

Visualization of Air Current when Noise Occurs with Throttle Rapidly Opening

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ABSTRACT

Pressure measurements were conducted and airflows were visualized inside the intake manifold to help enable an overall understanding to be obtained of the phenomenon of noise occurring under conditions of rapid throttle opening during engine operation. The use of plastic intake manifolds and drive-by-wire (DBW) has made this noise more conspicuous. The results of attempts to identify the sound source showed that the noise was radiated from the surface of the intake manifold. For measurements of the behavior of the airflows inside the intake manifold, airflows were visualized while the engine was in operation using a high-speed camera (taking advantage of recent performance enhancements) and a special lighting system in a method that can be applied during the development process. The results of these measurements demonstrated that noise resulting from the collision of high-speed airflows is the origin of the noise under study.

1. Introduction

Modularization and the achievement of weight savings have long been demanded for engine components, and the use of plastic as a material and the reduction of the thickness of parts have been pushed ahead in order to realize these goals. The use of plastic for intake manifolds came into use around 15 years ago, and today many engines employ plastic intake manifolds. At the same time, the expansion of the degree of freedom of throttle control with the application of DBW has increased the need for rapid opening of the throttle to control the resting position of the pistons, in order to respond to demands for enhanced driving performance and environmental performance.

This has resulted in noises, which were previously not heard when aluminum intake manifolds and mechanically controlled throttles were employed, becoming conspicuous when the throttle is rapidly opened.

Figure 1 shows the results of measurements of the frequency characteristics of transmitted sound and sound pressure for different intake manifold materials.

These results indicate that for intake manifolds of the same shape, the transition from aluminum to plastic as the material decreases sound transmission loss, thus increasing noise. Automakers have been conducting research on the reduction of noise under conditions of rapid opening of the throttle for more than 10 years⁽¹⁾. Technologies for noise reduction employing nets and other devices⁽²⁾ are widely applied in mass-production vehicles.

Previous research has conducted analyses using measurements of sound inside intake manifold pipes and computational fluid dynamics (CFD); there are few reported examples in which measurements of airflow behavior in actual pipes have been conducted⁽¹⁾.

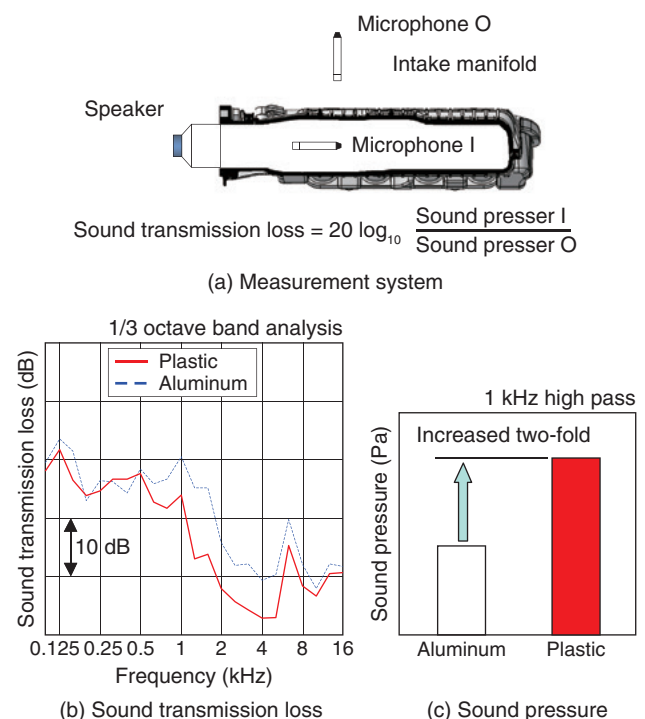


Fig. 1 Comparison of sound transmission loss and noise

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The research discussed in this paper sought to provide guideposts towards measures to respond to noises by visualizing and studying airflow behavior when noise is generated during engine operation.

2. Development Goals

The goals of the research were to:

- (1) Identify the location in which intake manifold noise is generated; and
- (2) Visualize airflow behavior in the intake manifold pipes. By these means, the relationship between noise and airflow behavior and fluctuations in the internal pressure of the intake manifold pipes is determined, and an understanding of the phenomenon of the noise is achieved.

