

Research of Low Heat-mass 4 in 1 Exhaust Manifold Noise Reduction Technology

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ABSTRACT

A noise generation mechanism of intermittent high-frequency noise during deceleration and high-frequency noise under load in a dual-thin-wall 4-in-1 exhaust manifold (hereinafter referred to as 4-1 manifold) have been investigated by using Computational Fluid Dynamics (CFD) and actual measurement of exhaust gas pressure fluctuation in the exhaust manifold. Modified gas flow in the exhaust manifold by CFD enabled a reduction in actual exhaust gas pressure fluctuation, which is the excitation force, and actual radiated noise has been reduced.

1. Introduction

As requirements for automotive emissions performance⁽¹⁾ become more stringent, increasing use is being made of the type of 4-in-1 (4-1) exhaust manifolds and manifolds with low heat-mass structures⁽⁴⁾ in order to enhance the temperature rise performance of the catalyzer^{(2), (3)}.

However, 4-1 exhaust manifolds and low heat-mass (thin-wall) structures generate more high-frequency noise than conventional type of 4-in-2-in-1 (4-2-1) exhaust manifolds, causing a decline of the quietness in cabin. Radiated noise levels were reduced in existing exhaust manifolds in one of two ways: either structural response is reduced by increasing the thickness of the walls, or separators are added into the collector area of the manifold to reduce excitation (semi 4-2-1). Both of these methods, however, directly increase heat mass, and are therefore incompatible with the enhancement of emissions performance. The purpose of the research discussed in this paper is to outline the noise generation mechanism in order to develop a technology capable of reducing noise by reducing excitation force, thus enabling radiated noise of a low heat-mass manifold equivalent to that of a 4-2-1 manifold.

The noise reduction technology developed in this project has been applied in the next mass production model, and has significantly reduced the high-frequency noise level radiated from the manifold under high load operating condition.

2. High-frequency Intermittent Noise at Deceleration

2.1. Characteristics of High-frequency Intermittent Noise at Deceleration

Figure 1 shows time history data for high-frequency intermittent noise, pressure measured at the exits of the manifold ports, the noise level close to the manifold (9k-12k [Hz] B.P.F.) and TDC pulse (2 [Pls./Rev.]) when the engine is decelerating.

These data indicate that high-frequency intermittent noise is generated 4 times for every 2 revolutions of the engine, and that negative pressure waves are generated in exhaust manifold ports 1 to 4 with the same timing. The timing of the negative pressure wave generation corresponds to the ignition timing in the test engine.

Figure 3 shows pressures measured at various parts of the engine shown in Fig. 2 in operation, plotted with crank angle.

During acceleration, as shown in Fig. 3(a), at exhaust valve open timing, combustion chamber pressure is higher than port pressure, and there are no negative pressure waves shown in Fig. 1 at the exit of the exhaust manifold ports. During deceleration, however, as shown in Fig. 3(b), fuel cut control suspends combustion and therefore at exhaust valve open timing, the combustion chamber pressure is lower than the pressure at the exits of the exhaust manifold ports. This induces a reverse flow, causing the rapid pressure drop at the exits of the ports, thus generating a

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negative pressure wave of the type shown in Fig. 1.

CFD was used to analyze the reverse flow of the gas, based on the assumption that this pressure fluctuation is the excitation force of high-frequency intermittent noise at deceleration.

2.2. Presumption of Noise Generation Mechanism by CFD

Steady flow CFD analyses were conducted using the model shown in Fig. 4 to analyze the reverse gas flow from the collector to the ports.

