Characteristics of Resonance Sound in a Circular Saw Enclosure

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Several studies have been conducted to reduce the idling noise of circular saws because the sound level is extremely high and harms the environment. However, conventional noise suppression technology only controls the vibrations of the circular saw itself, whereas idling noise can be generated when the air inside the enclosure is resonant. In this study, the relationship between the rotational speeds of the circular saw blade and the frequencies of the resonance sound when the circular saw blade is running idle in an enclosure was examined. Additionally, the sound pressure modes and frequencies of the air in the enclosure were analyzed using the finite element method of acoustic analysis. The results showed that resonance sound was generated only when the circular saw blade was enclosed. The frequencies of the resonance sound generated by a circular saw blade made of acrylic plastic were the same as those generated by a steel saw blade. The resonance sound was generated regardless of the outer diameter of the circular saw blade. The peak resonant frequencies formed a step-like line during the analysis in which the rotational speed of the saw blade was steadily increased.

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Keywords: Circular saw blade; Idling noise; Acoustic resonance; Finite element method

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INTRODUCTION

Industrial noise is a common problem in woodworking factories. In particular, idling circular saw noise is a major problem, as it can easily exceed 100 dB(A) in some cases. This is a serious problem for workers who spend a significant amount of time near such noise sources, with consequent adverse influence on their physical and mental health. Recently, various studies have been conducted because of the seriousness of the noise problem, and the noise level of circular saws has been decreasing.

According to studies on the mechanism of noise generation, noise in an idling circular saw was caused by alternating vortex shedding from the trailing edge of the saw tooth (Pahlitzsch and Friebe 1971). However, sustained fluid oscillations in water channel experiments were observed when a linear cascade of tooth models was excited into lateral resonance by flow (Dugdale 1969), which contradicts a vortex-shedding mechanism that predicts a monotonic and approximately linear relationship between frequency and tooth velocity (Mote and Leu 1980). In water channel tests, vortex shedding was observed in a single-tooth model (Kimura *et al.* 1976). A hot-wire anemometer was used to measure flow velocities behind a tooth model bonded to the rim of a rotating disc, but no strong periodic flow was observed (Cho and Mote 1979). Weak vortices were observed around single and cascaded tooth models using two hot-wire anemometers rotating with the blade and straddling the tooth. Although phase differences between the two probe data indicated vortices and clear organization of the flow in particular frequency bands, the peaks in the velocity spectrum for cascades of more than four teeth were not discernible (Price and Mote 1982). Based on the results of experiments conducted in a water tank, it was concluded that the aerodynamic sound of the circular saw was caused by pressure fluctuations as the vortex detached from the leading edge of the tooth passed over the tooth edge, resulting in a dipole sound source (Leu and Mote 1984). Another study measured the level of aerodynamic sound emitted by a blade with a notch around the disc and concluded that the aerodynamic sound is produced when a vortex detached from the upstream cutting edge collides with the leading edge of the downstream cutting edge (Martin and Bies 1992).

Practical solutions were also actively studied. A new design of circular saw with stepped thickness was proposed (Cheng *et al.* 1998). Slots were developed to reduce whistling noise (Singh 1988; Nishio and Marui 1996; Taki *et al.* 1975; Yokochi *et al.* 1994). Tapered teeth (Kimura and Fukui 1976) and irregular tooth pitches (Yokochi *et al.* 1984) have also been developed. Noise reduction was also attempted using special tooth designs (Yanagimoto *et al.* 1995). Additionally, a special alloy for circular saw blades with sufficient mechanical and damping properties have also been developed (Hattori and Iida; Hattori *et al.* 2001). The efficiency of various damping foils inserted between the collar and circular saw model has been studied (Marui *et al.* 1994). An inexpensive quieting method based on rubber rings has also been developed using a similar approach (Beljo-Lučič and Goglia 2002). Slots filled with damping material (*e.g.*, viscoelastic resin) on the surface of circular saws to reduce vibration have been used as one of the most commonly used solutions (Fig. 1), and the noise was reduced by up to 10 dB(A).

