In order to reduce the pantograph noise of Shinkansen rolling stock, large pantograph covers had been attached around conventional pantographs. But with increases in speed, the aerodynamic noise of the pantograph covers themselves becomes a problem. So, we have recently developed low-noise pantographs and low-noise insulators1) to replace pantograph covers.

For the FASTECH360S high-speed test train on which we have been proceeding with development with a target of achieving 360 km/h, further reduction of pantograph noise is required. Thus, we have improved the noise reduction performance of pantographs, and at the same time, introduced pantograph noise insulating panels to be attached on the both sides of the pantograph (hereinafter “noise insulating panels”).

In this paper, we will explain the development and the effect of the noise insulating panels for FASTECH360S.

2.1 Profile Shape of Noise Insulating Panels

Upon considering the rolling stock gauge and the insulation clearance from the pantograph, we carried out acoustic simulations to determine a profile shape that has a high diffraction effect. Fig. 1 indicates some examples of the profile shapes we examined.

In the acoustic simulation, we made two-dimensional boundary element analyses replacing the noise sources of a pantograph with three point sources at the insulator, the hinge and the contact strip. In the simulation, as shown in Fig. 2, we assumed a standard elevated section (7 m high, with upright sound barrier of 2 m) and made the evaluation point 25 m from the center of the track and 1.2 m high from the ground to analyze the noise reduction effect of each profile shape.

Fig. 3 indicates the frequency distribution of each profile shape at the evaluation point. Every profile shape significantly reduces the noise in the frequency of over 500 Hz compared to Case [00] where no noise insulating panels are installed. But we could not achieve satisfactory noise reduction performance around 315 Hz in Case [01] with flat type noise insulating panels, probably because of the effect of stationary waves between right and left noise insulating panels.

The final result showed that Case [12] has the highest noise reduction performance, at approx. 4 dB compared to Case [01]. In Case [12], we used the noise insulating panels with the diffraction point that projects outward more and higher, while considering the stationary waves between right and left noise insulating panels. Hereafter, we will call the noise insulating panel of the above-mentioned profile shape used in Case [12] a Z-shaped noise insulating panel.

**Keywords:** Shinkansen, Speed increase, Pantograph noise insulating panel, Noise reduction, Aerodynamic noise
2.2 Length of the Installed Noise Insulating Panels

In order to examine the relationship between the length of the installed noise insulating panels and the noise reduction effect, we carried out acoustic tests using a 1/5 scale model.

In the tests, noise was generated at the location of the noise source of the pantograph. As shown in Fig. 4, we measured noise by moving from P1 measurement point 25 m (converted for an actual train) from the center of the track in the direction of the sleepers by 150 m (converted for an actual train) in the direction of the rails to P9 measurement point. Since we could not secure sufficient measurement distance in the test room, we made measurements at the points from P5' to P9' as the points from P5 to P9 and corrected distance to those measurement points.

In those tests, we used Z-shaped noise insulating panels installed in four lengths that would be 3 m, 6 m, 9 m and 12 m if converted for an actual train. Fig. 5 shows the noise level at each measurement point.

If the noise insulating panels are 3 m long, the noise level at P1 measurement point was higher than that for other lengths, and it was affected by the diffracted noise from the front and rear ends of the panels. If the panels are 6 m or longer, the difference of noise levels between 9 m and 12 m panels is small at any measurement point. Accordingly, noise reduction effect is improved by only up to around 10 m extension of the length of the panels.

2.3 Shape of the Noise Insulating Panels for FASTECH360S

In order to check the reduction of the pantograph noise by Z-shaped noise insulating panels, we installed Z-shaped noise insulating panels to cars No. 2 and 7 of the FASTECH360S and carried out high speed running tests. The installation length of panels was 7 m, the maximum length of the installed panels could be attached to. Fig. 6 shows the Z-shaped noise insulating panels that were actually installed.

3.1 Z-Shaped Noise Insulating Panels

3.1.1 Noise Measurement Results

In order to check the noise reduction performance of the Z-shaped noise insulating panels, we measured noise source distribution using spiral microphone array2). Fig. 7 shows the measurement results around the noise insulating panels on car No. 2.

The figure proved that there are large noise sources at the front and rear ends of the panels in addition to the noise source near the contact strip at the center of the panel. The noise was caused by the separation vortex because that noise was generated only at the ends of the panel, and the frequency of the noise source was mainly 500 Hz, which was clarified by the 1/1 octave band frequency analysis results of the noise source distribution.

When we developed a Z-shaped noise insulating panel before the development of FASTECH360S, we expected that the aerodynamic noise of the noise insulating panels themselves would account for a relatively small amount of the total noise around pantographs; so, we put importance on the noise insulation performance in the development. But, since FASTECH360S is installed with new low-noise pantographs, the noise around pantographs is radically reduced.
and the aerodynamic noise of the noise insulating panels themselves would become relatively larger. Thus, in order to further reduce the pantograph noise, we undertook improvement to the end shape of the Z-shaped noise insulating panels to lower the noise of the panels themselves.