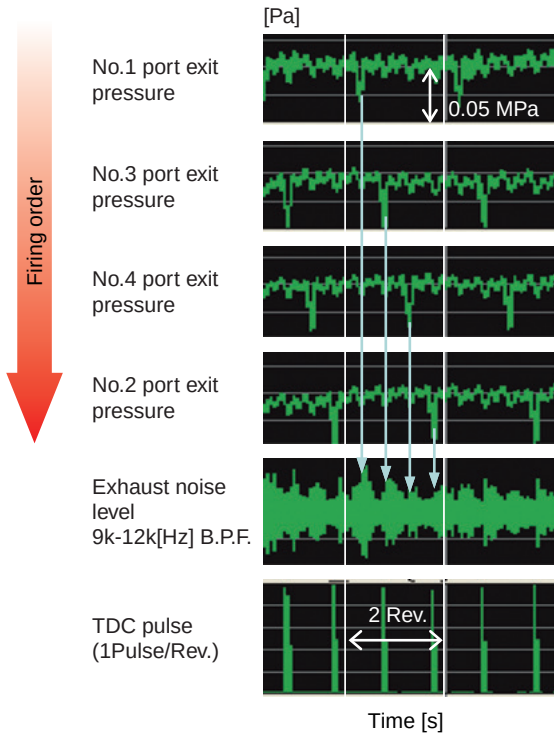


Fig. 1 Generating timing of high-frequency intermittent noises at deceleration

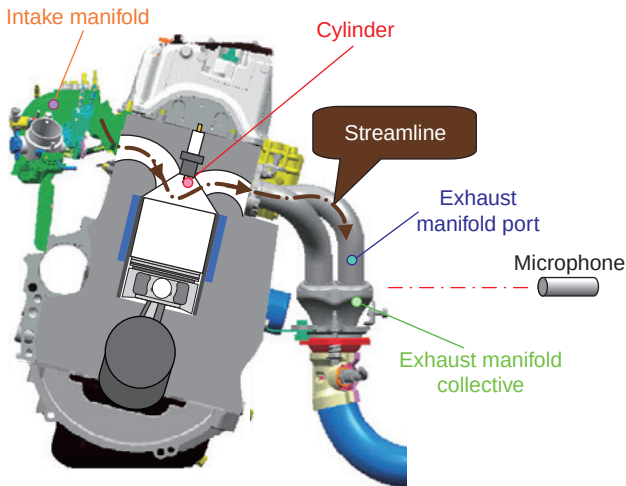


Fig. 2 Measurement position of engine and exhaust manifold pressure

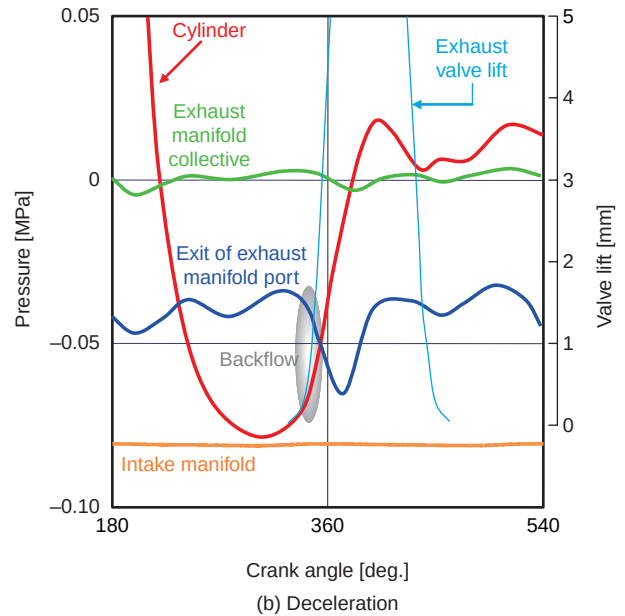
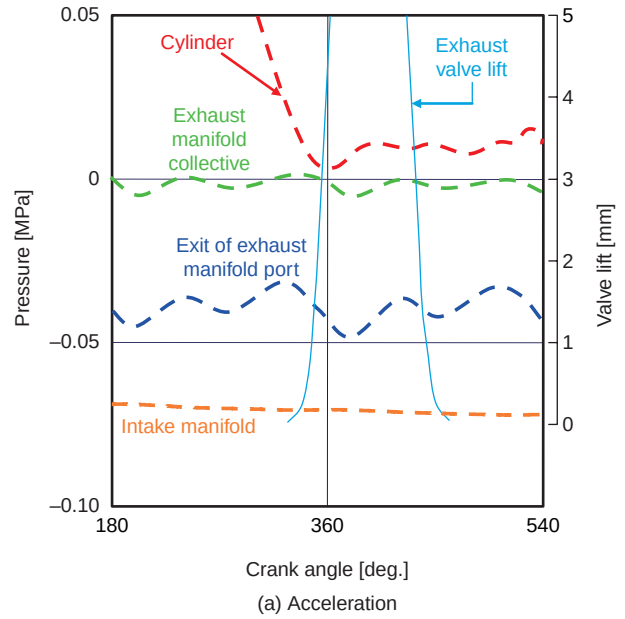


