Experimental Investigation On The Pulsation Noise Induced From Automotive Turbocharger Commpressors

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Abstract— A noise investigated in this study is the pulsation noise generated from compressor wheels, whose frequency is the same as the whine noise. Although they have the same frequency, their noise sources are absolutely different. The whine noise is induced from the unbalance of rotating modules, on the other hand, the pulsation noise is found to be generated by breaking the wheel's dimensional symmetry by tests. This asymmetry considered in this study is done by cutting partly compressor wheels' edge in order to remove its unbalance in a semi-circular shape. It was realized by tests that the number is directly related to the level of the pulsation noise, and a specific number exists to cause the noise problem. Additional tests have been done to investigate the characteristics of the noise by changing the numbers, the size, and the arrangements of the cuttings. Finally, this study concludes that the pulsation noise is related to the three factors of cuttings.

Keywords-Turbocharger, Noise, Pulsation, Compressor wheel. Balancing,

I. INTRODUCTION

Turbochargers are a device to allow more power for an engine by actively supplying more air to it. A turbocharger is composed of two main components, compressor and turbine wheels. The turbine wheels are rotated by dynamic energy of gas exhausted from cylinders, and the compressor wheels are run by a shaft directly connected to the turbine wheels, compresses air, and then supplies the air for cylinders. Engines can combust more fuel with the compressed parentheses, following the example. PLEASE DO NOT RE-ADJUST THESE MARGINS. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow. air, and generate more power with an engine of given exhaust volume. Due to the benefit, all of diesel engines adopt turbochargers, and gasoline engines start to install them recently also.(1)

Since turbochargers spin very high speed such as over 200,000 rpm, they need robust durability and unfortunately induce several noise problems. Most of noises occurred from turbochargers are generally pure tones, bothering passengers because they can easily recognize them even at low level.(2)-(3) As noise quality of cars has become very important, engineers of automakers as well as turbocharger makers exert every effort together to eliminate or reduce the noise as low as people cannot perceive them.(1)-(7)

Turbocharger noises can be largely classified into two categories, air-borne and structure-borne noises. The air-borne noises are BPF (blade-passing frequency) noises induced by wheels, blow(7), pulsation(8), surge, and hissing(9) noises, while the structure-borne noises are whine and howling noises. This paper investigated the pulsation noise, which has the same frequency characteristics of whine noise. But, the two noises have different mechanism of noise generation. The whine noise is caused by the unbalance of rotating parts, and its frequencies correspond to the turbocharger speed (marked as 1N). The pulsation noise was investigated with several combinations of balancing cuttings of compressor wheels, and a kind of countermeasures was found. With it, the noise could be successfully controlled by eyes or machine

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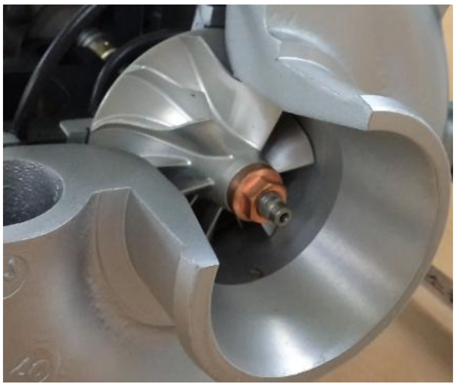
visions before compressor wheels are provided for production lines.

II. Pulsation noise

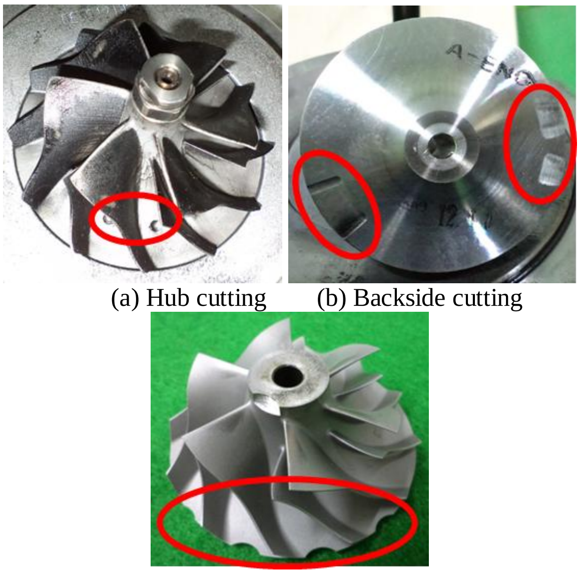
A. Mechanism of noise generation

Pulsation noise was known to be induced by air flow around asymmetric compressor wheels. Since the asymmetry may be made in the process of manufacturing or assembling them, it is natural that they all are asymmetric in some degree. The deviation from the symmetry causes aerodynamic pulsation, corresponding to the pulsation noise.(8) A compressor wheel is shown with main blades and splitters in Fig .1.