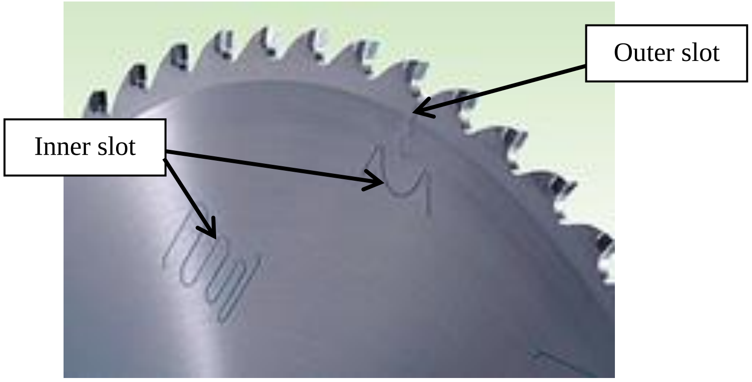


Fig. 1. Circular saw blade with outer and inner slots filled with damping material

However, even if the circular saw blade had sufficient internal damping, acoustic resonance generated within a circular saw enclosure can perpetuate the typical whistling sounds (often 2000 to 5000 Hz). In this study, the mechanism of the acoustic resonance generated in a circular saw enclosure was clarified. Using the finite element method, the resonance sound is predicted by analyzing the stationary wave shapes and natural frequencies of the air in the enclosure. Additionally, the rotational speeds of the saw spindle for idling saw resonance were measured. Then, using idling experiments with saw blades of different outer diameters, the relationship between the frequencies of the resonance sound and saw circumference was investigated.

EXPERIMENTAL

Finite Element Method Analysis

Figure 2 shows the equipment geometry used for the finite element method analysis. Acoustic analysis was used to analyze the shape and frequency of the stationary waves (Software: ANSYS). φ305 × 2 mm disk (simplified model of a circular saw) and two flanges (φ120 × 10 mm) that holds the circular saw in place were hollowed out from a 40 mm thick dome-shaped enclosure shape. This modeled the air inside the enclosure. The physical property data for the analysis included sound velocity 344 m/s and air density 1.204 kg/m^3. The sound pressure of the bottom surface (Fig. 2 A) was set at zero.

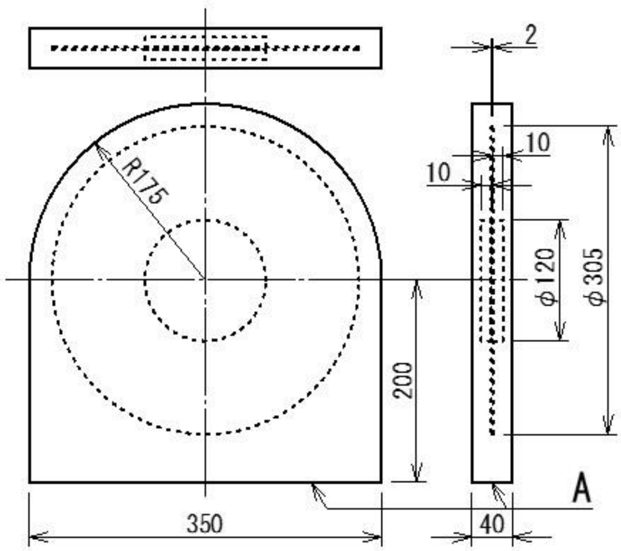


Fig. 2. Analysis model for the finite element method

Sample Preparation for Idling Tests

The experiments used circular saw blades with untipped teeth for simplicity. Each saw had six outer and inner slots, all filled with damping material. Table 1 lists the data for these circular saw blades. The acrylic blade (b) had the same size and shape as the circular saw blade (a) but without the outer and inner slots.

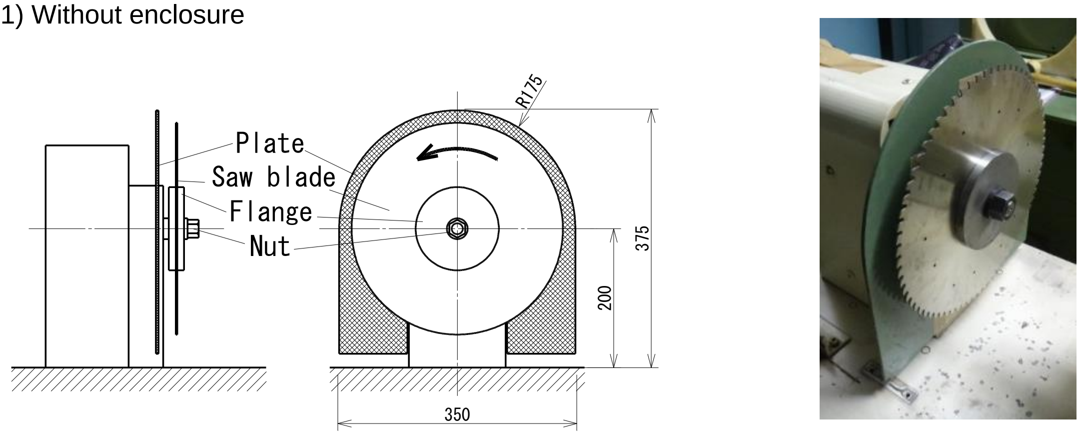
Table 1. Dimensions of the Circular Saw Blades and the Geometry of the Gullet Shape