3. Identification of Location of Noise Generation

A 2.4 L engine fitted with a plastic intake manifold was employed in tests. Table 1 shows the engine specifications.

The noise under consideration is most conspicuous when the throttle is rapidly opened while the driver races the engine and engine speed has dropped to 1000 rpm. These conditions were considered as one racing cycle, and tests were conducted in which this cycle was repeated. The setting for the degree of opening of the throttle was identical to the conditions under which the noise phenomenon becomes noticeable.

Airflow behavior when the throttle is rapidly opened is a transient phenomenon, and obtaining stable results therefore represents a challenge. Because of this, the maximum values for sound and pressure during a single racing cycle were measured several tens of times, and average values were obtained.

3.1. Tests using Sound Source Identification Device

A sound source investigation device employing multiple microphones, which is generally used for unsteady-state sound source investigation, was employed to examine the noise occurring during rapid opening of the throttle. Figure 2 shows the device employed and an example of the results obtained. The tests indicated that the noise is radiated from the surface of the intake manifold, as shown in Fig. 2.

3.2. Detailed Analysis of Intake Manifold

A detailed analysis of the intake manifold was conducted in order to further clarify the location in which the noise is generated.

3.2.1. Measurements of near-field sound, surface vibration, and internal pressure of intake manifold

Figure 3 shows the test intake manifold.

The intake manifold was divided into three sections (the section close to the throttle body, the chamber section, and

Table 1 Engine specifications

Item	Specification
Engine type	4-stroke gasoline engine
Cylinder configuration	In-line 4-cylinder
Bore x stroke (mm)	87 x 99
Displacement (cm ³)	2354
Compression ratio	10.5
Valve train	16-valve DOHC i-VTEC
Intake manifold	Plastic with glass fiber
Max. power (kW [PS] / rpm)	142 [193] / 7000
Max. torque (Nm [kgm] / rpm)	220 [22.4] / 4400

the port section), and the internal pressure of the manifold was measured in addition to near-field sound and surface vibration.

Because the internal pressure of the intake manifold instantaneously increases to atmospheric pressure from a state of vacuum when the throttle is rapidly opened during engine operation, high-frequency fluctuating components are generated in addition to a significant change in pressure. Given this, it is desirable to employ measurement equipment with a wide dynamic range, up to high frequencies. Conventionally, the fluctuating components of sound pressure have been measured using probe microphones, but the present project employed pressure sensors that have minimal effect on airflow behavior and are able to take measurements up to high frequencies.

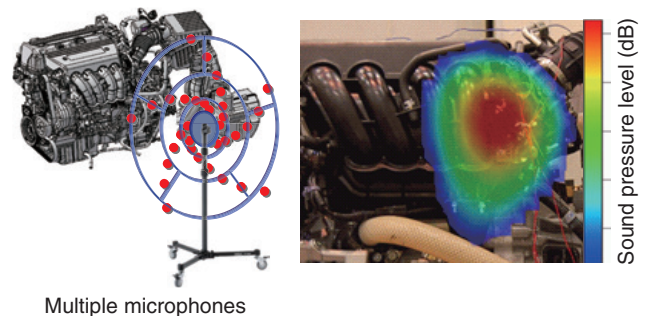


Fig. 2 Sound source investigation analysis

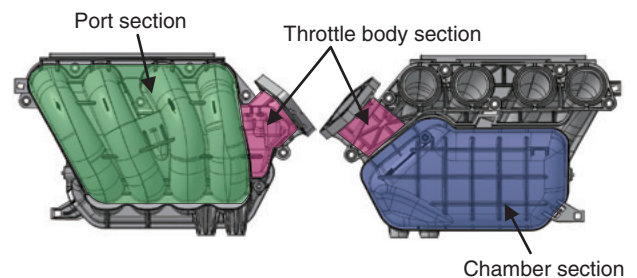


Fig. 3 Measurement intake manifold

The measurement results shown in Fig. 4 indicate the following:

- (1) (a) and (c) indicate that sound pressure is highest in the section close to the throttle body, where pressure fluctuation is high;
- (2) (a) indicates that the internal pressure fluctuations in the intake manifold are approximately five times greater in the section close to the throttle body than in the port section; and
- (3) (a), (b), and (c) indicate that an area in which the surface vibration of the intake manifold is high exists in the port section (in which internal pressure fluctuation is low), and the level of near-field sound is also high in this section.

