Radiated BPF sound measurement of centrifugal compressor

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Abstract. A technique to measure radiated BPF sound from an automotive turbocharger compressor impeller is proposed in this paper. Where there are high-level background noises in the measurement environment, it is difficult to discriminate the target component from the background. Since the effort of measuring BPF sound was taken in a room with such condition in this study, no discrete BPF peak was initially found on the sound spectrum. Taking its directionality into consideration, a microphone covered with a parabolic cone was selected and using this technique, the discrete peak of BPF was clearly observed. Since the level of measured sound was amplified due to the area-integration effect, correction was needed to obtain the real level. To do so, sound measurements with and without a parabolic cone were conducted for the fixed source and their level differences were used as correction factors. Consideration is given to the sound propagation mechanism utilizing measured BPF as well as the result of a simple model experiment. The present method is generally applicable to sound measurements conducted with a high level of background noise.

1. Introduction
Reduced vehicle noise is considered important in society and considerable research into engine noise, road noise and aerodynamic noise from the body has been conducted. In recent years, the usage of turbochargers as automotive engine components has been spread, since it helps downsize engines and thus reduce fuel consumption. Reflecting this trend, the problem of noise emission has also been studied [1].

Turbocharger noise can also be classified according to origin, with particular focus on its centrifugal compressor. Generally speaking, the main contributors of sounds at design speed are the noise of the blade passing and the buzz-saw noise, while the tip clearance noise dominates under low-speed conditions [2][3]. In this study, the BPF (Blade Passing Frequency) noise from the compressor impeller is focused on, since it often becomes prominent at conditions of higher rotor speed. Efforts were made to measure radiated BPF sound, particularly in the turbocharger performance test cell, but high-level background noise meant it was not possible to obtain the exact level of BPF noise. Accordingly, a microphone covered with a parabolic cone was developed to measure BPF noise under high-level background noise.

2. BPF sound measurement
A test cell to measure BPF noise is shown in Figure 1. The facility is designed to measure the aerodynamic performance of a turbocharger compressor and turbine. The room is not designed for sound measurements with an anechoic wall. In the test cell, a turbocharger is mounted at the
center of the cell and suctions/exhausts are connected to the tubing for both the compressor and turbine sides. Compressed air from an external source is supplied to the turbine suction and drives the rotating wheel.

While the turbocharger is in operation, the other components, such as the suction/exhaust air tubing, emit high-level background noise due to drive gas manipulation, which also serves to increase the level of background noise. According to this, the BPF level was not clearly identified in the preliminary measurement using a microphone only. In the present experiment, anticipating sound collection and background noise reduction, a microphone (B&K Type 4191) covered with a parabolic cone (15cm diameter) machined from an acrylic resin block is developed (see Figure 2). A probe microphone (B&K Type 2669) is flush-mounted to the inner surface of the compressor suction tubing for further discussion of the result.

When the parabola-microphone is used in the experiment, level correction is needed since the measured sound is amplified due to the reflection and superimposition effect. To correct the obtained level, a preliminary experiment was conducted based on the following idea. In the experiment, the speaker is used as a source and its sound is measured with/without a parabolic cone and equidistant
3. Results and discussion
Two compressor impellers with different numbers of blades (see Table 1) were tested to measure BPF sound using the aforementioned method. The measurement result is shown in Figure 5 with level correction applied. As can be seen in the figure, discrete BPF level peaks are observed in most cases. The BPF frequency of impellers A and B differs for the same rotative speed since the number of blades also differs. However, the background noise levels are generally the same in both cases (high in the lower frequency region), which implies that the compressor wheel difference has little effect on the background noise. According to this, it is easier to identify the BPF level under higher rotative speed conditions. Since impeller A has a higher BPF noise frequency at a certain rotative speed and
Table 3. Specification of tested impeller

|                         | Impeller A | Impeller B |
|-------------------------|------------|------------|
| Number of blade [-]     | 10 (Full blade) | 6 (Full blade), 6 (Splitter blade) |
| Impeller outlet diameter [mm] | 150        | 34.64      |

![Impeller A (60000 rpm)](image)

**Figure 5.** Measurement result using a microphone with a parabolic cone.
Figure 6. Radiated BPF sound level.

Figure 7. BPF level at the inner wall of the suction duct.

Figure 8. Schematic of the modeled experiment.

Gives clear identification compared to impeller B, impeller A is selected for further discussion. Figure 6 indicates the BPF peak level of impeller A obtained at different rotative speeds with level correction applied. It is clear that the level rises with increasing rotative speed. As mentioned in the previous section, the compressor suction internal sound is also measured by a probe microphone, the result of which is shown in Figure 7. Comparing BPF internal sound and outer sound (Figure 6), it is clear that the internal sound level generally exceeds the radiated sound level since the location is closer to the sound source. In addition, the overall gradient of the uprising trend is more intense for the internal sound. Reflecting this, another experiment was conducted to verify the sound propagation mechanism.

During the performance testing process of the turbocharger, the open connected tubing is all outside the cell (see Figure 1). Taking this into account, the BPF sound generated by the impeller does not directly propagate to the microphone measurement location (of the radiated sound). It is assumed that the BPF pressure fluctuation (originating from the compressor impeller) vibrates the compressor outer casing, whereupon the casing emits sound to an area outside the turbocharger. To verify this mechanism, a simple model experiment was conducted as shown in Figure 8. Here, only the compressor casing was prepared and its open sides were shuttered with plates and clay to avoid direct propagation of the internal sound. A speaker was extended with a narrow tube and its tip inserted into
the closed casing to imitate the BPF sound source. The sound was generated from inside the compressor casing and measured both inside and outside, maintaining the same location as for the

![Sound Level Difference Graph](image)

**Figure 9.** Sound level difference between the radiated noise and the noise inside casing

Experiments in the performance test cell. The result obtained (the level difference between the internal and outer sounds) is shown in Figure 9. The level difference of the previous experiment (Figures 6 and 7) is also plotted in the figure and they show good agreement. Based on the result, it is confirmed that the BPF sound measured in the performance test cell was propagated mainly via the structural vibration of the compressor casing. The level difference between the internal and radiated sound generally increases, which should result from the increment in transmission loss (mass law [3]) due to frequency. The theoretical curve of the transmission loss is also shown in the Figure, the trend of which generally agrees with the others.

4. Conclusion
A method of measuring the turbocharger compressor BPF sound using a microphone covered with a parabolic cone was introduced. A sound propagation mechanism that generated BPF sound inside an impeller, vibrated the compressor outer casing and emitted noise toward the outside was assumed and verified through a simple speaker test. The method proposed here is reasonable and also easy to apply to other problems concerning sound measurements under high-level background noise.

References
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