No.	(a)	(b)	(c)	(d)	(e)
Diameter (mm)	305	305	255	280	330
Thickness (mm)	2	2	2	2	2
Number of teeth	72	72	60	66	78
Material	Steel	Acrylic	Steel	Steel	Steel
Gullet shape					

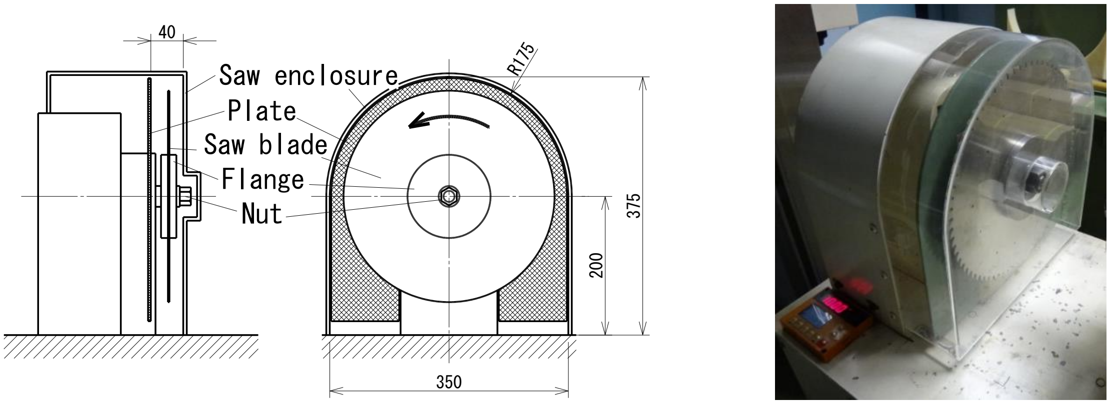
Idling Tests

Figure 3 shows the dimensions and photographs of the experimental apparatus. The enclosure was made of 5 mm thick polycarbonate, and the plates were made of 5 mm thick steel. These steel plates ware held in place by magnetic base. The rotational speed of the saw spindle was increased from 10 to 100 Hz in 1 Hz steps. A precision sound-level meter (RION, NL-16) was placed at the same height and 1 m away from the center of the circular saw blade. Frequency spectra were determined using an FFT analyzer (ONOSSOKKI, DS-2000). A test of different diameters of the circular saw was conducted only with an enclosure (Fig. 3-(2)).

(1) Without enclosure



(2) With enclosure



(3) With steel plates on both sides

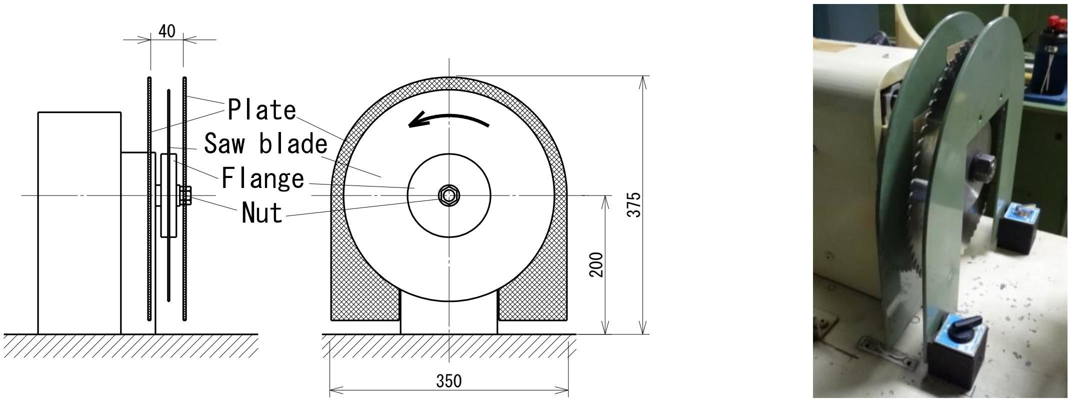


Fig. 3. Experimental apparatus

RESULTS AND DISCUSSION

FEM Analysis

Modal analysis was used to calculate several saw vibration modes. These modes, as well as mode shape, mode number, and the frequency of the sound pressure modes (*n* = 1-8) moving in a circumferential direction, are shown in Fig. 4.

