Aerodynamic Noise Reduction using Porous Materials and their Application to High-speed Pantographs

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Aerodynamic noise is a major source of wayside noise generated along high-speed railway lines, making it important to reduce the phenomenon. To this end, a new aerodynamic noise reduction method that involves covering the surface of objects with a particular porous material has been developed. To verify its aerodynamic noise reduction effects, wind tunnel tests using cylinders and a high-speed pantograph were conducted, and the noise produced was measured. The results showed that the noise generated from the cylinders and the high-speed pantograph were reduced by the application of porous materials, thus confirming that the method is effective in reducing such aerodynamic noise.

Keywords: high-speed railway, aerodynamic noise, pantograph, porous material

1. Introduction

In Japan, it is essential to reduce wayside noise along railway lines to enable the introduction of even faster high-speed trains. Aerodynamic noise generated from such trains represents the major noise source in the high-speed range, because the acoustic power of this kind of noise is proportional to the sixth power of the train speed [1].

In general, noise barriers are placed along high-speed railway lines in Japan to prevent propagation of noise from the lower part of the car body. However, these barriers have little effect in terms of preventing noise from the upper part of the body. Aerodynamic noise caused by pantographs installed on train roofs is one of the dominant sources of noise generated by high-speed trains, and it has therefore become increasingly important to reduce this kind of noise.

There are a number of methods of reducing the degree of aerodynamic noise, one of which involves modifying the shape of the structure in question. As aerodynamic noise is caused by unsteady vortices that occur in the flow [2], various structures with streamlined shapes that prevent unsteady vortex shedding have prevailed. As an example, attempts have been made to modify the shape of a panhead that forms part of a pantograph [3]. Such efforts have demonstrated that a streamlined panhead shape is effective in reducing aerodynamic noise.

Another vital method is flow control. Although the modification of structural shapes is effective in reducing aerodynamic noise, such measures are limited to a certain extent due to the various functions that must be maintained. The reduction of such noise has been achieved by covering the surface of objects with fur materials [4], [5] - a technique based on the reduction of vorticity. However, it is difficult with the application of fur materials to satisfy the requirements of durability against weathering in railway vehicles.

We have proposed the application of porous materials as a new method of airflow control that is broadly applicable to railway vehicles. To investigate the effects of such materials, we first applied them to cylinders and measured the aerodynamic noise radiated in wind tunnel tests. Next, we applied the materials to a high-speed pantograph and evaluated noise levels and noise-source distribution in wind tunnel tests.

This paper outlines the results of these tests and discusses the effects of porous materials.

2. Porous materials

Several types of porous material are used in industry, and it is possible to select structures and materials appropriate for the intended purpose. Porous materials are classified into open-cell and closed-cell types according to their structure, where open cells are mutually connected and closed cells are independent.

In this study, we selected open-cell type porous materials to reduce aerodynamic noise. We assumed that the closed-cell type would not be effective because flow is not able to enter the porous material. Verification of this supposition and the mechanism of noise reduction are described in the references [6].

Figure 1 presents enlarged views of two different open-cell type porous materials made of urethane and metal. These materials (porous urethane and porous
metal) have an identical form referred to as a three-dimensional frame (net-like) structure. The porosity of the materials applied is more than 97 percent, and the format ‘# + number’ is used as an index describing the number of cells. #8, #13 and #20 mean that approximately eight, thirteen and twenty cells are included per 25.4 mm (one inch) respectively. Large numbers represent high density, while small ones indicate lower values. The thickness of the materials can be freely selected and fixed as 5 mm or 10 mm in this study. These porous materials are applied to a cylinder and a high-speed pantograph. Porous urethane can be procured at low cost and is easy to handle, but has less durability against weathering. Conversely, porous metal is more expensive and is difficult to handle, but is preferable in terms of durability against weathering. These porous materials were used to reduce aerodynamic noise.