3.2.2. Modal analysis of intake manifold

Given that an area in which levels of intake manifold vibration and near-field sound are high exists in the port section, in which internal pressure is low, it was possible to consider that a vibration transmission effect was occurring due to the structure. A modal analysis was therefore conducted. Measurement conditions were identical to firing operation, and measurements were conducted with the intake manifold coupled to the engine and the engine supported by engine mounts. A film surface mode exists in the area in which vibration is high in the high-frequency range at 1 kHz and above. Figure 5 shows an example of the mode, surrounded by a red circle.

3.3. Summary of Clarification of Location of Noise Generation

Based on the results above, it was conjectured that the noise is airflow noise, produced by the sound component generated when pressure fluctuations close to the throttle

body are transmitted through the intake manifold, and the component radiated from the area in which the mode is generated when the intake manifold is excited from the interior and vibration is transmitted.

Given this, understanding airflow behavior close to the throttle body could be considered important in identifying the source of the noise.

4. Visualization of Airflow Behavior in Pipes

4.1. Study of Visualization Methods

Based on the results discussed in Chapter 3, it could be conjectured that the airflow behavior in the intake manifold close to the throttle body was a factor in the occurrence of noise. The potential for visualization of airflow in the intake manifold was therefore studied.

The following methods were available for overall visualization of the airflow:

- (1) Use of a transparent intake manifold of the same shape as the manifold under study; or
- (2) Insertion of a transparent cylinder in the area in which the airflow behavior occurs.

With regard to method (1), it would be possible to consider the airflow behavior occurring in the intake manifold identical to the actual airflow behavior, but the method presented numerous issues, including the setting of the light source, the position for measurements, the distortion of the image due to the shape of the manifold, and the transmission coefficient of the light. This method was therefore not employed in the present study.

Method (2) could be considered to offer measurements that resolved the issues indicated above, but also presented the possibility that the behavior of the airflow might differ. A test was therefore conducted to determine whether this would be the case.

Internal pressure was measured and the effect of the addition of a transparent extension pipe was studied in order to determine whether it produced any difference in internal airflow behavior.

The results are shown in Fig. 6. Comparisons at the same distance from the throttle body show almost identical values for fluctuation in internal pressure, indicating that airflow behavior remains the same even when a transparent extension pipe is used.

Based on this result, measurements were taken using method (2).

4.2. Overview of Visualization and Measurement

Figure 7 shows a diagram of the visualization and measurement system.

An oil mist is introduced upstream from the throttle body for the purpose of visualization. High-speed camera images in the transparent section and signals for sound, pressure, and other parameters transmitted via an A/D board are synchronized and input to a PC. By this means, it is possible to determine the behavior of the airflow when

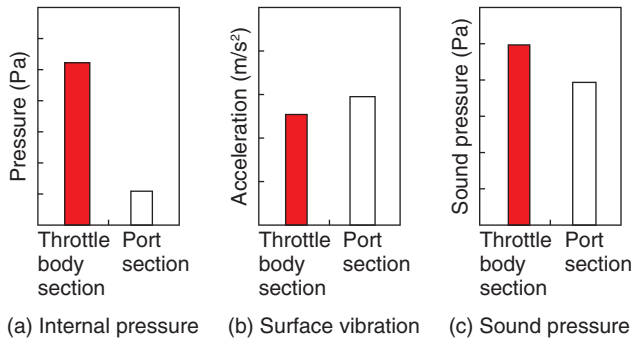
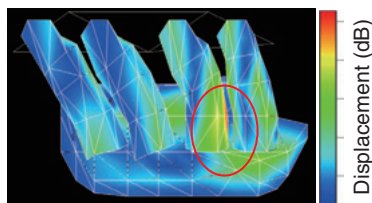


Fig. 4 Sectional analysis of sound source



Port section mode at 1280 Hz

Fig. 5 Modal analysis result

airflow noise occurs.

