With a target of achieving 360 km/h operation speed, JR East has developed FASTECH360 high speed test trains equipped with new noise reduction technologies such as new low-noise pantographs, pantograph noise insulating boards, noise absorption at the lower part of the car body and circumference smooth diaphragms for gaps between cars. Running tests of those trains have been ongoing since June 2005. We are continuing to make improvements even after the start of the running tests based on the measurement results of car noise sources acquired using a spiral microphone array. In the running tests of FASTECH360Z and FASTECH360S coupled to each other, we have achieved noise reduction by 4 to 5 dB compared to the noise caused in the coupled operation of present series E3 and E2. While we have not been able to reach the target speed 360 km/h, still we have successfully operated the coupled train set at around 330 km/h at a noise level that is equal to the level of present trains in operation running at 275 km/h. In other words, noise at 330 km/h is no worse than the present level.

Keywords: Shinkansen, Noise, Microphone array, Pantograph, Aerodynamic noise
Traditionally, a Shinkansen train collects current using two pantographs per train set (four pantographs in coupled operation) to prevent arc that might be caused by contact loss (pantographs of each section of a coupled train set are not electrically connected to each other, while two pantographs in a train set are connected with a bus line). However FASTECH360 is operated using only one pantograph per train set to collect current (Fig. 5, using a pantograph to the rear in terms of running direction); therefore, the pantograph for FASTECH360 has to have significantly higher current collection performance than PS207 to prevent contact loss as much as possible. Accordingly, we developed a multi-fractionated contact strip 1) (Fig. 6). Since the 10-fraction main contact strip is placed on a silicon rubber plate, each fraction is flexibly connected to each other and the contact strip has higher ability to follows contact lines because of its smaller movable mass. Using that together with high tensile overhead contact lines achieves good current collection performance; and noise can be reduced by current collection using only one pantograph per train set.

2.2.2 Noise from the Lower Part of Car Body

Reduction of noise from pantographs of series E2-1000 cars that incorporate PS207 pantographs and low-noise insulators results in relative increase of the noise from the lower part of the car body that is hidden by the noise barrier. Accordingly, reduction of noise from the lower part of car body is an important issue in reducing total noise.

We thus installed bogie side covers of the height to the bottom surface of underfloor equipment on FASTECH360S. In order to reduce the noise from the lower part of car body in the multiple noise reflection between car body and noise barrier, we also applied sound-absorbing panels 1) to car body side skirts including the above-mentioned bogie side covers and underfloor covers (Fig. 7).
2.2.3 Aerodynamic Noise from the Train Head

The noise from the train head mainly consists of aerodynamic noise from the head bogie, the handrail of the door of the crew cabin and the snowplow. We thus introduced bogie side covers, smoother handrails and snowplow covers (Fig. 8) to lessen that noise.

2.2.4 Noise from the Upper Part of the Car Body

We developed circumference smooth diaphragms (Fig. 9) to reduce noise from the gaps between cars. Sliding doors and windows on the side are also smooth with the surface of the car body.

Fig. 8 Snowplow Cover

Fig. 9 Circumference Smooth Diaphragm

3. Running Test Results

3.1 Efforts in Noise Reduction after the Start of the Running Tests

3.1.1 Identification of Noise Sources and Study of Countermeasures

Fig. 10 and 11 show a schematic diagram of noise measurement for FASTECH360S using a spiral microphone array and the measurement results.

Fig. 11 (a) shows the measurement results at the early stage of the running test. The figure shows that much noise is generated at the rear end of the pantograph noise insulating panel as well as from some wheels and circumference diaphragms. Therefore, we studied methods to reduce that noise.

We thought that the noise source at the pantograph noise insulating panel, particularly the source of the aerodynamic noise at the rear end, was from the wake vortices. In order to reduce the relative length of the wake vortices in the direction of the height of the noise insulating panel, we carried out running tests in turn attaching vortex generators (small process that have the shape of a semicircular pillar, Fig. 12) and flat-sectional pantograph noise insulating panels with a 45 degree bevel at both ends of the panel.