3. Aerodynamic noise reduction for cylinders

3.1 Cylinder specimens

Seven types of cylinder specimen (listed in Table 1 and shown in Fig. 2) were used in the wind tunnel tests described in this chapter. Types A and B are bare cylinders as shown in Fig. 2 (a), and types C, D, E and F are covered with porous materials, as shown in Fig. 2 (b). The materials of types C, D and E are porous urethane with different numbers of cells, and the material of Type F is porous metal. The number of cells in this porous metal is the same as the porous urethane of Type D. Type G is a cylinder covered with fur material, as shown in Fig. 2 (b). The fur material’s fiber diameter is approximately 10 μm, and its area density is approximately 50,000 fibers/cm² [5]. The diameter of Type B corresponds to the outside diameter of the cylinder with porous material or fur material.

![Fig. 1 Porous materials](image1)

![Fig. 2 Outline of cylinder specimens](image2)

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<thead>
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<th>Table 1 Parameters of cylinder specimens</th>
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3.2 Experimental apparatus

We conducted wind tunnel tests in the large-scale low-noise wind tunnel of the Railway Technical Research Institute in Maibara, Shiga Prefecture [7]. Figure 3 shows a view of the experimental assembly. The cylinder was rigidly fixed to the ground plane of the test section, and aerodynamic noise at a wind velocity of 300 km/h (83.3 m/s) was measured with an omnidirectional microphone.
3.3 Measurement results of aerodynamic noise radiated from the cylinder

Figure 4 shows a comparison of the aerodynamic noise levels radiated from each cylinder (1/3 octave band analysis). Types A and B produce intense narrow-band noise with frequencies corresponding to the respective vortex shedding frequencies.

Figure 4 (a) shows that types C, D and E consisting of a core cylinder and porous urethane generate no narrow-band noise, and that their overall noise levels are far lower than those of types A and B. The aerodynamic noise level radiated with Type B is louder than those from types C, D and E. This implies that the reduction of noise levels cannot be achieved with the same bare cylinder diameter as outside cylinder diamater using porous materials.

In types D and E (made of #8 and #13 porous urethane respectively), noise levels above the 8 kHz band tend to increase compared to Type C (made of #20 porous urethane). However, noise levels below the 6.3 kHz band tend to decrease compared with Type C. This result suggests that #13 is the best, since noise levels below 6.3 kHz are low and those above 8 kHz are limited. Accordingly, only #13 porous materials are addressed from this point onward.

Figure 4 (b) shows the notable result that types D and F have identical aerodynamic noise characteristics. The only difference between these cylinders is the type of material used - porous urethane or porous metal. Since the results indicate that aerodynamic noise reduction is not influenced by the hardness of the porous material, porous metal with high durability against weathering is preferable, and can be widely applied to railway vehicles. Figure 4 (b) also shows that porous materials have the same or a superior aerodynamic noise reduction effect in comparison to fur material.

As aerodynamic noise radiating from bare cylinders is attributed to large-scale vortex shedding, the application of porous material is effective in reducing such noise.

4. Application to a high-speed pantograph

4.1 Installation of porous metal on a high-speed pantograph

This chapter describes the results of research on the application of porous materials to a high-speed pantograph. We applied porous metal to the high-speed pantograph shown in Fig. 5 (a). The metal was installed on four FRP covers (the base frame cover, the main shaft cover, the hinge cover and the panhead support cover) and the bottom side of the base frame of the high-speed pantograph, as shown in Fig. 5 (b). These areas were selected to minimize influence on current collection performance and for ease of installation and removal.

In the wind tunnel tests, we used three pantograph combinations as described below. The thickness of the porous metal is 10 mm (in application to the base frame cover and the bottom side of the base frame) and 5 mm (in application to the main shaft cover, the hinge cover and the panhead support cover).

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![Fig. 3 View of wind tunnel test (cylinder)](image)

![Fig. 4 Comparison of aerodynamic noise from each cylinder specimen](image)
Case 1: Without porous metal (normal condition, see Fig. 5 (a))

Case 2: Applying porous metal to the base frame cover and the bottom side of the base frame (the main shaft cover, the hinge cover and the panhead support cover are the normal covers.)