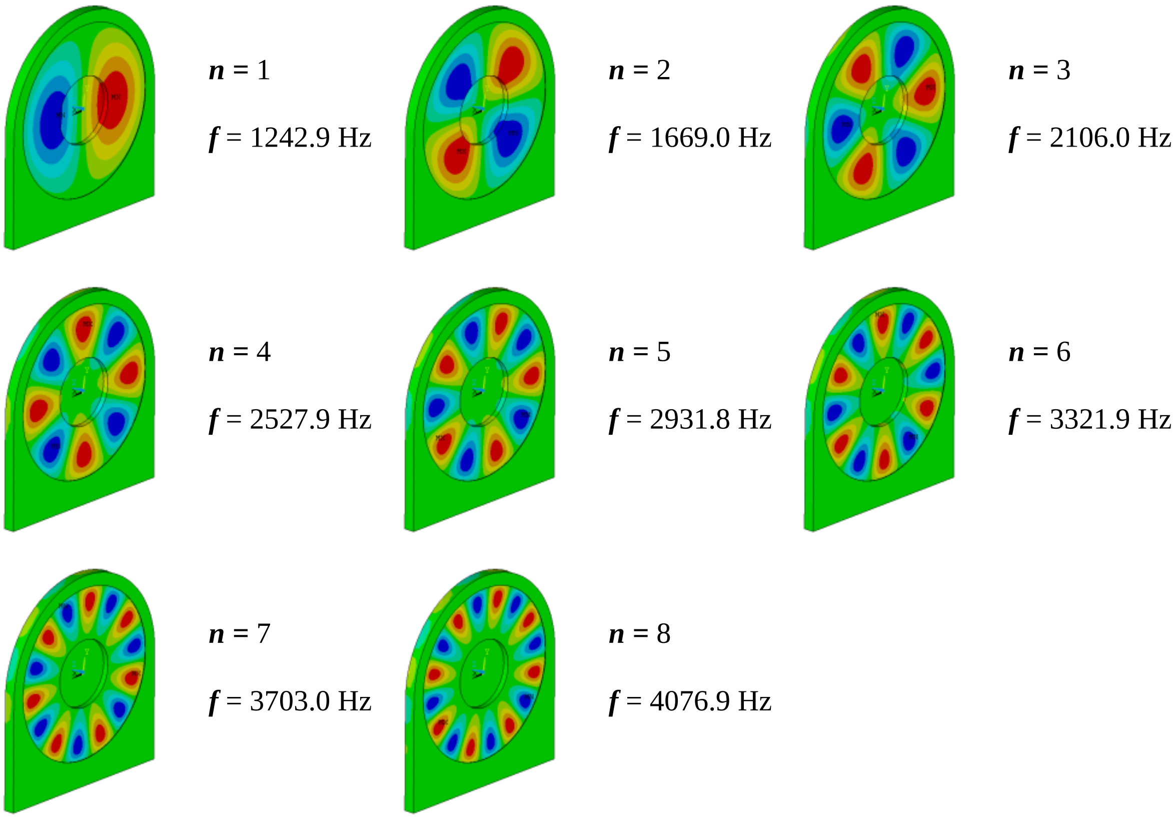
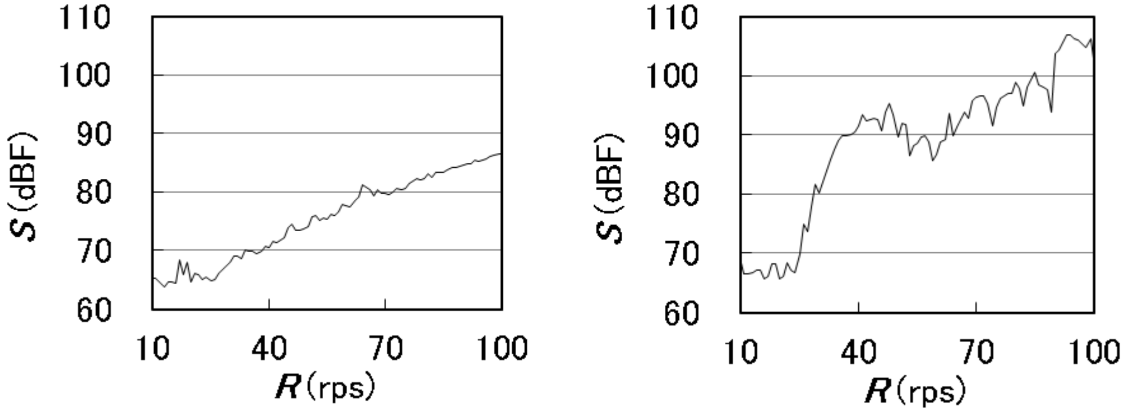