Fig. 3 Pressure relationships of engine and exhaust manifold

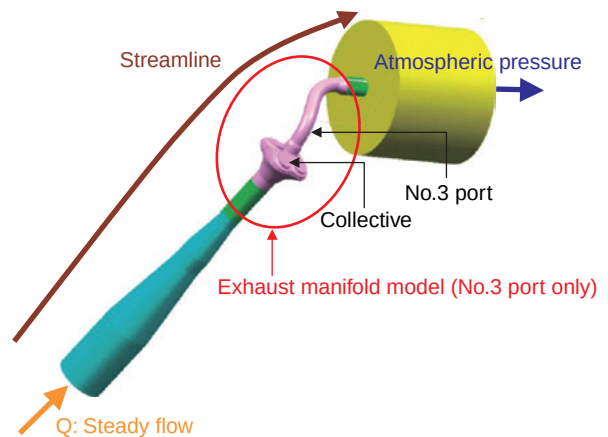


Fig. 4 CFD model for reversed flow analysis

Figure 5 shows the streamlines around the port collector by CFD analysis. As Fig. 6 shows, in a conventional dual-thin-wall configuration, the bulges near the edges of the ports enable the structure to slide, producing gaps at the port edges. When exhaust gas flows in reverse it is blocked by these gaps, and this is believed to produce an excitation force that leads the increase in the level of negative pressure waves. Calculations made with the gaps closed showed a reduction in reverse flow in the collector.

2.3. Effect of Port Edge Shape Modification

Figure 7 shows the negative pressure waves in exhaust manifold ports with and without the gap at the edge of the port exits, measured

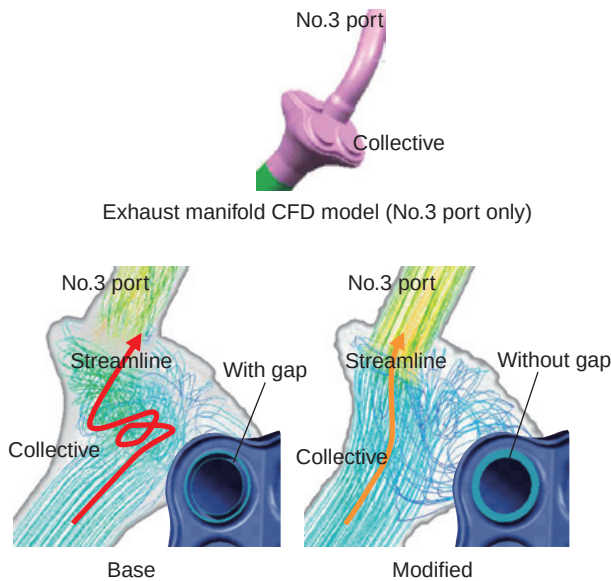


Fig. 5 Result of reversed flow streamline analysis by CFD

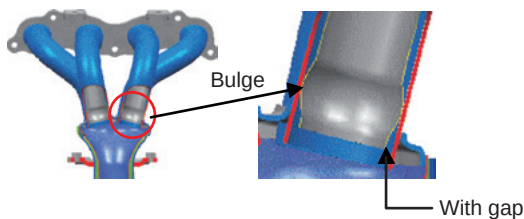


Fig. 6 Edge shape of exhaust manifold port

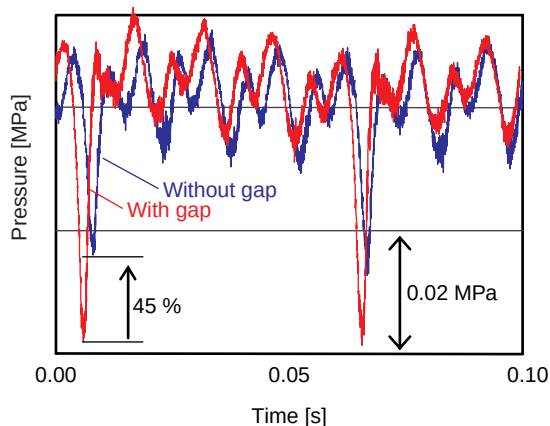


Fig. 7 Port exit pressure of effective edge shape

on an actual engine on the basis of the results of the CFD analysis described in section 2.2. The port without the gap produces negative pressure waves approximately 45% lower than that of the port with the gap.

Figure 8 demonstrates the effect of eliminating the gap at the edge of the port exits on high-frequency intermittent noise at deceleration. Intermittent high-frequency noise in the 9-12 kHz range is reduced by a maximum of 8 dB.

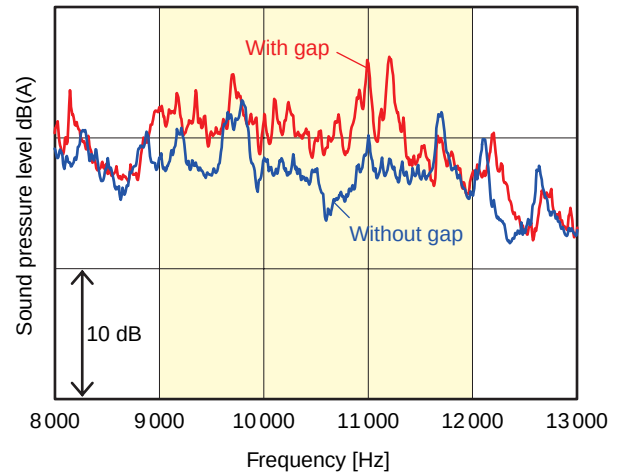


Fig. 8 Level of high-frequency intermittent radiation noises of exhaust manifold

3. High-frequency Noise when Engine is Under Load

3.1. Characteristics of High-frequency Noise when Engine is under Load

Figure 9 shows the high-frequency noise level measured close to the exhaust manifold when the engine is under load. The sound pressure level of the 4-1 low heat-mass manifold at frequencies of above 4 kHz is approximately 8 dB higher than that of the conventional 4-2-1 manifold.

In addition, as Fig. 10 shows, the exhaust gas pressure level in the exhaust manifold collector is approximately 7 dB higher at above 4 kHz in the 4-1 low heat-mass manifold than in the 4-2-1 manifold.

3.2. Presumption of Exhaust Gas High Frequency Fluctuation Generation Mechanism

CFD was used to calculate fluid velocity vectors and pressure distribution in order to determine the cause of the pressure fluctuation difference in the port collector of the manifolds.

Figure 11 shows an enlarged view of the edge of a port exit in a 4-1 low heat-mass exhaust manifold. Where the bulge causes the cross-sectional area to change, there is a change in the gas flow speed, causing pressure to increase.

Figure 12 shows results for (a) pressure distribution on the inner wall of the exhaust manifold and (b) fluid velocity vectors obtained by steady flow CFD.

Pressure on the wall of the port collector was higher in a 4-1 manifold than in a 4-2-1 manifold, as shown in Fig. 12(a). In