When imaging using a high-speed camera under normal light, light from the exterior continuously radiates onto the surface, and this means that the images become darker the higher the speed at which they are taken.

When measuring airflow behavior in a transparent pipe, noise generated by surface reflection and internal reflection, in addition to darkness, makes it challenging to isolate the airflow to be studied.

Particle image velocimetry (PIV) measurement using laser sheet light, a method in which strong light energy that can be synchronized with the operation of a high-speed camera is radiated onto the subject, is available to respond to these issues, but this method necessitates large equipment and advanced technology, and it is therefore not employed for measurements while engines are being operated in development laboratories.

It proved to be possible to visualize the airflow during engine operation using a special light (manufactured by nac

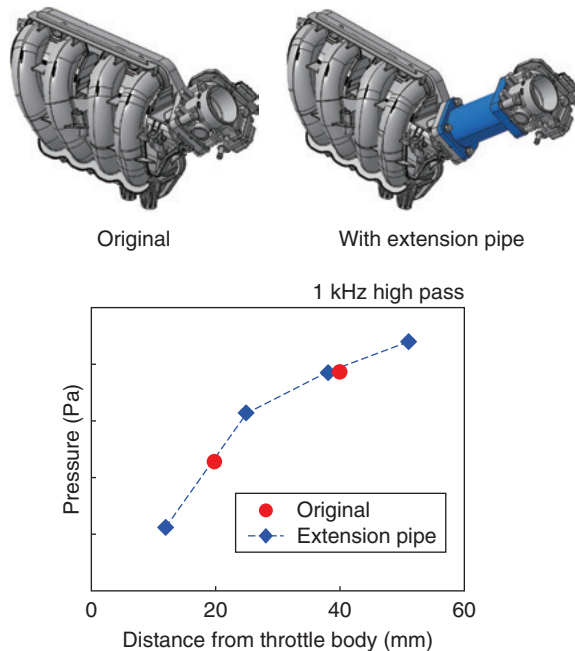


Fig. 6 Comparison of internal pressure

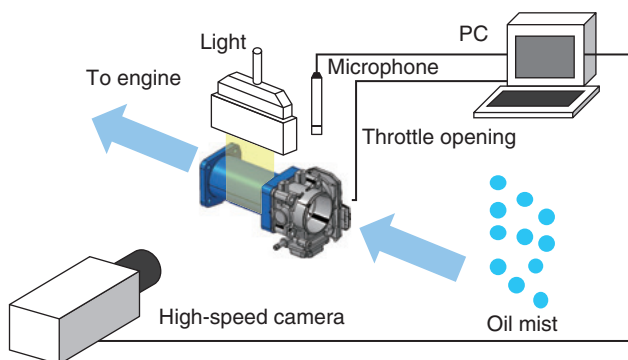


Fig. 7 Visualization system

Table 2 Specifications of light source

Light	250 W metal halide
Power consumption	290 W
Voltage	100 V 50/60 Hz
Filter	UV, IR cut
Shutter	Continuously mechanical type
Cooling	Fan

Image Technology) that employs linearly arrayed optical fibers with a metal halide light as a light source; the system concentrates scattered light by means of a cylindrical lens to form a light sheet.

Table 2 shows the specifications of the special light system, and Fig. 8 shows its configuration.

4.3. Measurement of Internal Pressure Distribution in Pipes

First, measurements of the internal pressure distribution in the pipes were conducted.

