CASE 59

Airflow Noise Reduction of Intercoolers

Abstract: Trying to solve the problem of airflow noise motivated us to apply the quality engineering technique. However, we attempted to measure noise, but the ideal function was discussed to improve the uniformity of airflow in the intercooler. As a result, the optimum parameter setting not only solved the noise problem but also improved the cooling system function and reduced the cost.

1. Introduction

As shown in Figure 1, an intercooler (I/C) is placed in a suction air path between a turbocharger (T/C) and engine. Although two cooling methods (air and water) exist, the former is more widely used because its structure is simple, its capacity is easy to increase, and it needs no maintenance.

Figure 2 outlines the structure of an air-cooled I/C. Compressed and heated up by a T/C, sucked air is cooled down when it passes through tubes inside the I/C. At this point, if there is a large amount of resistance against the airflow traveling each tube, the cooling performance deteriorates, and at the same time, the charging efficiency of air into engine cylinders decreases. In addition, if imbalance in airflow occurs in some portions, the cooling performance worsens, and in some cases, a noise problem called airflow noise takes place.

Trying to solve the problem of airflow noise motivated us to apply the quality engineering technique. We attempted not only to take measures for this noise problem but also to establish a design technique applicable to future products and to reduce airflow noise by improving the function of an air-cooled I/C.

2. SN Ratio

The function of an I/C is to cool air, which is compressed and heated up by a compressor of a turbocharger while it passes through tubes inside the I/C. Therefore, to improve the charging efficiency and cooling performance, we needed to reduce resistance against air passing through each tube and to equalize its velocity at any position of the tubes.

Since we can theoretically calculate the airflow velocity traveling inside the I/C, we regarded as the ideal state of the I/C system function that the airflow velocity inside the I/C, y, is proportional to the theoretical velocity, M (i.e., $y = \beta M$), and the velocity is equal at each position.

Thus, in this study we computed airflow velocity from the revolution of I/C and airflow for each condition and evaluated its relationship with actual velocity. For theoretical velocity as a signal factor, denoted by M (m/s), we determined its level by considering the entire range of a car-driving condition.

As noise factors, we picked the position inside the I/C and fluctuation in airflow. For the former we chose two levels, denoted by I_1 and I_2, the nearest (upper) and farthest (lower) positions to the intercooler's inlet. This is because no velocity difference at both positions was considered to indicate that the velocity is equalized all over the I/C. For the latter, maximum and minimum airflows, denoted by J_1 and J_2, respectively, were measured (Table 1).

Judging from our technical experience and knowledge, as control factors we selected eight factors, including dimension and shape, which were regarded to greatly affect the airflow velocity inside the I/C. Table 2 shows the control factor and level selected.

Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

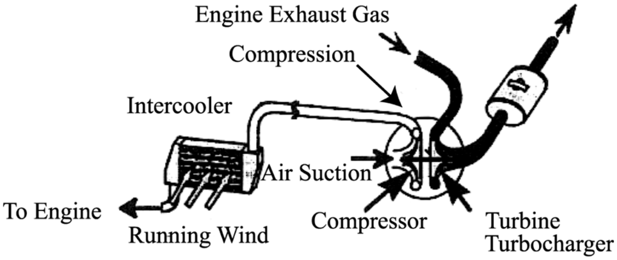

Figure 1
Turbocharger and intercooler

Using an L_{18} orthogonal array, we assigned control factors to its inner array and signal and error factors to its outer array for experiments 1 to 18. Table 2 shows the data. Based on these data, we proceed with our analysis for computing SN ratio and sensitivity (Figure 3) using the following calculations.

Total variation:

$$S_T = 3.4^2 + 5.6^2 + 6.7^2 + \cdots + 34.4^2 = 11{,}009.41 \qquad (f = 28) \tag{1}$$

Effective divider:

$$r = 29.0^2 + 30.1^2 + 40.0^2 + \cdots + 58.1^2 = 26{,}007.54 \tag{2}$$

Linear equations:

$$L_1 = (29.0)(3.4) + (30.1)(5.6) + (40.0)(6.7) + \cdots + (58.1)(12.2) = 2539.58$$

$$L_2 = 2003.07$$

$$L_3 = 8772.67$$

$$L_4 = (29.0)(13.6) + (30.1)(18.3) + (40.0)(20.0) + \cdots + (58.1)(34.4) = 7340.69 \tag{3}$$

Variation of proportional term:

$$S_\beta = \frac{(L_1 + L_2 + L_3 + L_4)^2}{4r} = 8202.828 \qquad (f = 1) \tag{4}$$

Variation of proportional terms due to noise:

$$S_{N\beta} = \frac{L_1^2 + L_2^2 + L_3^2 + L_4^2}{r} - S_\beta = 2663.807 \qquad (f = 3) \tag{5}$$

Error variation:

$$S_e = S_T - S_\beta - S_{N\beta} = 142.775 \qquad (f = 24) \tag{6}$$

Error variance:

$$V_e = \frac{S_e}{24} = 5.9490 \tag{7}$$

Total error variance:

$$V_N = \frac{S_T - S_\beta}{27} = 103.9475 \tag{8}$$

SN ratio:

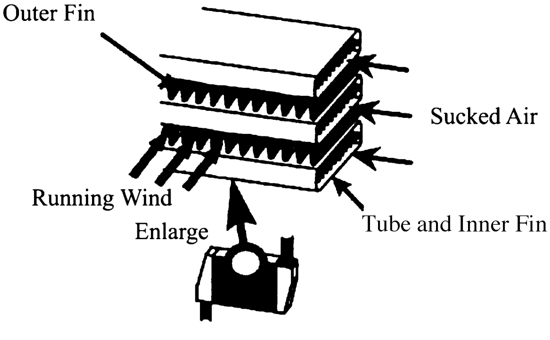

Figure 2
Structure of intercooler

Table 1
Measured data of airflow (m/s)

Number of Revolutions of T/C:		6	8			10		
Amount of Airflow:		6	6	8	10	6	8	10
M: Theoretical Velocity (m/s):		M_1 29.0	M_2 30.1	M_3 40.0	M_4 46.1	M_5 41.3	M_6 49.5	M_7 58.1
I_1: upper	J_1: max.	3.4	5.6	6.7	9.0	8.5	10.7	12.2
	J_2: min.	2.7	4.4	5.4	7.0	6.5	8.4	9.8
I_2: lower	J_1: max.	15.4	21.8	24.0	26.3	31.3	36.0	41.7
	J_2: min.	13.6	18.3	20.0	21.8	26.8	30.0	34.4

$$\eta = 10 \log \frac{(1/4r)\ (S_\beta - V_e)}{V_N} = -28.19 \text{ dB} \qquad (9)$$

Sensitivity:

$$S = 10 \log \frac{1}{4r} (S_\beta - V_e) = -8.02 \text{ dB} \qquad (10)$$

Under the estimated optimal and current conditions, we prototype I/Cs and conduct a confirmatory experiment. For the sake of simplicity, we do not detail the measured data and calculation procedure. The results are summarized in Table 3 and Figure 4.

Looking at the confirmatory experimental results, we can see that reproducibility was good for the SN ratio. Under the optimal condition, we improved the SN ratio by 8.77 dB compared to that under the current conditions. This is equivalent to reduction of variability in airflow velocity by two-thirds. On the other hand, the sensitivities under both conditions did not differ significantly. As a result, we notice that we can drastically reduce the difference in airflow velocity at each position without changing the average flow (Figure 4).

3. Confirmation of Improvement

Figure 5 shows the result for improvement confirmed based on measurement of airflow noise under the current and optimal conditions.

As the figure shows, under the optimal condition, we can reduce the noise level by 6 dB at the

Table 2
Control factors and levels[a]

Control Factor	Level 1	Level 2	Level 3
A: inlet tank length (mm)	Standard[a]	Standard + 20	—
B: tube thickness (mm)	5*	7	9
C: inlet tank shape	1	2[a]	3
D: inflow direction of inlet tank	1[a]	2[a]	3[a]
E: tube length	120	140[a]	160
F: tube end shape (deg)	0	30[a]	60
G: inner fin length (mm)	Standard −7.5	Standard[a]	Standard + 7.5
H: inner diameter of inlet tube (mm)	Φ45	Φ55[a]	Φ65[a]

[a] Current level.