### 3.1.2 Improvement of the Panel End Shape

Since Z-shaped noise insulating panels have no tilt at the front and rear ends, the phases of the separation vortexes can easily match, and that causes noise of a particular frequency to be generated easily. So, we examined application of small protrusions (vortex generator) to control the phase of the separation vortex.

As shown in Fig. 8, we examined height, length and attachment angle against air flow for the vortex generator with protrusions at the profile that has a semicircular upper part and the same height as the diameter.

Fig. 8  Shape of Vortex Generator

The wind tunnel test results using a 1/5 scale model indicate that the distance from the end of noise insulating panels to the protrusion (L) should be shortened to locate the protrusion near the ends of the noise insulating panels, and that when the height of the protrusion (P) is 0.6 mm (scale model dimension) the peak noise in the 630 – 800 Hz band can be greatly reduced to the minimum noise.

When changing the attachment angle of the protrusion (θ) as shown in Fig. 9, we found that the angle being 45 degrees is most effective. Comparing the length of the protrusion (Lₜ), 5 mm and 2.5 mm produce almost the same noise reduction effect.

Based on those results, we determined the shape and the location of the vortex generator. By attaching that vortex generator to the Z-shaped noise insulating panels, the noise by the panels can be reduced by approx. 4.1 dB.

### 3.1.3 Noise Measurement Results after Improvement of the Panel End

Based on the effects confirmed in the wind tunnel tests, we attached the vortex generator to Z-shaped noise insulating panels as an improvement to performance. The length of the protrusions (Lₜ) is 25 mm, and the attachment angle is 45 degrees. They are attached at intervals of 5 mm at the end of the noise insulating panel (L₁) and 9.8 mm on the opposite side (L₂); and the distance from the end to the protrusions (L) is 26 mm. Calculating from the boundary layer thickness of actual trains, we made the height of the protrusions 6 mm. Fig. 10 shows the end of the improved Z-shaped noise insulating panel.

Fig. 10  Improved Panel End Shape of the Z-shaped Noise Insulating Panel

Fig. 11 and 12 show the measurement results of the noise source distribution in the high speed running test using the improved Z-shaped noise insulating panels. We assumed that the difference of the noise level due to the difference of the speed before and after the improvement predominantly came from aerodynamic noise; so, we adjusted the level, considering that the energy of the noise is proportionate to the sextuplicate of the speed.

Since the noise source at the rear end of the noise insulating panel of car No. 7 is hidden by the noise between cars in Fig. 11, the difference of the noise before and after the improvement can not be identified; but the noise of car No. 2 is significantly reduced as shown in Fig. 12. On the other hand, the noise at the front end of the noise insulating panel is worse, while the noise of car No. 7 is slightly reduced.

Although we could confirm the effect of that improvement on the aerodynamic noise at the rear end of the noise insulating panel, the noise became worse at the front end of the panels in some cases. We thus could not bring about satisfactory effects only by improving the shape of the end of the noise insulating panel.
### 3.2 Conventional Noise Insulating Panels

Since we did not see sufficient effect by improving the end of the Z-shaped noise insulating panel, we carried out some tests by installing the same noise insulating panels as those used in the high speed running test with the E2-1000 series cars (hereafter “conventional noise insulating panels”) to FASTECH360S. Fig. 13 shows the conventional noise insulating panels installed on the FASTECH360S.

Fig. 14 shows the measurement results of noise source distribution after installing conventional noise insulating panels. The difference of the noise level due to the difference of the speed is adjusted in Fig. 14 to allow for comparison with Fig. 11 and 12.

The figure shows that the noise at both ends of the noise insulating panels on car No. 2 and 7 is greatly reduced. Since car No. 7 runs with the pantographs folded, the noise source at the center of the noise insulating panels is the diffracted sound of the noise by the pantographs. As the diffraction effect of the conventional noise insulating panel is lower than that of the Z-shaped panel, noise is slightly increased. As for car No. 2, the noise around the contact strips reaches the microphone directly and no difference in the noise source at the center of the panels is found since car No. 2 runs with the pantographs lifted.

### 4.1 Study of the Shape of the Noise Insulating Panel

As explained in 3.2, comparison of Z-shaped noise insulating panels and conventional noise insulating panels clarifies that conventional panels reduce the pantograph noise by drastically improving the aerodynamic noise of the panels themselves, while the conventional panels have a lower diffraction effect than the Z-shaped panels. Accordingly, we developed a noise insulating panel of a new shape that has noise insulating performance and low aerodynamic noise characteristics of the panel itself better than the total performance of conventional panels.

In order to examine three shapes of the new noise insulating panel—profile shape of the panels, front and rear tilt and profile of the front and rear edge—we carried out wind tunnel tests using a 1/10 scale model.

### 4.2 Proposed Shape of the New Noise Insulating Panel

As shown in Fig. 15, we compared the profile shape of the front and rear edge of the panel having a 15-degree diffuser and a φ30 mm circular edge (hereafter "φ30 + 15-degree type") with the shape having rounded corners of 25 mm radius (converted for actual train) as with the conventional panel (hereafter "R25 type").