Figure 9 shows a cross-section of the extension pipe

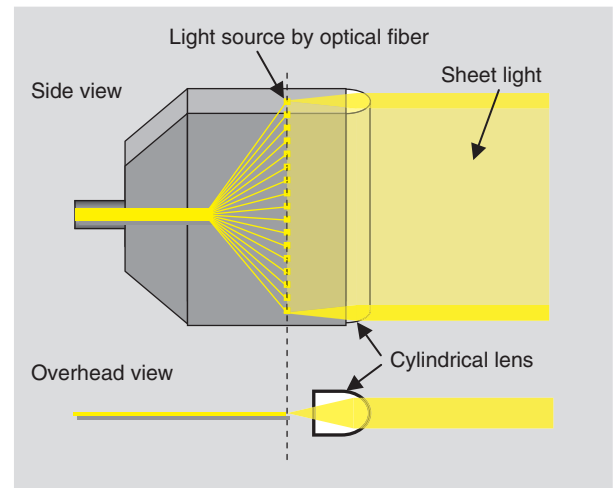


Fig. 8 Special light system

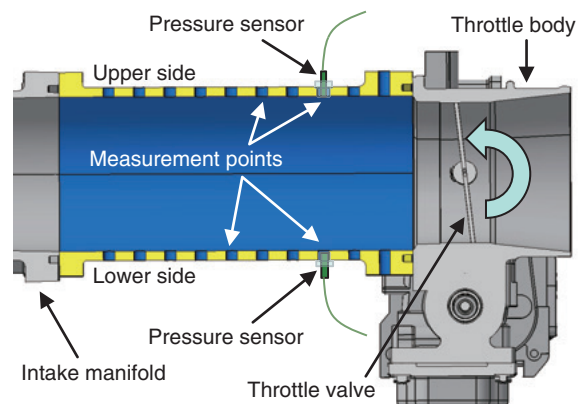


Fig. 9 Measurement extension pipe

used in the measurements. Ten pressure sensors were positioned at uniform intervals on the interior surfaces of the upper and lower sides of the pipe in relation to the throttle, for a total of 20 sensors. As described in Chapter 3, the maximum values during a single racing cycle were measured several tens of times, and expressed as an average.

The results shown in Fig. 10 demonstrate the following:

- (1) The amount of pressure fluctuation close to the throttle body is higher on the lower side of the pipe than on the upper side; and
- (2) Pressure fluctuation reaches its maximum at a distance of between 40 and 90 mm from the throttle body.

These results indicate that when airflow noise is produced, there is intense pressure fluctuation close to the throttle body.

4.4. Visualization of Airflow

The imaging conditions for the high-speed camera were set at a resolution of 448 x 368 pixels and a frame rate of 10000 fps, and moving images were taken of one racing cycle. Synchronized with the camera, sound and degree of throttle opening were measured, and visualization results with values close to average measurements for sound were employed.

Still images were captured from the sequence of moving images where the airflow noise was at its maximum.

Figure 11 shows an image of the measurement planes.

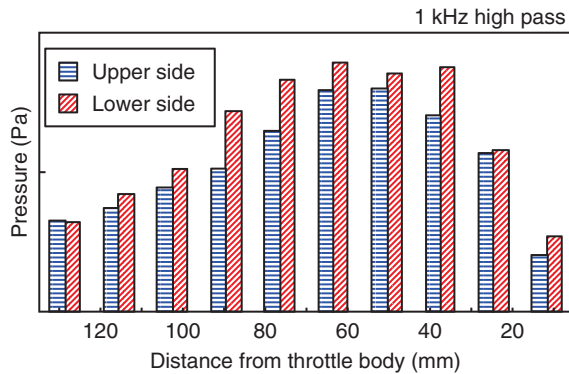


Fig. 10 Inner pressure distribution of extension pipe

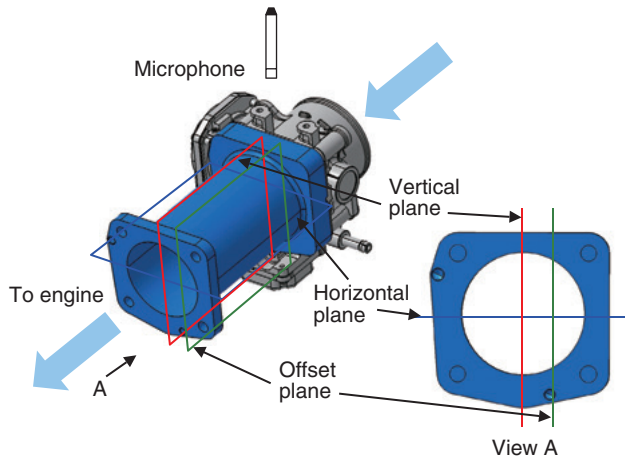


Fig. 11 Visualization planes of air flow

Measurements were conducted in a perpendicular direction to the throttle valve axis, where airflow fluctuation was considered to be most intense, and in a central cross-section in the direction of the axis of the extension pipe (vertical plane). The conditions for isolation of the still images are shown in Fig. 12, and the measurement results are shown in Fig. 13.

