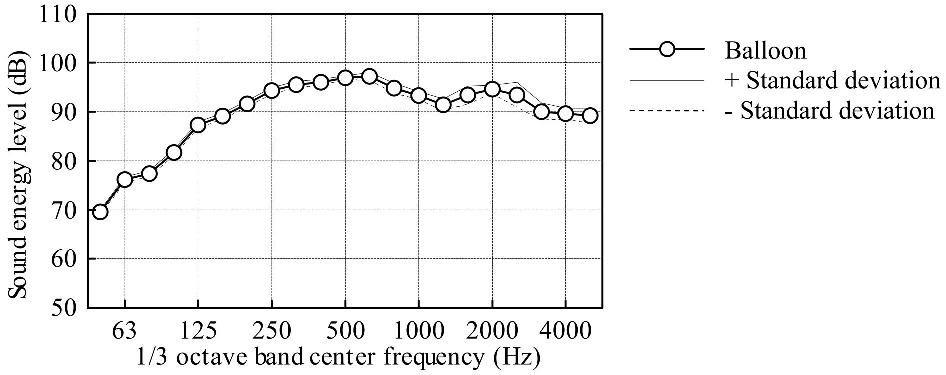


Figure 5: Measurement results of the sound energy levels of the balloon.

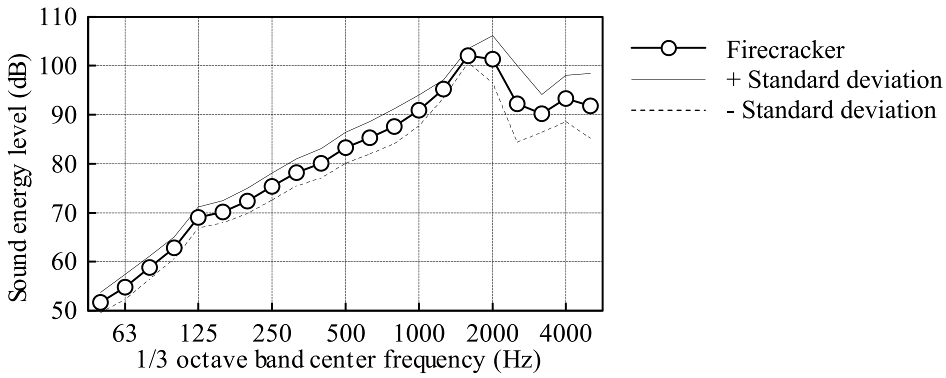


Figure 6: Measurement results of the sound energy levels of the firecracker.

B. Radiation directivity characteristic

In order to examine the radiation directivity characteristic of the impulse source, the maximum sound level (slow time weighting) was measured in an anechoic room. As sound sources, the OIS (Type M), the balloon, and the firecracker were used. Figure 7 shows the arrangement of the sound source and the microphone positions on a circle having a radius of 1.5 m. The microphones were positioned at 15-degree intervals. When the OIS was manipulated downward, the operator stood at a central point assumed as facing 0-degree position. When bursting the balloon, the operator stuck a needle into the middle of the balloon at an angle of 90 degrees. When the firecracker was used as an impulse source, the operator aimed upwards.

The horizontal directivity characteristics for each octave band are plotted in Fig. 8. These are normalized by the 0-degree position. In the case of the OIS, the sound pressure levels measured on the left side (195-300 degrees) and the right side (60-165 degrees) were lower than the results at the front and rear positions at 63 Hz, 125 Hz, 250 Hz, and 4 kHz. The directivity characteristic can be considered to be omni-directional at mid-frequencies. In the case of the balloon, the patterns are distorted toward the direction of the needle puncture at 63 Hz to 500 Hz. In the case of the firecracker, the directivity characteristic is almost omni-directional at all frequencies except 63 Hz.

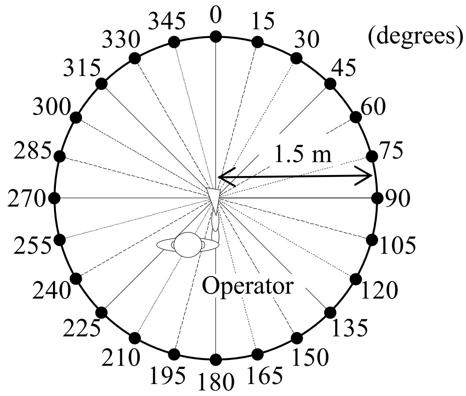


Figure 7: Arrangement of the sound source and the microphone positions.

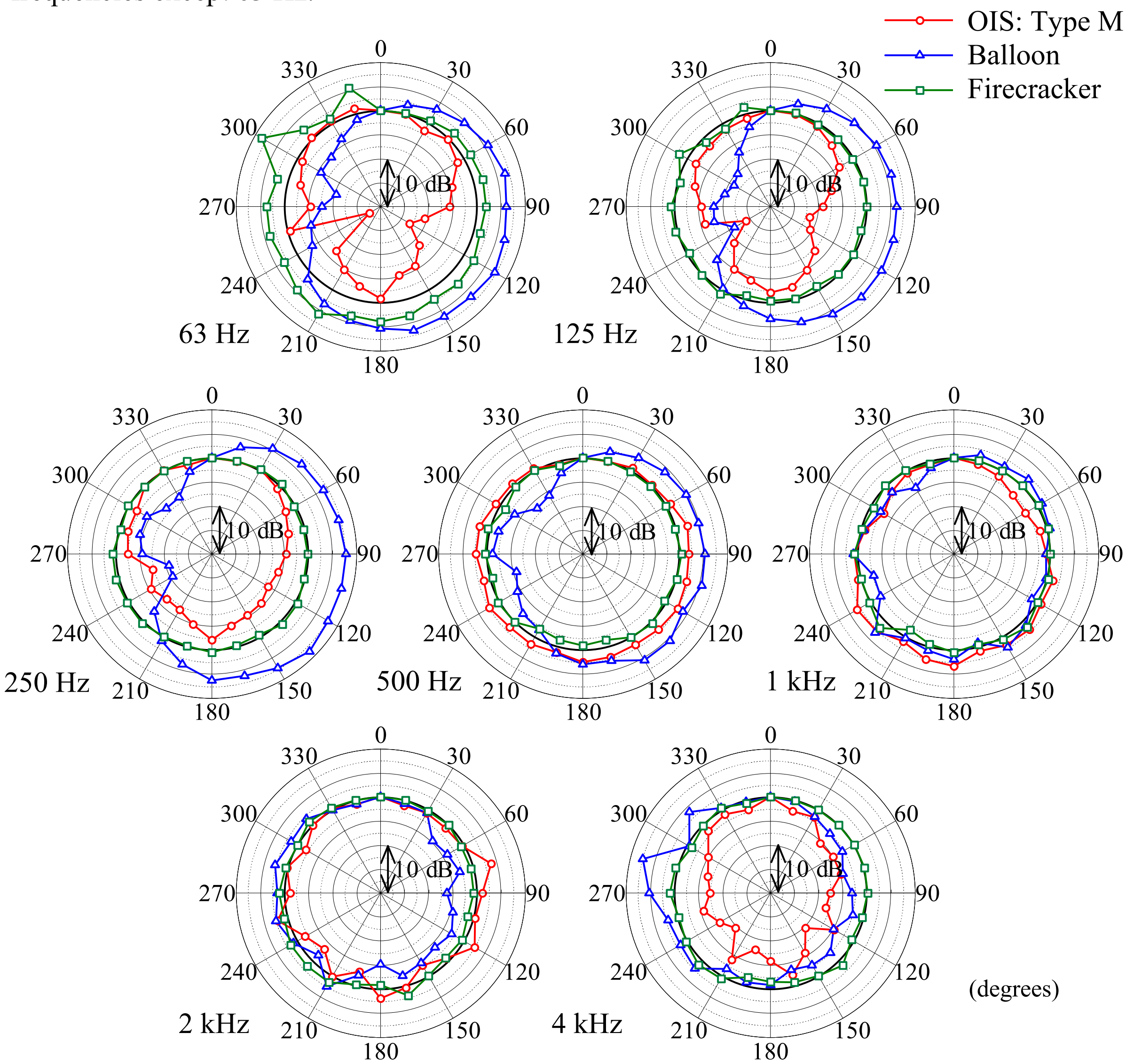


Figure 8: Horizontal directivity characteristics of impulse sound sources.

C. Frequency characteristics

Figure 9 shows the impulse response measured at 0 degrees. The impulse response of the OIS shows a more dominant peak than the impulse responses of the other two sources. The results of the power spectrum analysis of these impulse responses are shown in Fig. 10. These results indicate that, unlike the frequency characteristics of the other two sources, which have peaks and dips, the frequency characteristic of the OIS is relatively broad at frequencies lower than 2 kHz. The sound power of the firecracker is lower at low frequencies, as compared with the other two sources.

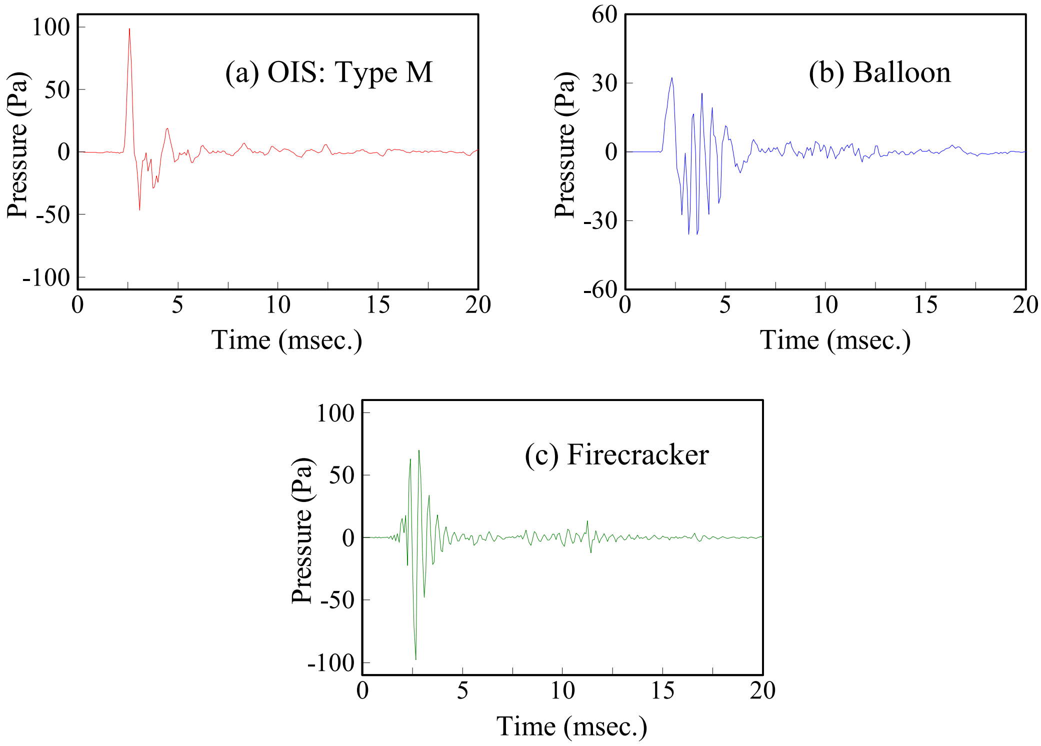


Figure 9: Impulse response measured at 0 degrees.

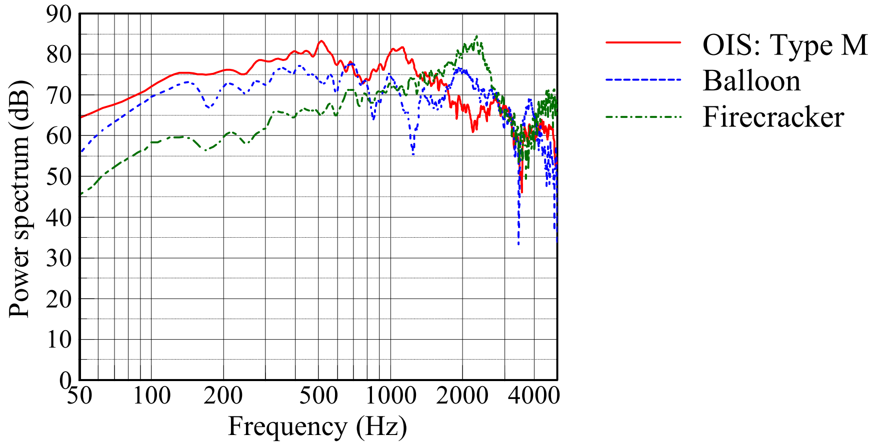


Figure 10: Results of power spectrum analysis.

4. APPLICATION TO THE MEASUREMENT OF REVERBERATION TIME

A. Measurement method

The OIS (Type L) was practically applied to the measurement of reverberation time using the integrated impulse response method. Figure 11 shows the arrangement of the sound source and the three microphone positions in a small meeting room (approximately 45 m^3). For the purpose of comparison, measurement by the interrupted noise method was also performed. An omni-directional loudspeaker was used as a sound source, and the positions of the sound source and the microphones were the same as those for the integrated impulse response method using the OIS. In order to match the sound absorbing condition of the room in both methods, one person (the operator of the OIS) remained in the room during measurement using the interrupted noise method. In both methods, the reverberation time for each octave band from 50 Hz to 5 kHz was calculated using the decay curves from 5 dB to 25 dB below the initial level.

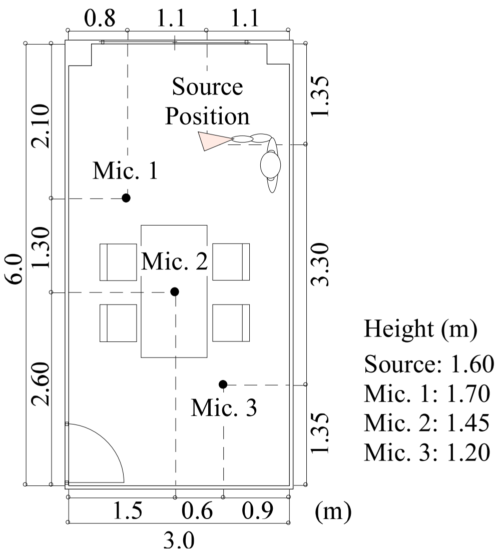


Figure 11: Schematic diagram of the arrangement used to measure reverberation time.

B. Measurement results

The results of five measurements by the integrated impulse response method using OIS are shown in Fig. 12. At any position, the results of the five measurements show no variation. Figure 13 shows the results of spatial averaging by both methods. When using OIS, 15 results (five measurements for three positions) were averaged. When using the interrupted noise method, 30 results (10 noises for three positions) were averaged. In both methods, small standard deviations were obtained. The results of the reverberation times for both methods were in good agreement. Therefore, the capability of the origami impulse source for acoustic measurements has been established.

The results at 63 Hz are shown as a reference because the range of evaluation was from 5 dB to 20 dB below the initial level due to bending of the decay curves.

5. CONCLUSIONS

The origami impulse source (OIS) was developed and its acoustic characteristics were investigated by comparing the OIS with conventional sources. The OIS can produce an impulsive sound that is sufficient for measuring impulse responses for the measurement of reverberation time. The present study revealed the following:

(1) The sound energy levels of the OIS increase as the dimensions of the paper increase, and high repeatability is obtained.

(2) The radiation directivity characteristic of the OIS is omni-directional at mid-frequencies.

(3) The frequency characteristic of the OIS is relatively broad at frequencies below 2 kHz.

(4) The results of reverberation time for the OIS were compared with results obtained by the interrupted noise method. The results obtained by these two methods were in good agreement. Therefore, the capabilities of the OIS for acoustic measurements have been established.