"Figure .1" A compressor wheel

It was realized that there exist geometric asymmetries of compressor wheels, which are made in the process of balancing them. Every rotating part should be precisely balanced or machined respectively before assembling since turbochargers spin very high speed and the unbalance of rotating parts causes sometime serious durability problems as well as noises. A compressor wheel and a turbine rotor (made with a turbine wheel and a shaft) are balanced to two planes respectively, and three kinds of methods for balancing compressor wheels are shown in Fig .2. All of the methods cut the end of boss at one plane, but they cuts at different positions at the other plane – hub, backside, or edge marked by a circle in the figure respectively. This paper considered the pulsation noise generated from the compressor wheel of Fig .2(c). Since the number of cuttings is a reason of breaking the symmetry, it was studied by tests how the number, positions, and their combinations of balance cuttings should be related to the noise.



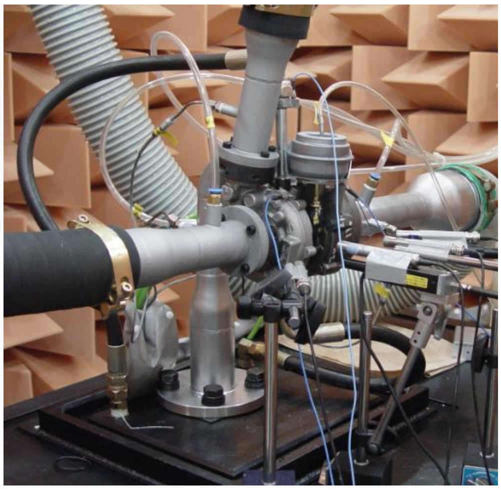
(a) Hub cutting (b) Backside cutting

(c) Edge cutting

"Figure .2" Balancing methods compressor wheel

B. Test facility

Noise tests were done in a semi-anechoic chamber built for turbochargers, which were operated by a control device utilizing air compressed at room-temperature. Boost pressure of compressors was controlled by a valve installed after compressor outlet. The facility is shown in Fig .3.



"Figure .3" Semi-anechoic chamber for turbochargers

Pressures of compressor inlet and outlet were measured with noise and vibration. The noise was measured at 10 cm from the center of a bearing housing, and the vibration was measured on compressor housing at the axial direction of a rotating shaft. The speed was calculated from vibration signals without measuring it.

C. Characteristics of pulsation noise

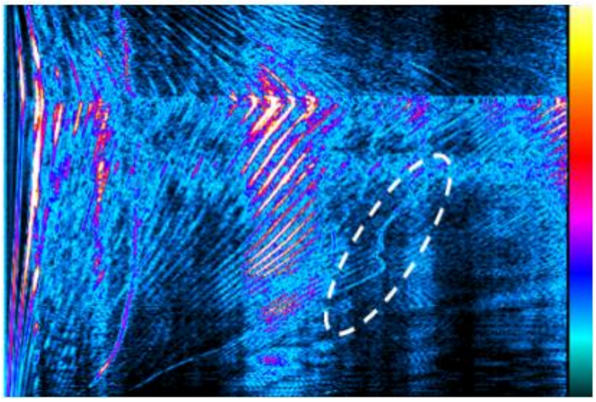
A turbocharger studied in this paper was for a 1.4-liter diesel engine. The noise characteristics were acquired from several times of tests on cars and in the semi-anechoic chamber before this study started in depth.

• The amplitude of whine noise generated from the unbalance of rotating parts of turbochargers might not be related to that of the pulsation noise.
• The strength of pulsation pressure inside compressor outlet seemed to be related to the number of balance cuttings of compressor wheels.

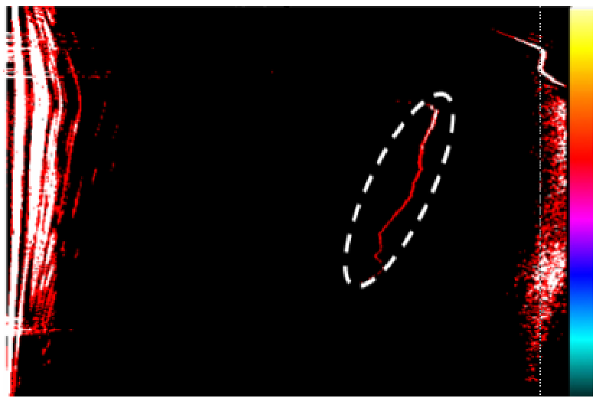
III. IDENTIFICATION OF PULSATION NOISE FACTORS

A. Whine and pulsation noises

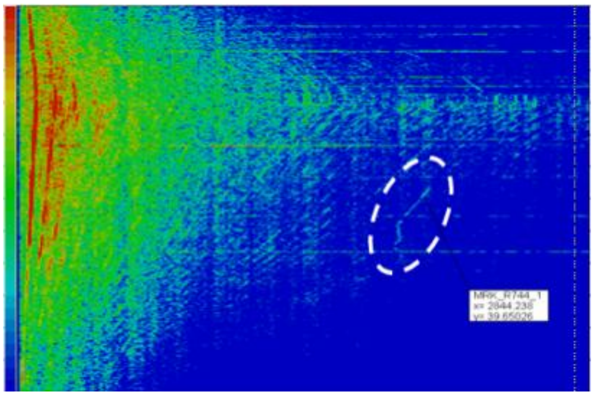
Noise, vibration, and pressure were measured in a running car in order to examine the relation among the values, and 1N components were compared by dotted-circles as shown in Fig .4. The vibration of the whine noise is shown in Fig .4(a), and the pressure of the pulsation noise is shown in Fig .4(b). The 1N noise in cabin is shown in Fig .4(c), and it should be determined by the superposition of the two noise components. But, they could not be separated by signal processing.



(a) Vibration on compressor housing



(b) Pressure inside compressor outlet



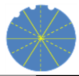
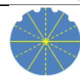
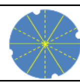
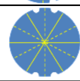
(c) Noise in cabin

"Figure .4" 1N signals in a running car

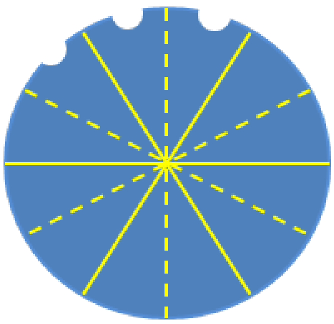
B. Test Samples

It was known by the tests that the pulsation noise is related to the number of balancing cuttings of compressor wheels. In order to numerically relate the number and their arrangement to the strength of the pulsation noise, compressor wheels were prepared. They had 0 to 5 cuttings, and some samples did additional or special ones by machining. The test samples are shown at Table 1, they were investigated in the semi-anechoic chamber.

TABLE 1 Summary of test samples

Items	No.	Positions	Comments
1. Cuttings	0		ex) 
	1-5		No.=3
2. Positions of cuttings	4	Base : next to each other	
		evenly spaced by 1	
		180 degrees by 2	
3. Area of cuttings	-	Base, A	2xA, 4xA
		1 x 2A	vs. 2xA
		2 x 2A	vs. 4xA

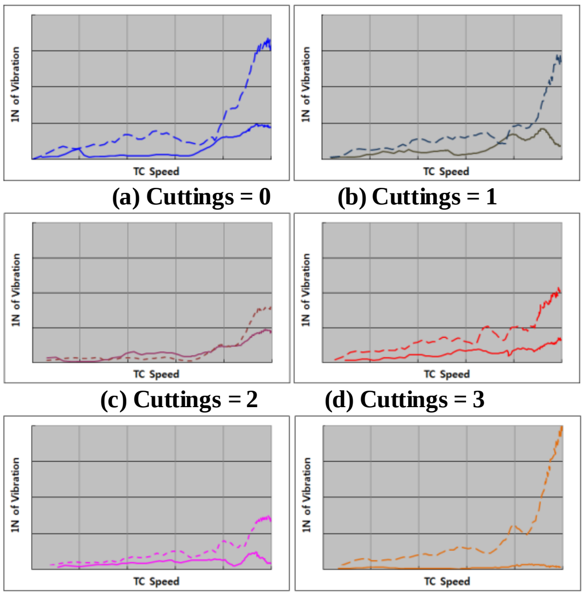
There is an example of a balanced compressor wheel with 3 cuttings shown in Fig .5. The compressor wheel considered in this paper had 6 main blades and 6 splitters. So, the edge of compressor outlet was evenly divided by 12 blades.



"Figure .5" The mumber and positions of balancing cuttings

C. Independency of whine and pulsation noises

In order to see the independency of the two noises first – the whine and the pulsation noises, the two groups of samples were prepared for the same number of cuttings. The one was passed at a balancing production line, and the other was failed to pass because of higher unbalance. The vibrations of whine noise are compared at Fig .6, showing that the values are clearly dependent upon the evaluation results (Pass or Failure) from the production line. On the other hand, the pressure differences of the pulsation noise are negligible for the vibration differences as shown in Fig .7, and the amplitudes of the pressure are globally dependent upon the number of cuttings. It means that vibrations do not affect the amplitude of pressure, furthermore it allows us to appropriately evaluate the pulsation by changing compressor wheels even at breaking the balancing.

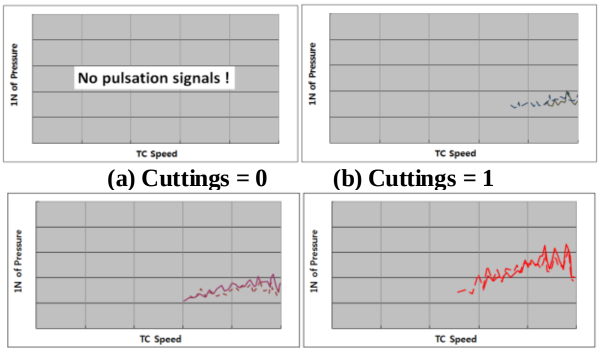


(a) Cuttings = 0 (b) Cuttings = 1

(c) Cuttings = 2 (d) Cuttings = 3

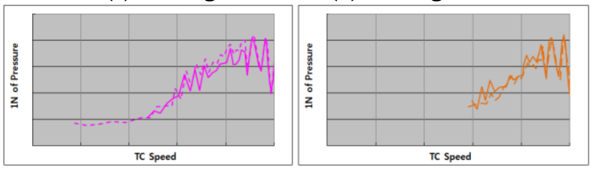
(e) Cuttings = 4 (f) Cuttings = 5

"Figure .6" Vibration comparison to the number of balancing cuttings of compressor wheels and the balancing results (Pass and Failure) in a production line – Solid=Pass, Dotted=Failure in the balancing production line



(a) Cuttings = 0 (b) Cuttings = 1

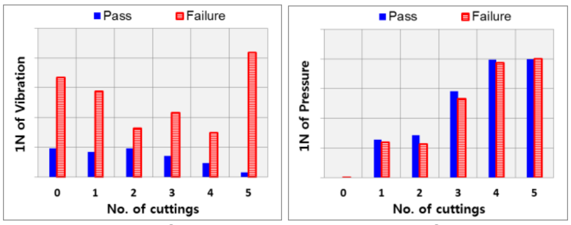
(c) Cuttings = 2 (d) Cuttings = 3



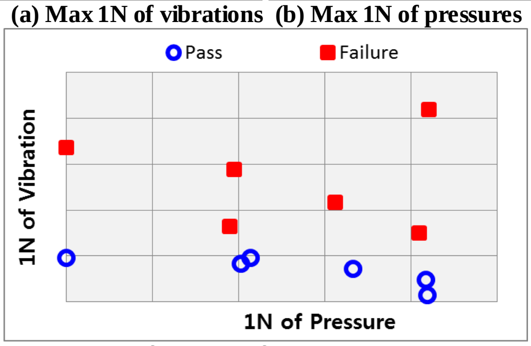
(e) Cuttings = 4 (f) Cuttings = 5

"Figure .7" Pulsation pressures to the number of balancing cuttings and the balancing results (Pass or Failure)

The maximum values of the vibrations and the pressures are briefly compared at Fig .8(a) and Fig .8 (b). Fig .8(c) shows that there is no linear relation between the two factors.



(a) Max 1N of vibrations (b) Max 1N of pressures

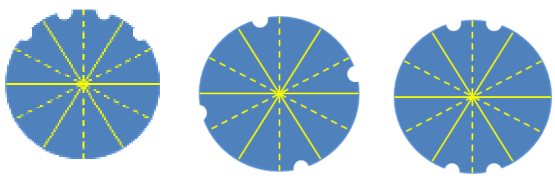


(c) Relation of max 1N of vibrations and pressures

"Figure .8" Comparison of maximum 1N vibrations and pressures to the number of balancing cuttings and "Pass and Failure" in the production line

D. Test samples of different arrangements and areas of cuttings

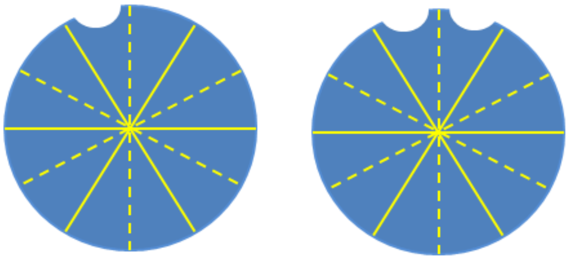
The cuttings are fundamentally gathered at one area or opposite side, next to each other. The size of cuttings is dependent upon the unbalance of compressor wheels, and its maximum width of one cutting is limited in production lines. The distributions of cuttings were investigated for 4 as shown in Fig .8.