By reducing the tilt of the panel end, we can significantly prevent the phases matching of the separation vortex, and thus reduce aerodynamic noise. On the other hand, smaller tilt reduces
the area of the noise insulating panel and lowers noise insulation performance. So, while keeping the length on which the panels are attached the same, we compared the horizontal tilt angle of 45 degrees that is same as of the conventional panel with angles of 30 degrees and 25 degrees that are expected to reduce aerodynamic noise.

For the profile shape of the panel, we compared six types shown in Fig. 16. (a) and (b) are the conventional panels installed to FASTECH360S and the Z-shaped panel respectively, (c) and (d) are the shapes for which improved diffraction effect at the top of the panel are expected, and (e) and (f) are the shapes to reduce the effect of stationary waves between right and left noise insulating panels. In (e), we also compared three shapes with different bend points. In (f), flat panels the same as conventional panels are used, but the panels are inclined outward to have the upper diffraction point at the same position as the Z-shaped panel.

4.3 Testing Method
In order to assess in total about the noise insulating performance and aerodynamic noise reduction performance, we produced a model consisting of a car roof, a pantograph and noise insulating panels, and conducted wind tunnel tests on that. As shown in Fig. 17, the noise measurement point was located 750 mm from the center of model car (scale model dimensions). At that measurement point, we set up a microphone to have the same angle in actual-environment measurement where a Shinkansen train runs on an elevated section approx. 7 m high (hereafter "25 m model point"). In order to measure the noise before and after when the pantograph passes in front of the measurement point (at positions offset from the front of the measurement position), we moved the microphone in the direction of the rails for measurement in some tests.

4.4 Wind Tunnel Test Results
The 30 + 15 degree type edge shape could reduce more noise in higher frequency bands than the R25 type, but it considerably increased noise in the 80 to 630 Hz band; so, in total, the R25 type showed higher noise reduction performance.

As the length of the installed panel is kept the same, smaller tilt angles at the front and rear ends of the panel result in less noise insulation area. So, we made measurements moving the microphone in the direction of the rails. As can be seen in Fig. 18, the results show that the 45-degree type could reduce the noise alongside the contact strip by approx. 1.5 dB, and the 30- and 25-degree types a further 2 dB, compared to without noise insulating panels. In the cases when locating the microphone forward and backward, that tendency remained the same. The measurement results of the 30-degree type were slightly better than the results of the 25-degree type in any case.

As for the profile shape, we found only slight differences due to the difference of the profile shapes of (a) – (d) cases using 45-degree type noise insulating panels. Then, we compared (a), (e) and (f) types of panels of 30-degree type panels. The results were, as indicated in Fig. 19, that (f) type showed the lowest noise level, lower by 2.0 dB at the overall value than (a) type conventional panel.

Based on the above-mentioned results, we concluded that the optimal noise insulating panel that has R25 type front and rear edges, tilt of 30 degrees at the front and rear ends and (f) type profile shape where (a) type is inclined outward. Hereafter we will call the panels of this shape “30-degree noise insulating panels”.

Upon attaching 30-degree noise insulating panels to cars No. 2 and 7 of FASTECH360S, we checked the noise reduction effect. Fig. 20 shows the noise insulating panels of the final shape.

Fig. 21 and 22 show the measurement results of noise source distribution of the conventional panels and 30-degree noise insulating panels. Fig. 21 shows that on car No. 7 that runs with pantographs folded, the noise source at the center of the noise insulating panels was the diffraction noise not including the direct noise from around the contact strips; so, improved diffraction effect reduced noise. But, at the same time, we found that diffraction noise occurred above the rear end of the noise insulating panels since the noise insulation area was reduced.

Fig. 22 proved noise reduction at the rear end of the noise
insulating panels on car No. 2. And, we found no diffraction noise at the front and rear ends due to the smaller noise insulation area.

Fig. 23 shows the noise measurement results using an microphone array at the point 25 m from the center of the track. In this figure, (a) is the results without noise insulating panels and (b) is the results with 30-degree noise insulating panels. Comparing the peak noise levels of (a) and (b) when car No. 7 with the same type pantographs passed the point, the peak level was reduced by approx. 4 dB by installing 30-degree noise insulating panels.

Conclusion

In the development and improvement of noise insulating panels to reduce the pantograph noise of FASTECH360S, we found the following.

1. The Z-shaped noise insulating panel that we initially developed has high noise insulation performance; but the noise reduction effect of that panel on the pantograph noise is insufficient because the panel itself generates much aerodynamic noise.

2. For FASTECH360S that employs new low-noise pantographs, it is important to reduce the aerodynamic noise of the noise insulating panels themselves to reduce total noise around the pantograph.

3. Based on the study of noise insulating panels with high performance in noise insulation and low-aerodynamic noise in total, the optimal noise insulating panel has a profile shape where the conventional panel is inclined outward and has a 30-degree tilt to the front and rear ends.

4. By attaching 30-degree noise insulating panels, the peak noise level around pantographs can be reduced by approx. 4 dB.

Reference: