Reduction of pantograph noise

Takeshi Kurita *, Masaaki Hara *, Masahiko Horiuchi *

In order to reduce noise from the Shinkansen, it is essential to reduce the pantograph noise that greatly contributes to overall noise. Two types of low-noise pantograph have been developed. One is a <−shaped arm type pantograph, an improved version of the PS207 type pantograph used on series E2-1000 Shinkansen, and the other is a single arm type pantograph without the intermediate hinge. The noise reduction performance of these pantographs was confirmed through wind tunnel tests. Further noise reduction was realized by increasing the effects of attenuation of the pantograph noise insulation plate, and by using only one pantograph per trainset. A “Multi-segment slider” was also developed to increase the performance of following the overhead contact line, which is necessary when running with only one pantograph per trainset.

1 Introduction

Shinkansen noise can be classified into four categories; pantograph noise, aerodynamic noise from the train nose, aerodynamic noise from the upper parts of cars, and noise from the lower parts of cars and structure-borne noise as shown Fig.1. Pantograph noise is one of main sources of noise.

Pantograph noise is composed of aerodynamic noise from the pantograph itself, spark noise caused by contact loss, and sliding noise generated between the contact strips and the overhead contact line. If there is a decreased amount of contact loss, most of the pantograph noise is due to aerodynamic noise from the pantograph itself (including insulators). Therefore, the noise sources of the PS207 type pantograph (Fig.2) were investigated in detail, and two types of low-noise pantograph were developed; <−shaped arm type pantograph, which is an improved version of the PS207 type pantograph, and a single arm type pantograph without the intermediate hinge. The noise reduction performance of these pantographs was confirmed through wind tunnel tests. Further noise reduction around pantographs was realized by increasing the effect of attenuation of the pantograph noise insulation plate. The aim of using only one pantograph per trainset was to reduce pantograph noise by folding and hiding one of the two pantographs behind the noise insulation plate, so it could not be seen from the measurement point. A “Multi-segment slider” was also developed to increase the performance of following the overhead contact line, which is necessary when running with only one pantograph per trainset.

2 Development of low-noise pantographs

2.1 Investigation of the noise sources of the PS207 type pantograph

We investigated the noise sources of the PS207 type pantograph with an X-shaped microphone array (Fig.3) in the large-scale low-noise wind tunnel at the Railway Technical Research Institute. As shown in Fig.4, the most conspicuous noise source is at the center of the base frame. This part is located between two windscreen covers for the base frame, and the two angular pipes that compose the base frame are exposed at front and back of the main axle. This part is also the location of circular and angular rods such as those for the link mechanism that supports the main frame of the pantograph, and is considered to be a large source of noise due to the fast flow of air between the two divided windscreen...
covers for the base frame. The intermediate hinge located between the upper and lower frames is also considered to be a large source of noise.

2.2 <shaped arm type pantograph
In the PS207 pantograph, components such as the main spring, the damper and the down cylinder are arranged separately within left and right windscreen covers for the base frame. Because the most conspicuous noise source is at the center of the base frame as mentioned above, each component is arranged to one side and covered with the windscreen covers so that the angular pipes of the base frame that are thought to cause noise are no longer exposed. The PS207 also has an exposed bracket for the balance rod other than the main axle. Therefore the axle of the balance rod bracket is run through the main axle and attached so that the components exposed outside the windscreen cover appeared to become one component. For further noise reduction, the hook, which is arranged in the center of the base frame, was also stored in the windscreen cover and can be hooked onto the main frame. Therefore, it was possible to remove the hook projection that was attached to the upper frame. Fig.5 shows the <shaped pantograph, which was developed based on the PS207 after considering aforementioned points.

2.3 Single arm type pantograph
Fig.6 shows a single arm type pantograph designed for further noise reduction. This pantograph has a cantilever main frame, and components below the intermediate hinge are stored in the windscreen cover to reduce noise from the hinge. Only one main frame is visible outside the windscreen. In order to store components below the hinge inside the windscreen cover, it was necessary to make the upper frame longer than the one used in the conventional pantograph. If the frame is too long, inertia force at the top of the pantograph head increases, causing a deterioration in overhead contact line following. Therefore, the main frame length was kept to the minimum necessary. As a result of the examination, the length of the main frame was set at 1800mm and the ratio of the main frame and the lower frame was fixed at 7.2:1. The main frame was constructed from CFRP, and lightened to increase performance in overhead contact line following.

2.4 Wind tunnel tests
In order to examine the noise reduction performance of the two newly developed pantographs, Tests were performed in the large-scale low-noise wind tunnel. The arrangement of the normal microphones is shown in Fig.7.

Measurement results and a comparison of noise spectrum are shown in Table 1 and Fig.1. Differences were observed in the left and right sides of both pantographs. This is due to asymmetry of the cantilever main frame. Noise level in the main frame side was higher than that in the other side. Overall, the single arm pantograph generated less noise than the <shaped arm type pantograph. The results showed that the <shaped arm type pantograph reduces noise by 1.2dB and the single arm pantograph reduces noise by 2.4dB from the PS207 level when comparing the microphone NM6 results. The NM6 microphone corresponds to the actual measurement point for Shinkansen noise.