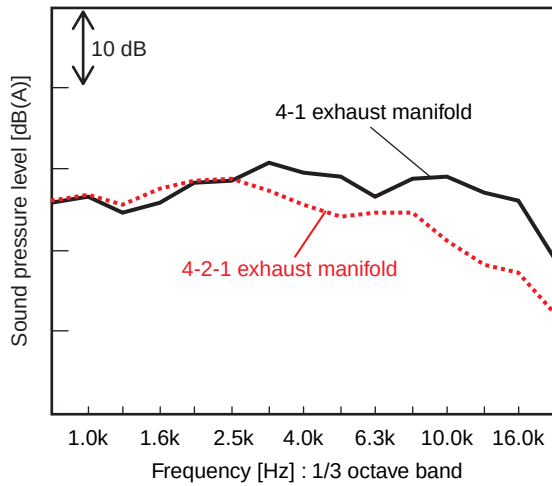


Fig. 9 Sound pressure level close to exhaust manifold

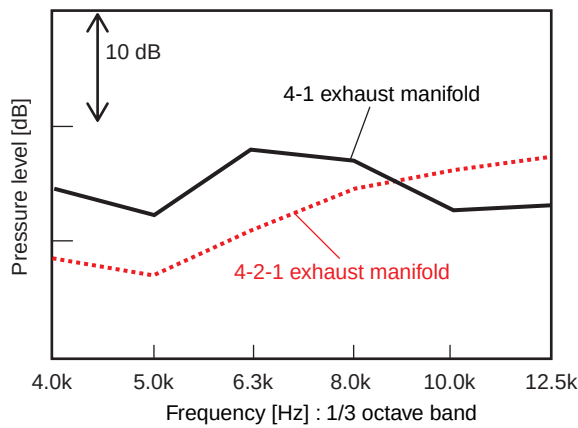


Fig. 10 Pressure at collective of exhaust manifold

addition, the fluid velocity vectors shown in Fig. 12(b) demonstrate that in the 4-1 manifold the flow path of gas flowing from the port to the collector is constricted, and the gas flow impinges on the collector wall.

These results led to the presumption that the cause of the high levels of high-frequency pressure fluctuation in 4-1 low heat-mass exhaust manifolds is the increase in the flow speed of gas flowing into the collector caused by the change in the cross-sectional area at the edge of the port, and by the impact of the gas with the collector wall.

3.3. Countermeasure Study of High-frequency Noise when Engine is under Load

Studies were conducted to determine a shape for the exhaust manifold that would enhance gas flow and reduce high-frequency exhaust pressure fluctuation.

(1) Modifications to change flow speed at edge of port exit

As Fig. 13 shows, the bulge was eliminated to make the port exit straight.

In addition, SUS mesh support was adopted as the method of support for the outer and inner pipes.

(2) Modifications to reduce gas impingement on collector wall

The incident angle of the ports was changed to 20° and the shape of the collector has also been changed according to this angle change

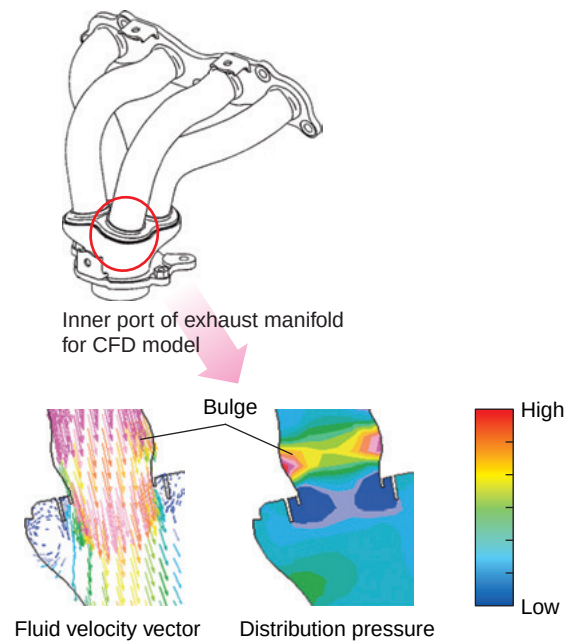
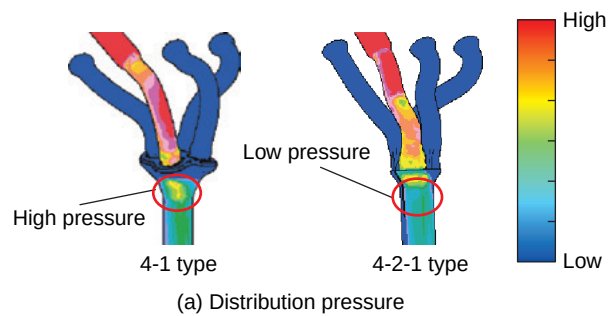
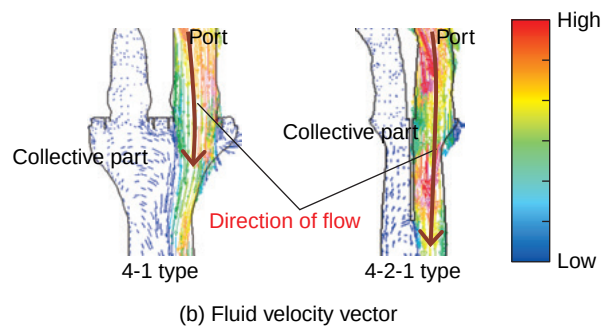