Case 3: Applying porous metal to the base frame cover, the bottom side of the base frame, the main shaft cover, the hinge cover and the panhead support cover (see Fig. 5 (b))

4.2 Outline of wind tunnel tests

We conducted wind tunnel tests in the same wind tunnel as described in Chapter 3. Figure 6 shows a view of the experimental assembly. We measured aerodynamic noise with an omnidirectional microphone and noise source distributions with a microphone array system [8] at a wind velocity of 360 km/h (100 m/s).

A model known as the single-arm pantograph is used in two directions (as shown in Fig. 7) - the knuckle-upstream and knuckle-downstream directions. With this model, the pantograph rises and touches the contact wire in the knuckle-upstream direction, and lowers in the knuckle-downstream direction. The wind tunnel tests were conducted for Case 1, Case 2 and Case 3 in each direction.

4.3 Wind tunnel test results

Figure 8 shows comparisons of the aerodynamic noise levels measured with the omnidirectional microphone.

With the knuckle-upstream direction (Fig. 8 (a)), the overall noise level of Case 2 is 0.4 dB lower than that of Case 1. The spectrum indicates that the noise level of the 315 Hz band is reduced significantly by the porous metal. This noise is mainly generated from low-noise insulators; as porous metal may affect the flow around them, the noise they generate is reduced. The overall noise level of Case 3 is 0.4 dB lower than that of Case 2 and 0.8 dB lower than that of Case 1. The spectrum of Case 3 is slightly lower than that of Case 2 from the 1 kHz band to the 10 kHz band.

With the knuckle-downstream direction (Fig. 8 (b)), the noise level of Case 2 is much lower than that of Case 1, and the overall noise level of Case 2 is 1.5 dB lower
than that of Case 1. The overall noise level of Case 3 is 0.4 dB lower than that of Case 2 and 1.9 dB lower than that of Case 1. The spectra of Case 2 and Case 3 are remarkably lower than that of Case 1. The effect of porous metal is very high in the case of the knuckle-downstream direction compared to that of the knuckle-upstream direction because noise generated from the panhead is reduced in addition to the reduction of noise from the insulators in the 315 Hz band. This result is discussed further below.

Figures 9 and 10 show comparisons of noise source...
distributions (sound pressure levels) measured with the microphone array system. Noise source distributions can be obtained for each 1/3 octave band frequency, but Figs. 9 and 10 show the results of Case 1 and Case 3 from the 1 kHz band to the 1.25 kHz band as an example.

In the case of the knuckle-upstream direction (Fig. 9), noise emitted from the panhead and main shaft cover in Case 3 are reduced compared to those in Case 1. In particular, the reduction of noise from the main shaft cover is substantial.

In the case of the knuckle-downstream direction (Fig. 10), noise emitted from the panhead and the hinge cover in Case 3 are remarkably reduced compared to those in Case 1. Though porous metal is not applied to the panhead, noise from it is reduced. In the case of the knuckle-downstream direction, the panhead and the hinge cover are close to the base frame cover because the pantograph is lowered. As a result, aerodynamic interference is induced, causing strong aerodynamic noise. In our understanding, porous metal can weaken aerodynamic interference, and aerodynamic noise is reduced as a result.

The application of porous material is therefore effective in reducing aerodynamic noise caused by high-speed pantographs.

5. Conclusions

In this study, we applied porous materials to cylinders and a high-speed pantograph to reduce aerodynamic noise, and investigated the effects of these measures in wind tunnel tests. The following major conclusions were reached:

(1) The application of porous material is very effective in reducing aerodynamic noise radiated from cylinders.

(2) Porous metal and porous urethane have the same level of aerodynamic noise reduction effect.

(3) In the conditions of this research, porous materials that include approximately thirteen cells per 25.4 mm (one inch) have the greatest aerodynamic noise reduction effect.

(4) The application of porous metal is effective in reducing aerodynamic noise caused by high-speed pantographs.

We consider that the application of porous materials is widely applicable to industry, and that the technique is suitable for use in various fields including high-speed railways.

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References