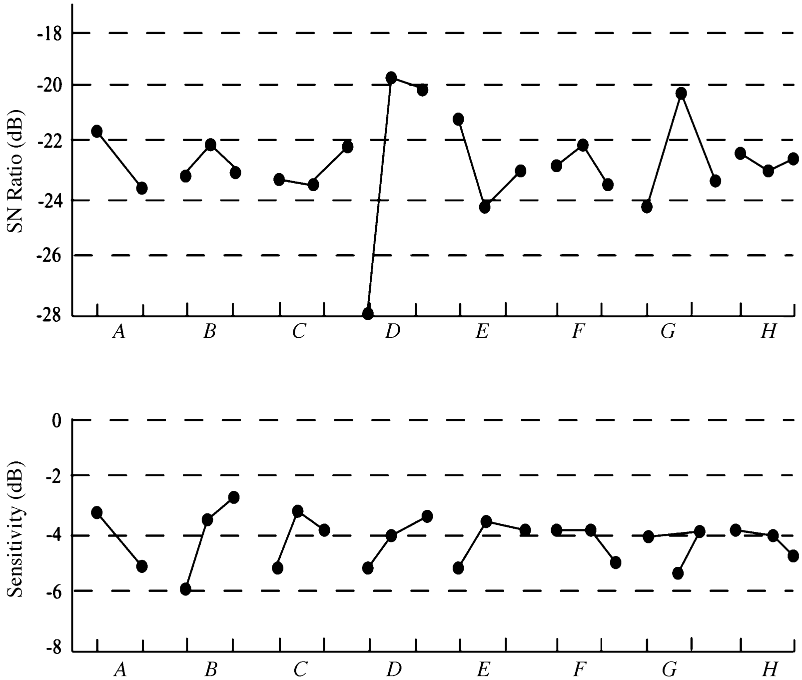

Figure 3
Response graphs

driving condition where a maximum airflow noise is generated in contrast to that under the current condition. This level can be regarded as satisfactory for our design target.

Similarly, we confirm the improvement of cooling performance and show the results in Figure 6. The temperature shown in the figure indicates the decrease in the temperature of airflow per unit length of tube. The larger the value becomes, the higher the cooling performance.

Under the optimal condition, the cooling performance was improved by 20% as compared to that under the current condition. This performance improvement represents that the total efficiency of the engine was also ameliorated by 2%.

In addition, if the cooling performance required for a certain I/C was the same as before, we could reduce the size of the I/C, thereby leading not only to cost reduction but also to higher flexibility in the layout of an engine room and easier development.

Table 3
Estimation and confirmation of SN ratio and sensitivity (dB)

	SN Ratio		Sensitivity	
Condition	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Optimal	−19.07	−19.74	−4.33	−4.22
Current	−26.55	−28.51	−5.76	−5.15
Gain	7.48	8.77	1.43	0.93