(a) Base (b) Evenly spaced by 1 (c) 180 degrees by 2

"Figure .9" Three samples of 4 cuttings

Additionaly, in order to see the influence of its area to the pulsation pressure, different areas of cuttings were compared to the regular size of 1 cutting. The large one had about twice of the regullare size of cuttings, and the wheels were shown in Fig .9. The one large cutting corresonded to 2 regular ones in area, and the two large cuttings did to 4 regular ones.



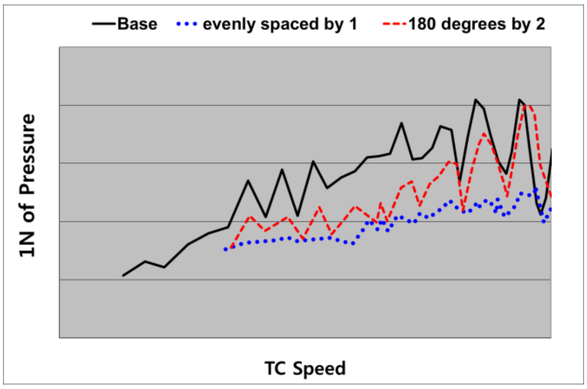
(a) One large cutting (b) Two large cuttings

"Figure .10" Two samples with large cutting areas

E. Test results

a) Different cutting arrangements

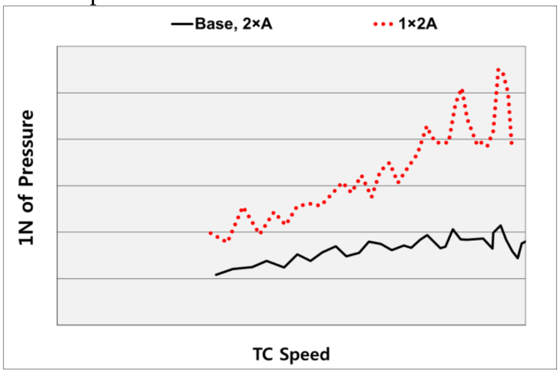
The pressures of the pulsation noise are compared in Fig .10 for the samples with 4 cuttings, shown in Fig .8. The results concluded that the pulsation was stronger as cuttings closely positioned.



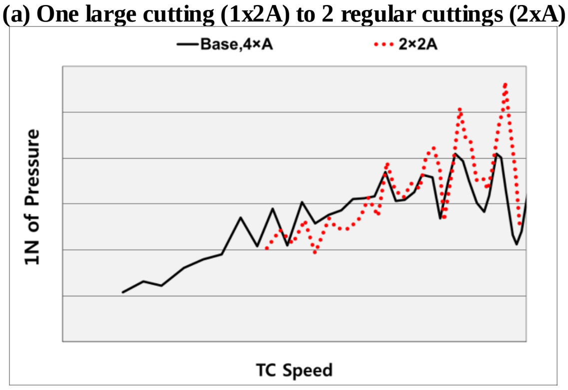
"Figure .10" Pulsation pressures to the three arrangements of 4 cuttings

b) Different cutting areas

The pressures of the two samples shown in Fig .9 were compared for those of 2 and 4 cuttings at Fig .11 respectively. Fig .11(a) showed that one large cutting had much higher pressure than 2 regular cuttings. On the other hand, two large cuttings had higher pressure only at high speed than 4 regular cuttings. It seemed that the large cuttings generally had the same effect of the closely positioned cuttings. It indicated that there was a proper size of cuttings as well as the appropriate number in order to limit the pulsation.



(a) One large cutting (1x2A) to 2 regular cuttings (2xA)



(b) Two large cutting (2x2A) to 4 regular cuttings (4xA)

Fig .11 Pressure comparison for larger cuttings to regular cuttings in the same area

IV. CONCLUSIONS

The pulsation noise of TC noises was investigated, which was generated from a flow inside compressor blades. It was shown by a test that it was not influenced by vibration induced from unbalance of rotating parts. This paper investigated by tests which factors should affect the noise based on the fact that it was related to the number of balancing cuttings of compressor wheels. It concludes as followings.

• The pulsation noise generally increases as the number of cuttings. Thus, the number should be limited to control the noise.
• The noise is dependent upon the arrangement of cuttings. It is higher when these cuttings are next to each other.
• One cutting with the same area of two cuttings has higher pressure than the two cuttings. It seems that there exists a proper size of cuttings as well as the appropriate number for controlling the pulsation noise.

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