Fig. 4. Mode Shapes of FEM analysis (***n*** **=** 1 to 8). ***n*****:** mode number; ***f*****:** mode frequency

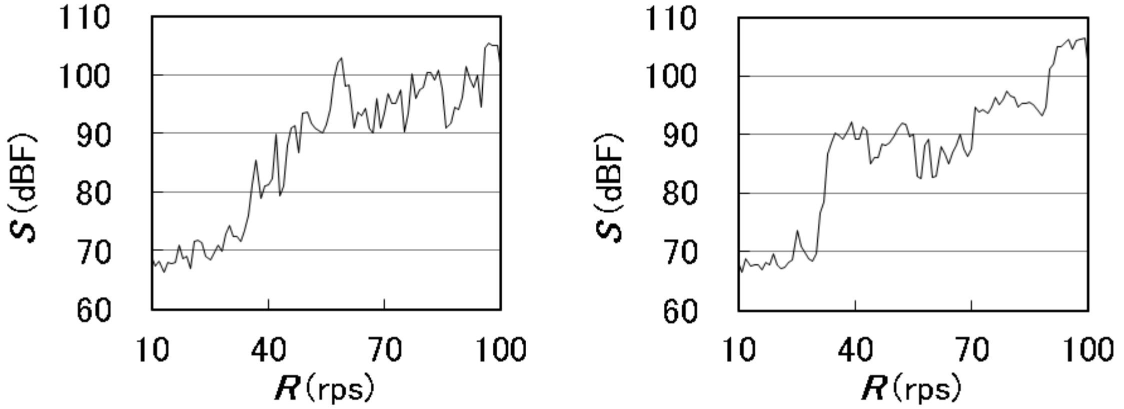
Idling Tests: Different Conditions

Figure 5 shows the relationship between the rotational speed and measured sound pressure level. In the case of (a) diameter 305 mm without enclosure (Fig. 5-a1), the sound pressure level increased approximately linearly with rotation speed. In cases of (a) 305 mm with enclosure (Fig. 5-a2), (a) 305 mm with steel plates added on both sides (Fig. 5-a3), and (b) 305 mm of the acrylic body with enclosure (Fig. 5-b1), the sound pressure level increased drastically in the range of rotational speed 35 to 40 Hz, followed by several large sound pressure level occurrences. This showed that when the circular saw-shaped disk was enclosed, a specific resonance sound was generated.

Figure 6 shows the relationship between the rotational speed and resonant noise frequency. The size of the open circles indicates the sound pressure level. In the case without enclosure (Fig. 6-a1), no resonance sound was generated, but an aerodynamic sound called "wind noise" occurred. The aerodynamic sound had a low sound pressure level, with peak frequencies in a linear sequence, as shown by red lines in Fig. 6-a1.