Fig. 11 CFD result for bulge effects



(a) Distribution pressure



(b) Fluid velocity vector

Fig. 12 CFD result for steady flow

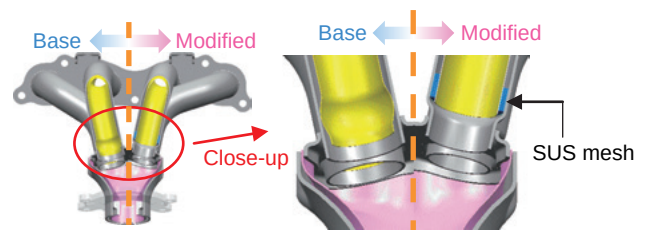


Fig. 13 Enhancement of edge shape of exhaust manifold port

as shown in Fig. 14.

Figure 15 shows CFD results for the modifications shown in Figs. 13 and 14.

The elimination of the bulge, in other words, straightening of the edge of the port, has reduced pressure at the port exits, and the incident angle change of the ports and the shape change of the collector has reduced the pressure increase caused by gas impingement on the collector wall.

3.4. Verification of Effectiveness of Modified Manifold in Actual Engine

Figures 16 and 17 respectively show comparisons of pressure at the edge of a port and in the collector, before and after modifications.

These results show that the change of gas flow has reduced the high-frequency exhaust pressure fluctuation that acts as the excitation force for high-frequency noise when the engine is under

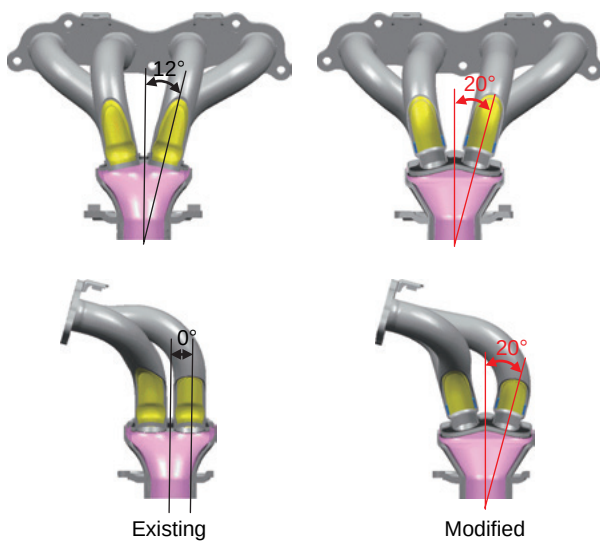


Fig. 14 Enhancement of angle of incidence of exhaust manifold port

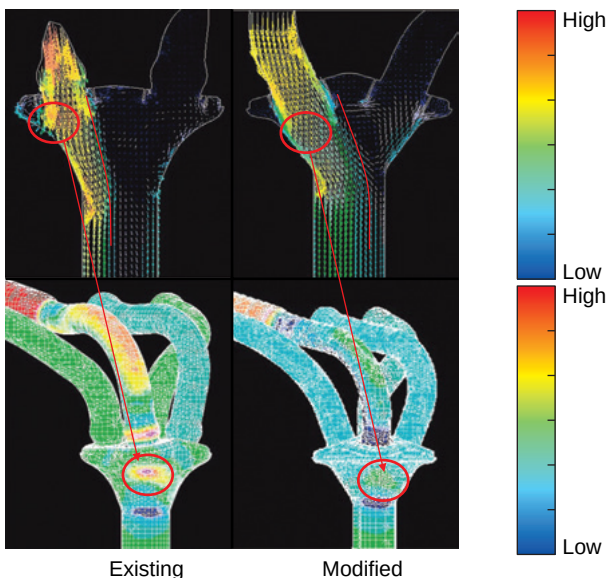


Fig. 15 CFD result for fluid velocity vector and pressure

load by approximately 6 dB.

3.5. Effect of Change in Inner Port Support Structure

Tests were conducted to verify the effectiveness of using SUS mesh as the support structure for the inner ports of the modified exhaust manifold shown in Fig. 13. Figure 18 shows the results of dividing the outer port vibration level by the inner port exhaust pressure level (excitation force), to compare the vibration level of the outer port per unit excitation force. Sensitivity in the high-frequency range has been reduced by 6 dB in the manifold employing SUS mesh support.