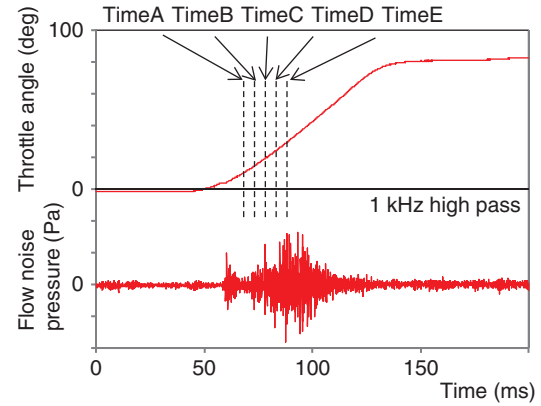


Fig. 12 Condition of visualization of air flow at vertical plane

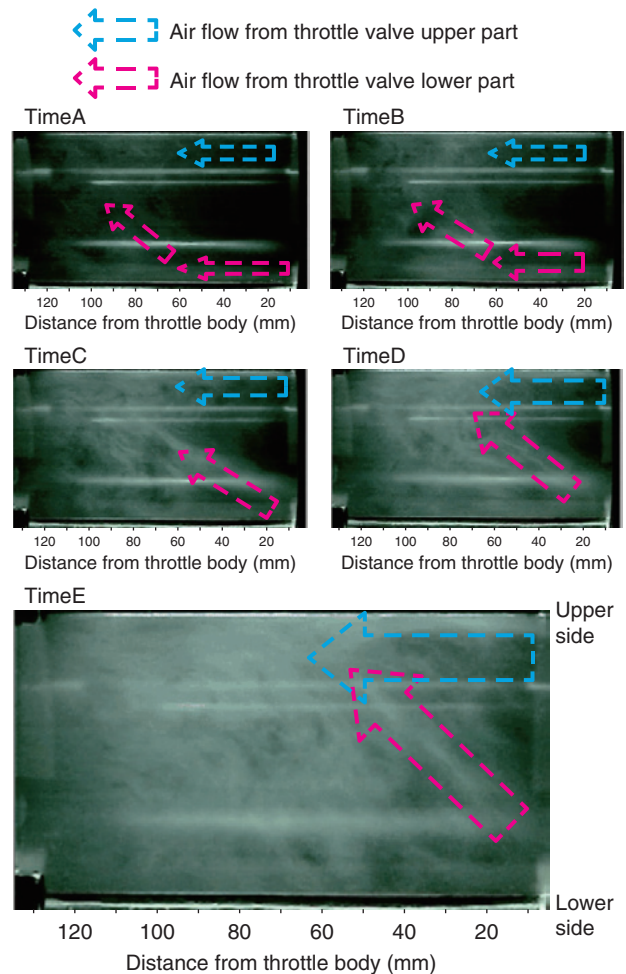


Fig. 13 Visualization of air flow at vertical plane

Figure 14 shows results for visualization with the position of the light offset 20 mm towards the camera in the direction of photography (offset plane). Figure 15 shows results for visualization in a horizontal cross-section through the center of the throttle valve axis (horizontal plane).

Conducting measurements in each of these planes makes it possible to easily obtain a three-dimensional grasp of airflow behavior in the pipes.

The following results were obtained using this method:

- (1) Results for Time A to E in Fig. 13 show that when the throttle valve is opened, the airflow flowing from the lower side of the valve rises diagonally within the pipe at a distance from the throttle body, and during the timing when noise is at its maximum, it collides, at the distance of 40 to 90 mm, with the airflow flowing directly along the surface of the inner wall of the upper side of the pipe and the upper side of the throttle valve;
- (2) For the airflow flowing along the upper side of the throttle valve, there is a high-speed flow flowing directly along the upper side of the interior of the pipe at Time E (Fig. 13), and a high-speed flow flowing diagonally downwards along the surface of the pipe wall (Fig. 14); and
- (3) The airflow flowing from the upper side of the throttle valve in a downwards direction along the inner wall of the pipe (Fig. 14) collides with the airflow from the lower side of the throttle body at a position from 40 mm to 90 mm from the throttle body (Fig. 15).