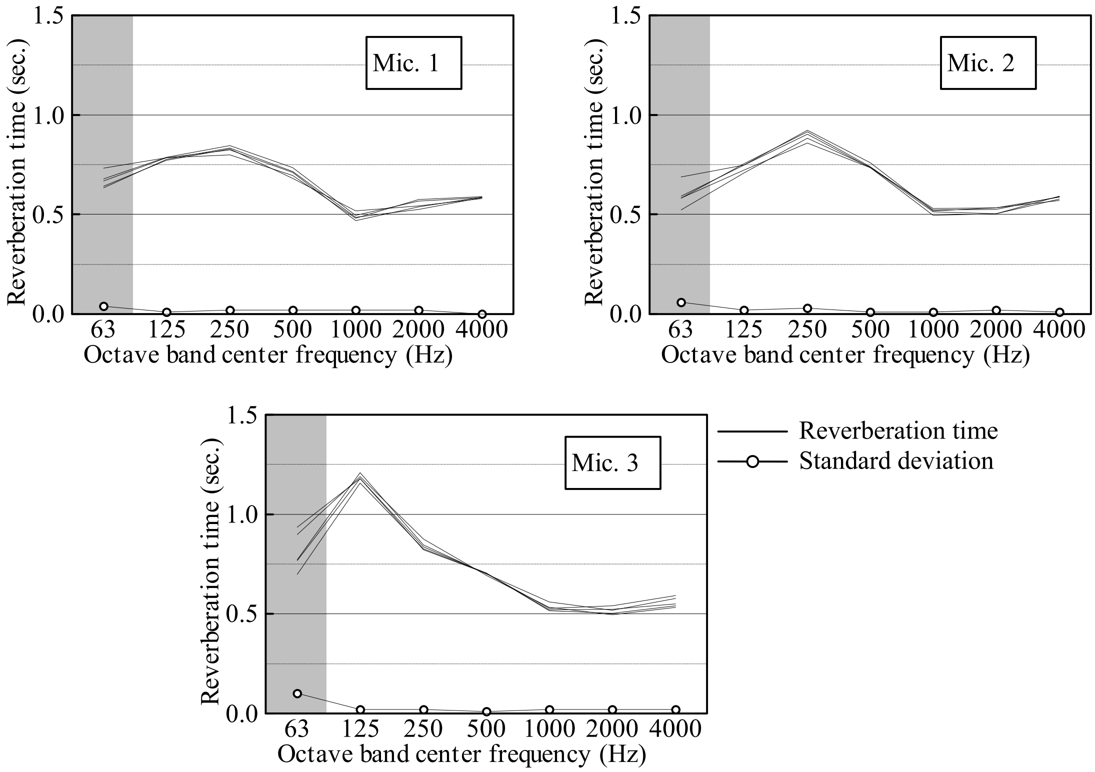


Figure 12: Results of five measurements obtained by the integrated impulse response method using the OIS.

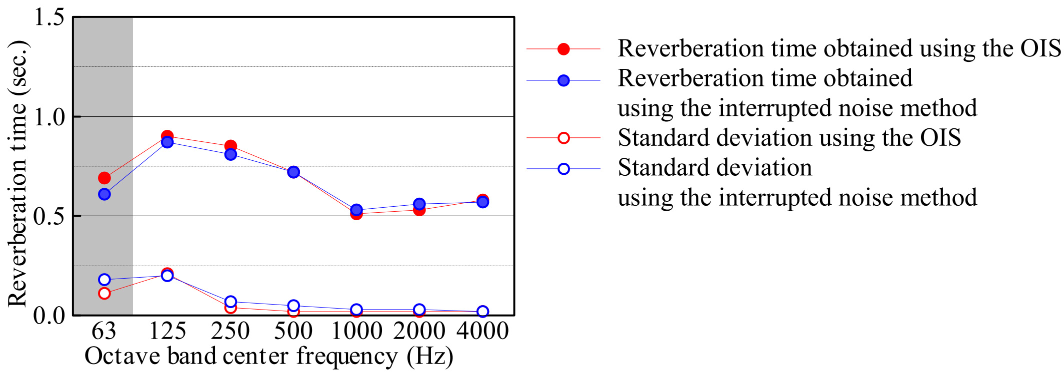


Figure 13: Results of spatial averaging obtained by the OIS and the interrupted noise method.

REFERENCES

1. Hideki Tachibana, Hiroo Yano, and Koichi Yoshihisa, "Definition and measurement of sound energy level of transient sound source," *J. Acoust. Soc. Jpn.* (*E*) vol. **8,** No. 6, 235-240 (1987).
2. JIS Z 8734:2000, "Acoustics – Determination of sound power levels of noise sources using sound pressure – Precision methods for reverberation rooms"
3. ISO 3741:1999, "Acoustics – Determination of sound power levels of noise sources using sound pressure – Precision methods for reverberation rooms"