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<thead>
<tr>
<th>Pantograph</th>
<th>Measurement microphone</th>
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<tr>
<td></td>
<td>NM1</td>
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<tr>
<td>PS9037</td>
<td>Knuckle forward</td>
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<tr>
<td></td>
<td>Knuckle backward</td>
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<tr>
<td>PS9038</td>
<td>Knuckle forward</td>
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![Fig.8: Comparison of frequency analysis results (Measurement microphone: NM6)]
The development of a low-noise pantograph is one of the countermeasures used to reduce noise. It has been shown that adding flat type pantograph noise insulation plates is an effective way to avoid the propagation of pantograph noise. Optimization of the cross sectional shape of the noise insulation plate is also effective in further reducing pantograph noise. Therefore, the effect of noise insulation plates was investigated by changing the cross sectional shape by acoustic simulation, and measuring the relationship between the length of the noise insulation plate and the effect in acoustic experiments using 1/5-scale models.

3.1 Optimization of cross sectional shape

As it is necessary to consider the limit for rolling stock moving dimensions and the insulation distance from a pantograph when investigating cross sectional shape, it is impossible to make large increases in the length and height. Therefore, a number of types of cross sectional shape were considered to have high insulation effects within these constraints. Assuming pantograph noise to be a point source, the insulation effect was investigated with 2-dimensional acoustic simulation. Fig.9 shows a part of the cross sectional shapes, Fig.10 shows the analysis range, and Fig.11 shows the results of the simulation.

Noise was reduced over 500Hz in every cross sectional shape when compared to the control case [00] that did not have noise insulation plates. However, in the conventional flat type plate (case [01]), it was impossible to obtain sufficient insulation performance at 315Hz due to the influence of standing waves between the left and right insulation plates. Insulation performance was improved in cases [03] and [04], where the insulation plates were either concavely or convexly curved weakening the influence of the standing wave. Case [12], in which the insulation plate has a shape with the diffraction point high outside the plate itself to avoid the standing wave between left and right plates, showed better result than cases [03] and [04], reducing noise by approximately 4dB. The design of the insulation plates adopted for the high-speed test train were based on this section.

3.2 Determination of the length of insulation plates

Fig.12 shows the measurement point in the acoustic experiment using a model, and Fig.13 shows the measured noise level. At P1 in front of the pantograph, improved type (3m) showed worse result than the other insulation plates of different lengths. This is due to the influence of noise that diffracts around the front and rear edges.
of the insulation plates, which indicates that a length of 3 meters is not enough to insulate noise from the pantograph. With the improved type (3m), a high level of noise was also recorded at P4. As shown in Fig.12, this is because the range reached by direct sound and the range reached by reflected sound at the back insulation plate overlap between P3 and P4. In case of the improved type (6m), the overlap range shifts to between P6 and P7. Although the increase in noise level is not as great when compared to improved type (3m), the influence was still confirmed.

From these results, it was found that insulation plates with less than 6m lengths are influenced by diffraction around the front and rear edges of plates and reflection at the back insulation plate, and that the effectiveness of noise reduction increases with increased plate length up to approximately 10m. Finally, when considering the attachable length for the high-speed test train, 7m plates were installed for the test trainset which has Shinkansen clearance, and 5m for the test trainset for through operation between Shinkansen and conventional lines. The length of each plate was double of the length from the center of the pantograph head to the edge of the car body.

Because running with only one pantograph per trainset requires improvement in the performance of overhead contact line following, a Multi-segment slider was developed.

The central part of the contact strip body in the PS207 (contact strips are set on a leaf spring made of titanium alloy) (Fig.15) is movable, but the edges are not because they are fixed with pins. Although the central part has ±5mm maximum spring stroke, actual stroke is thought to be smaller because of the large spring constant. Therefore, the Multi-segment slider shown in Fig. 16 was developed. The structure realizes the reduction of movable mass, which is the most effective element in increasing the performance of overhead contact line following. The details of the structure are shown in Fig. 17. While the main contact strip is divided into four pieces in PS207, it is divided into 10 pieces in the new slider, and springs are inserted between the pieces. The contact strips are on glass fiber reinforced silicon rubber, and copper plate and guide are under the rubber. These are connected with phosphorus bronze bolts and composed of the contact strip body. This structure achieved improvement of performance by allowing the contact pieces to be connected flexibly, and only allowing a few contact pieces around the contact point with the overhead contact line to move.

This Multi-segment slider was combined with the frame of the PS207 and used in running tests at 360km/h with series E2-1000 from March to May in 2003, and it showed satisfactory results of 2% average contact loss ratio, and good prospects for running with only one pantograph per trainset.

All of the development results to reduce pantograph noise described in this paper have been incorporated E954 type Shinkansen high-speed test train launched in June 2005. In future running tests, the reduction effect of pantograph noise will be evaluated. So far, new issues have appeared such as large aerodynamic noise presumed to be due to a separated vortex in the wake of the new insulation plates. We are therefore currently working on further improvements.

References
1) Masaaki Hara, Takeshi Kurita, Masahiko Horiuchi, Hitoshi Sato, ToshioShikama; Development of a low noise pantograph (reduction of aerodynamic noise), Proceedings of the 14th Transportation and Logistics Conference (Japan Society of Mechanical Engineers), No. 05-52, pp 103-104, 2005 12