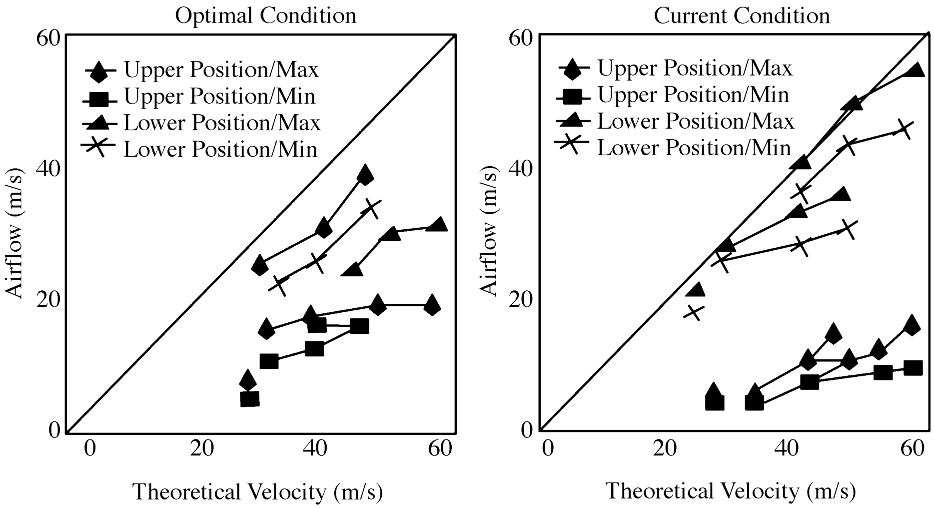

Figure 4
Airflow in confirmatory experiment

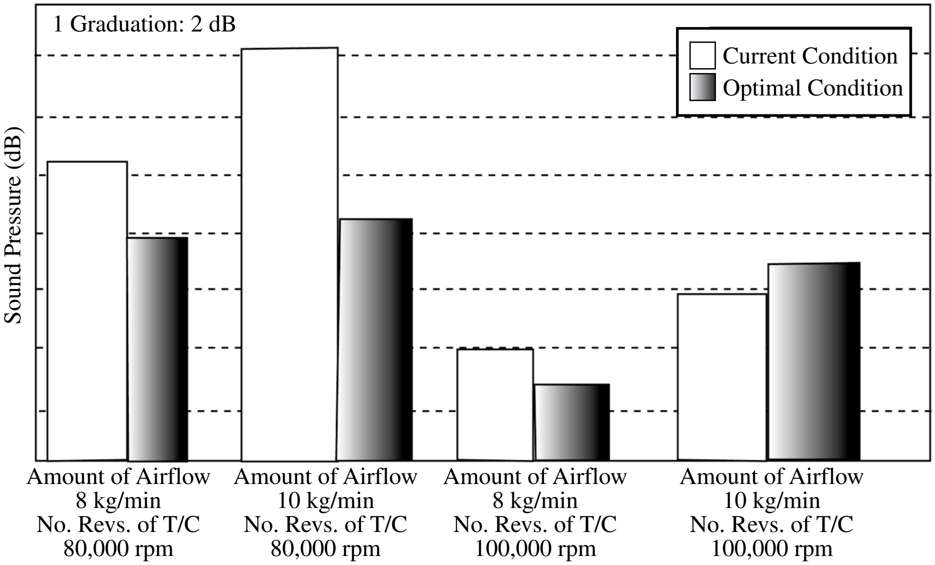

Figure 5
Confirmatory result for intercooler airflow noise

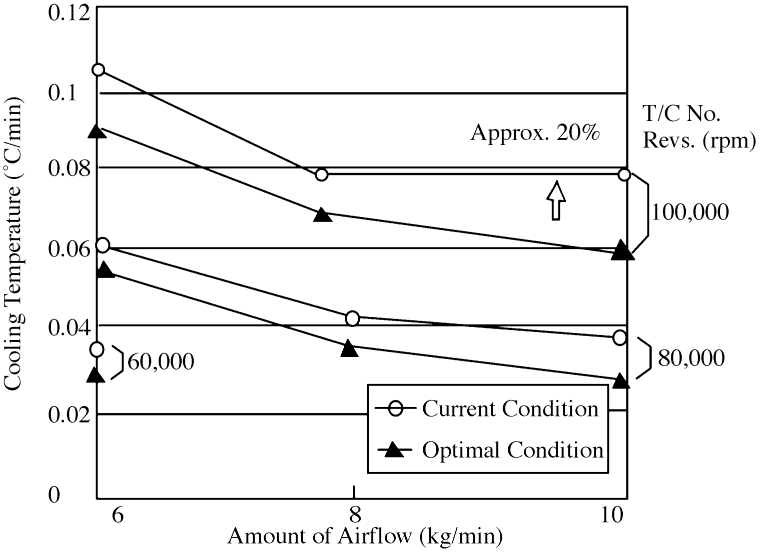

Figure 6
Confirmatory result for cooling performance

Reference

Hisahiko Sano, Masahiko Watanabe, Satoshi Fujiwava, and Kenji Kurihara, 1998. Air flow noise reduction of inter-cooler system. *Quality Engineering*, Vol. 6, No. 1, pp. 48–53.

This case study is contributed by Hisahiko Sano, Masahiko Watanabe, Satoshi Fujiwara, and Kenji Kurihara.