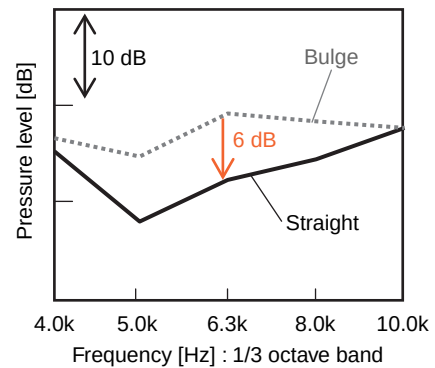


Fig. 16 Effect of edge shape on pressure level

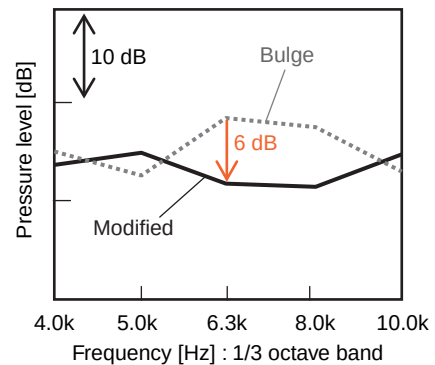


Fig. 17 Effect of enhancement of angle of port

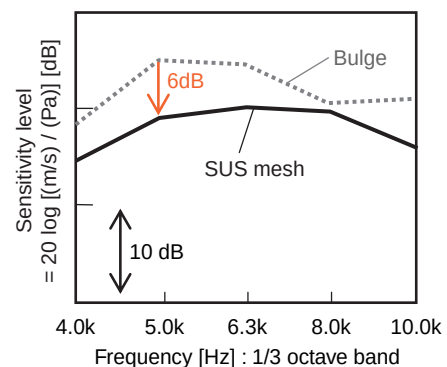


Fig. 18 Estimate of sensitivity to vibration/pressure of exhaust manifold

3.6. Effectiveness in Radiation Noise Reduction in an Actual Manifold when Engine is Under Load

Figure 19 shows measurements for noise from conventional and modified low heat-mass manifolds compared with target measurements from a 4-2-1 manifold.

The measurements show that modification of the flow in the modified exhaust manifold has enabled achievement of the initial target: the same level of high-frequency noise as produced by a 4-2-1 manifold when the engine is under load.

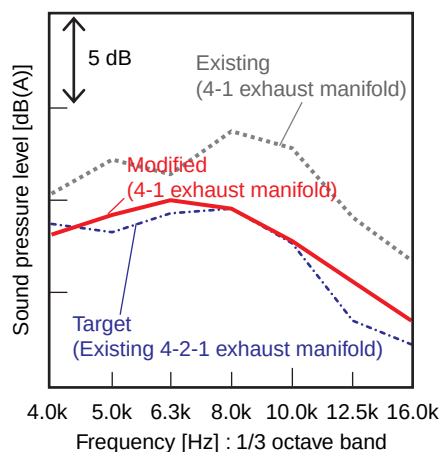


Fig. 19 Radiation exhaust manifold noise

4. Conclusion

This project outlined the noise generation mechanism of high-frequency intermittent noise during deceleration, and of high-frequency noise when the engine is under load, in a dual thin-wall 4-1 exhaust manifold. The development of a noise reduction method to reduce excitation force enabled the achievement of a noise level equivalent to that produced by a 4-2-1 exhaust manifold while retaining a low heat-mass structure.

- (1) This research demonstrated that high-frequency intermittent noise during deceleration is caused by reverse flow in the exhaust manifold. Elimination of the gap at the edge of the ports of the dual-wall manifold reduced the level of negative pressure waves, thus reducing the generated noise level.
- (2) This research demonstrated a correlation between the impact of the gas flow against the exhaust manifold collector wall and the generation of high-frequency noise when the engine is under load. Modification of the port exit shapes and the collector (angle of incidence of the ports) modified the gas flow, reducing the high-frequency component of exhaust pressure fluctuation.
- (3) The employment of SUS mesh support for flotation between the inner and outer pipes in the dual-wall structure was extremely effective in reducing surface vibration in the exhaust manifold.

References

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