4.5. Changes in the Behavior of the Airflow when the Throttle Opening Speed is Reduced

Measurements were conducted after reducing the speed of throttle opening in order to measure behavior when the airflow was altered. The results of visualization are shown in Fig. 16, and results for airflow noise are shown in Fig. 17.

Comparison with the results shown in Fig. 13 indicates that the reduction of the speed of opening of the throttle eases the behavior of the inflowing airflows. This results in a reduction in sound pressure.

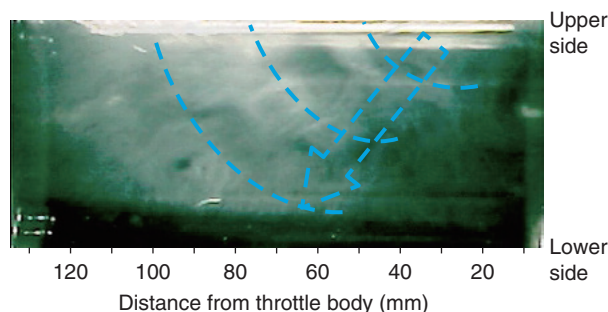


Fig. 14 Visualization of air flow at offset plane

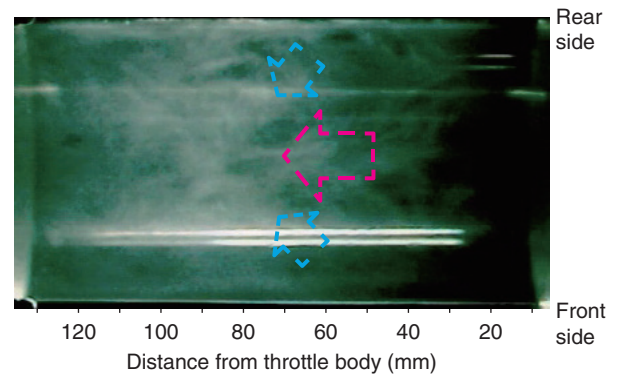


Fig. 15 Visualization of air flow at horizontal plane

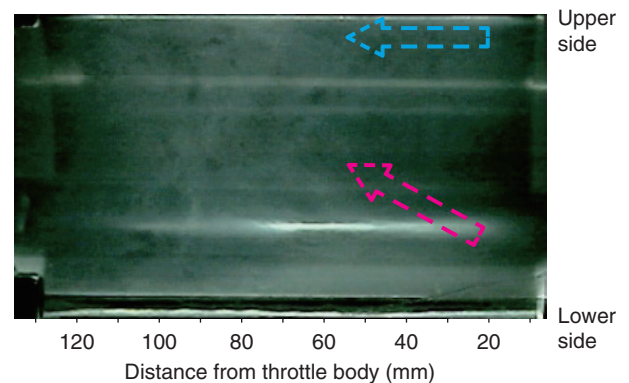


Fig. 16 Visualization of air flow at vertical plane when decreasing throttle speed

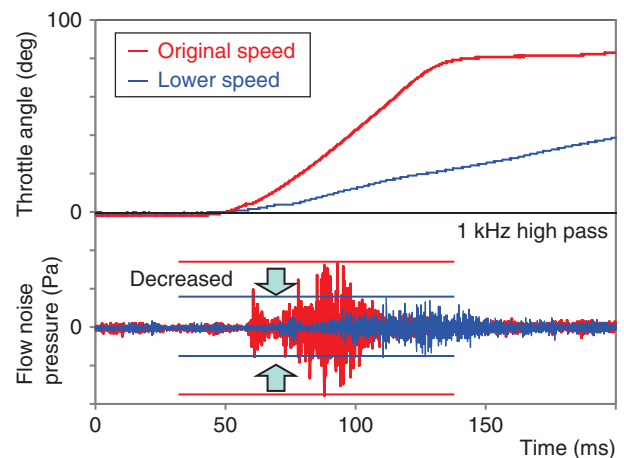


Fig. 17 Comparison of flow noise when decreasing throttle speed

5. Study of Reduction of Airflow Noise and Summary of Visualization

5.1. Study of Reduction of Airflow Noise

Measurements were conducted with a split board dividing the interior into upper and lower sections in order to alleviate the collisions between airflows. The results of

visualization are shown in Fig. 18, and results for airflow noise are shown in Fig. 19.