(a1) Without enclosure

(a2) With enclosure

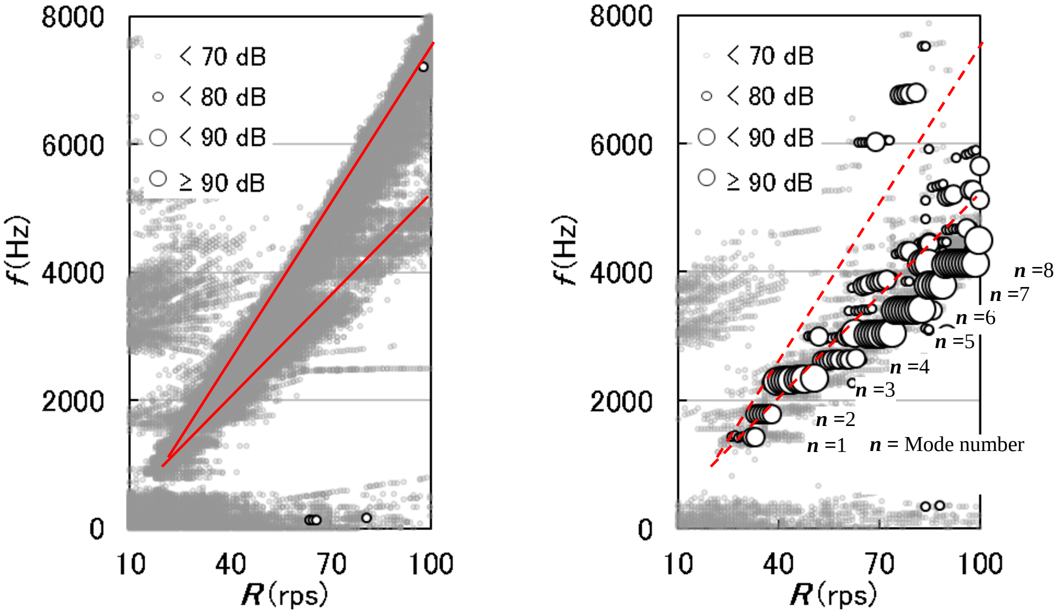

(a3) With steel plates on both sides

(b1) Acrylic body with enclosure

Fig. 5. Relationship between sound pressure-level ***S*** and rotational speed ***R***
(a1): Steel body circular saw blade without enclosure. (a2): Steel body circular saw blade with enclosure.
(a2): Steel body circular saw blade with steel plates on both sides. (b1): Acrylic body circular saw blade with enclosure.

Resonance sound was generated in the cases with enclosure (Fig. 6-a2), with steel plates on both sides (Fig. 6-a3), and acrylic body with enclosure (Fig. 6-b1), and the peak frequencies in a step-like sequence. In these figures, the red solid line shown in Fig. 6-a1 was copied and shown as red dashed lines. Because the starting points of these peak frequencies corresponded approximately to the red dashed line, it is assumed that the vortex frequencies were the excitation frequencies of the resonance sound.

The frequencies of the resonance sound generated by the acrylic body saw with enclosure (Fig. 6-b1) corresponded to those generated by the steel saw with enclosure (Fig. 6-a2). This type of resonance sound was not affected by the material of the circular saw blade. Figure 4 shows that the resonant frequencies in the gap between the circular saw blade and the enclosure were equal to those of the circumferentially moving modes. The stationary wave modes calculated by the finite element method corresponded to the experimentally measured peak resonant frequencies, as shown in Fig. 6-a2. The aerodynamics sound generated in the rim of the circular saw blade in the enclosure was resonated with the air between the enclosure and the circular saw blade. Stationary wave modes were generated, resulting in large noise production.


(a1) Without enclosure **(a2)** With enclosure

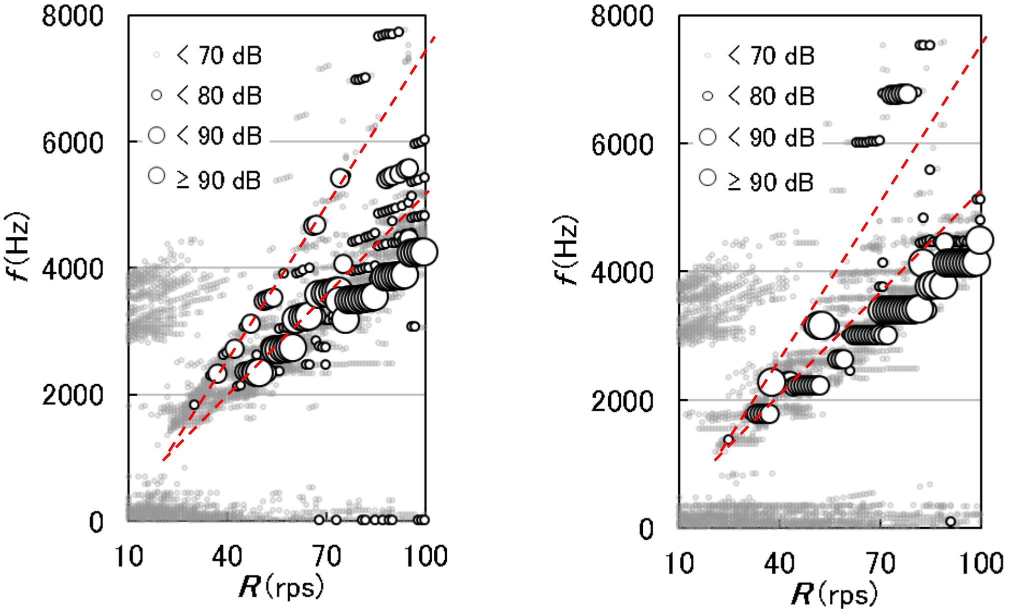

(a3) With steel plates on both sides **(b1)** Acrylic body with enclosure

Fig. 6. Relationship between rotational speed ***R*** and resonant frequency ***f***
(a1): Steel body circular saw blade without enclosure. (a2): Steel body circular saw blade with enclosure.
(a2): Steel body circular saw blade with steel plates on both sides. (b1): Acrylic body circular saw blade with enclosure.

Idling Tests: Different Diameters of the Circular Saw Blades

Figure 7 shows the relationship between the rotational speed and sound pressure level. At the highest rotational speeds, the sound pressure level was greater than 100 dB(A) in all diameters of the circular saw blades in an experimental range.

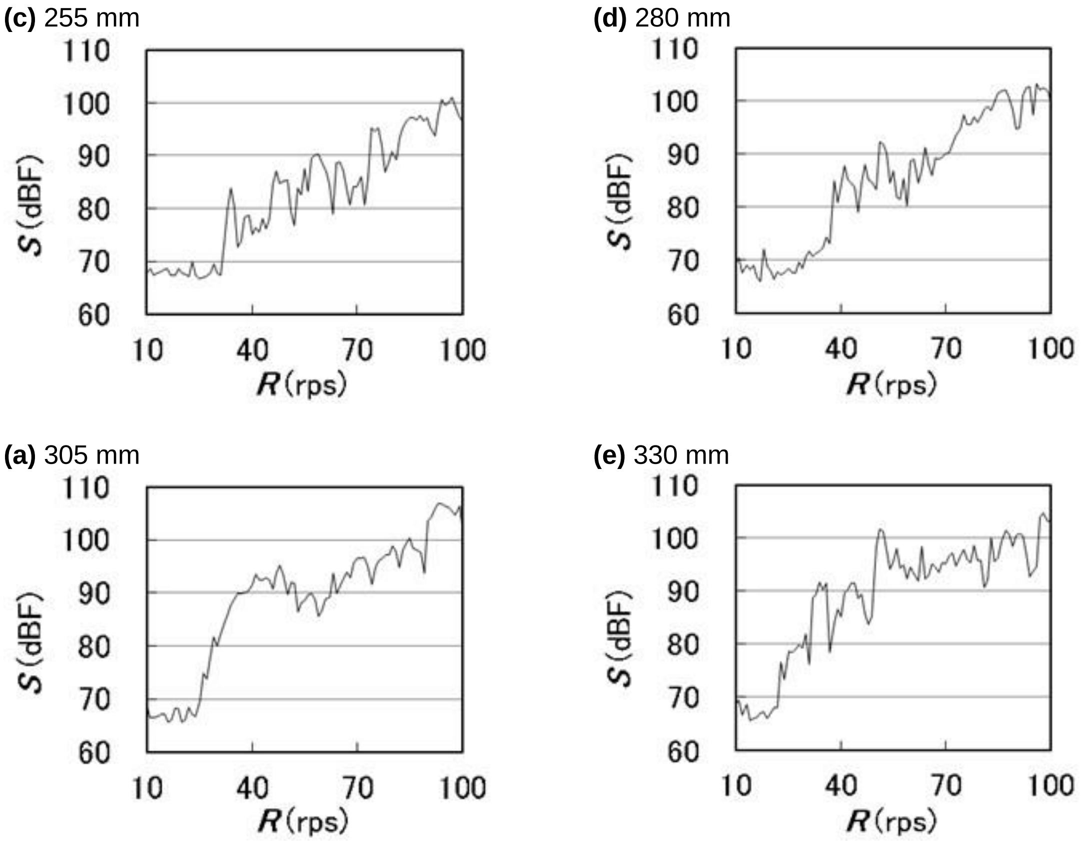
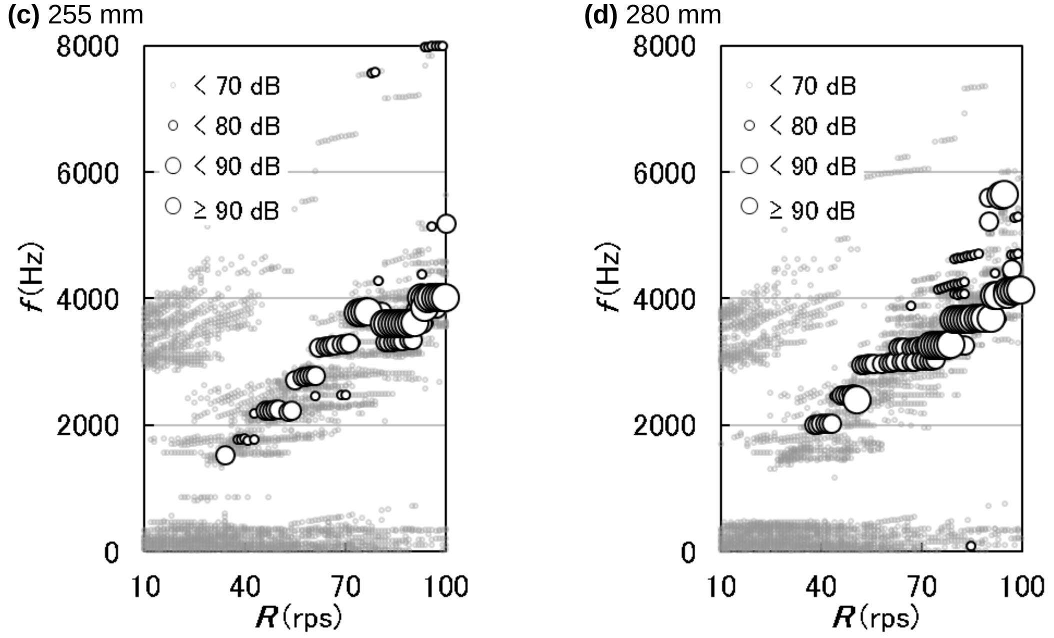