Comparison with the results shown in Fig. 13 indicates that the use of a split board helps to prevent the collision between the inflowing airflows, thus reducing sound pressure.

5.2. Summary of Visualization of In-pipe Airflow Behavior

Because measurements of in-pipe pressure and the results of visualization show that airflow noise occurs at the same timing as the maximum fluctuation in the pressure inside the pipe occurs in the region in which the airflow flowing diagonally upwards from the lower side of the throttle valve collides with the airflow flowing directly along the wall surface of the upper side of the pipe and the upper side of the throttle valve, it is believed that this collision between airflows is the major factor in the occurrence of airflow noise.

This conjecture is also supported by the fact that measurements conducted when the speed of throttle opening was reduced and measurements conducted when a split board was added showed a reduction in sound pressure.

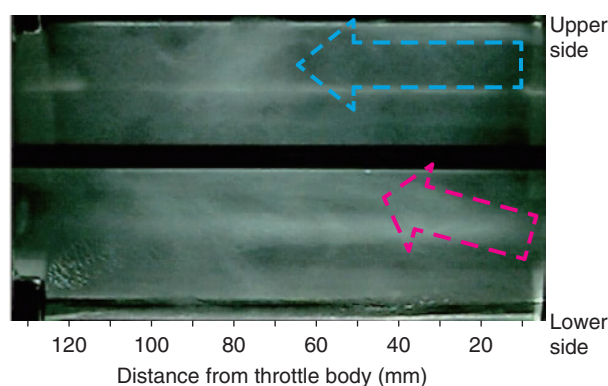


Fig. 18 Visualization of air flow at vertical plane when appending separator

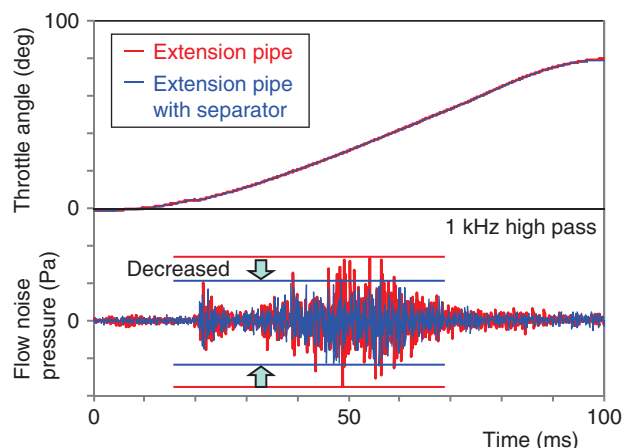


Fig. 19 Comparison of flow noise when appending separator

6. Conclusion

- (1) It was determined that noise occurring when the throttle is rapidly opened is airflow noise originating in airflows inside the intake manifold, radiated from the surface of the intake manifold.
- (2) The phenomenon of collision between high-speed airflows close to the throttle body inside the intake manifold when the engine is in operation was clarified, and was found to contribute to airflow noise.
- (3) The results of measurements of airflow behavior inside the pipe during engine operation conducted with the aid of a transparent pipe and special lighting clarified the factors involved in airflow noise. The method was shown to be an effective method of visualization able to be used in the vehicle development process.

The results of the study discussed in this paper have clarified the behavior of the in-pipe airflows when airflow noise occurs. They have also provided guideposts for ameliorating airflow noise.

References

- (1) Nakase, Y., Kanehara, K., Ohara, K., Yamamoto, K., Miyaji, Y.: The Flow Noise Reduction when Rapidly Opening The Throttle, JSAE Paper, No. 12-00, p. 13-16 (2000)
- (2) Nakase, Y., Kanehara, K., Ohara, K., Yamamoto, K., Miyaji, Y.: Flow Noise Reduction upon Quick Opening the Throttle, SAE Paper, 2001-01-1429 (2001)
- (3) JP, 3337630, B (1997)

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