Fig. 7. Relationship between sound pressure-level ***S*** and rotational speed ***R***
(c): Diameter 255 mm (d): Diameter 280 mm (a): Diameter 305 mm (e): Diameter 330 mm



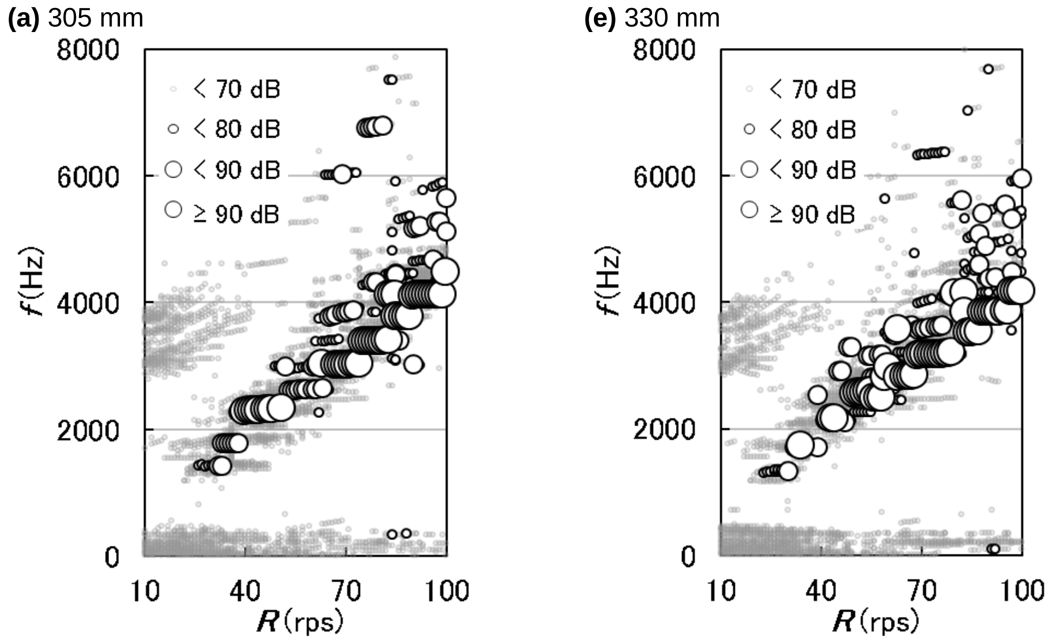

(a) 305 mm (e) 330 mm

Fig. 8. Relationship between rotational speed ***R*** and resonant frequency ***f***
(c): Diameter 255 mm (d): Diameter 280 mm (a): Diameter 305 mm (e): Diameter 330 mm

Figure 8 shows the relationship between the rotational speed and resonance sound frequency. The resonance sound was generated even when the outer diameter was changed, and the frequencies of the resonance sound formed in a stepped sequence with all outer diameters. The frequencies of the resonance sound became lower for saws with larger outer diameters. In this result, the length of the circumference of the circular saw blade was found to determine the frequencies of the resonance sound.

CONCLUSIONS

1. The resonance sound was generated when the circular saw was enclosed even when the circular saw did not produce any resonance sound in the absence of an enclosure. This type of resonance sound was still generated when the circular saw blade ran between steel plates without there being a full enclosure.
2. The frequencies of the resonance sound for a plastic circular saw blade model made of acrylic plastic were the same as those for steel saws. Therefore, the resonance sounds were caused by the circular saw shape, not the circular saw material.
3. The resonance sound frequencies in an enclosure corresponded to the peak frequencies of the idling sound without an enclosure. Therefore, the air vortex frequencies were the excitation frequencies of the resonance sound.
4. The frequencies of resonance sound formed a step-like sequence corresponding to increasing rotational speed of the saw blade. Resonance sound was generated even when the outer diameter of the circular saw blade was changed. Lower frequencies were observed when saws with larger outer diameters were used. Therefore, the frequency of the resonance mode was determined by the circumference of the circular saw blade.

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