Fig. 12 Vortex Generator Added to Z-Shaped Pantograph Noise Insulating Panel

Fig. 13 45-Degree Type Flat-Sectional Pantograph Noise Insulating Panel

Fig. 11 Measurement Results of Rolling Stock Noise Source Distribution for FASTECH360S
(at Around 340 km/h, Noise Barrier Removed for Measurement)
in the side view that showed good results in past running tests of series E2-1000 cars (Fig. 13, hereinafter "45 degree type flat-sectional pantograph noise insulating panels"). As shown in Fig. 11 (b), 45 degree type flat-sectional pantograph noise insulating panels showed better results in significant noise reduction from the noise insulating panels themselves.

For the noise from the wheels (front half of the train set), we carried out running tests blocking the ventilation route for the cooling fins on the back of the brake disc on the wheel side. The tests result proved that the noise could be reduced to the level at the other wheels as shown in Fig. 11 (b). In other words, the source of the noise was found to be aerodynamic noise from the cooling fins. Regarding noise from the circumference diaphragms, we found that much noise was generated when air flowed in the gap of the diaphragm plates; therefore, the noise could be reduced by blocking the gaps as shown in Fig. 11 (b).

3.1.2 Noise at 25 m from the Track Center

Fig. 14 and 15 respectively show the noise measurement overview and the measurement results using nondirectional microphones (dynamic characteristic: SLOW). Based on the results shown in Fig. 15, we gained a perspective in November 2005 that we would be able to improve the running speed of FASTECH360S (non-coupled operation) to approx. 320 km/h at the noise level equivalent to that of present trains running at 275 km/h by applying the noise reduction method in 3.1.1.

3.1.3 Other Rolling Stock Improvements for Noise Reduction

Based on the study explained in 3.1.1, we further improved noise reduction for FASTECH360S. For pantograph noise insulating panels, we carried out a wind tunnel test using a 1/10 scale model in March 2006 and replaced in July to September 2006 the panels with 30 degree type flat-sectional pantograph noise insulating panels that generate less noise (Fig. 16). In August 2006, we unified both pantographs of a train set to single-arm type pantographs that have better noise reduction performance. From May through September
2006, we improved the shape of the cooling fins on the back of the brake disc on the wheel side (Fig. 17, added ribs on the inner periphery of the disc to reduce air flow to the fins) and improved the circumference diaphragm (Fig. 18, changed the material of the middle of the three diaphragm plates to rubber and connected both end plates with rubber to block the gap where air enters).

For FASTECH360Z that started running tests in April 2006, we applied the same improvement as FASTECH360S. For example, we changed the angle of the front and rear ends of the retractable pantograph noise insulating panels from a right angle to 30 degrees (Fig. 19).

Comparing Fig. 15 (a) and (b) we can see that the effect shown in (b) is around 1 dB, while the effect in (a) is around 0.5 dB. Since the effect of the improvement on rolling stock around 374k300 is relatively small, we assumed that structure-borne noise affected the smaller effect. In order to reduce the structure-borne noise, we replaced the track pad with the low-spring constant track pad (Fig. 20, static spring constant is 30 MN/m, approx. half the usual track pad) in a 200 m section (100 m in each direction) from around 374k300 in July 2006.

3.2 Noise Reduction Performance of FASTECH360

Fig. 21 and 22 show the peak level at the pantograph and the peak level between cars without pantographs that were measured using a liner microphone array (time constant 35 ms) at around 387k750 on the Tohoku Shinkansen from August through November 2006. Fig. 23 shows the measurement results with a nondirectional microphone (dynamic characteristic: SLOW), around 374k300 and 387k750 on the Tohoku Shinkansen from August through
Considering the noise reduction performance of FASTECH360, the contribution of structure-borne noise to the total noise is not negligible.

**Future Works**

We have achieved some improvements in noise reduction in the development and running tests of FASTECH360. However it is clear that we need to take more overall approaches in future. To achieve further noise reduction for the Shinkansen, we will work to improve accuracy of estimating the contribution of each noise source; and we will need to clarify noise generation mechanisms and countermeasures for aerodynamic noise from the pantograph including the pantograph head, noise from the lower part of the car body including the aerodynamic noise from the bogie and structure-borne noise.

**Conclusion**

1. The running speed of the coupled operation of FASTECH360Z and FASTECH360S with the same noise level as 275 km/h running of present coupled Shinkansen trains is 330 km/h, and is 340 km/h in FASTECH360S single operation.
2. By using new low-noise pantographs and 30 degree type flat-sectional noise insulating panels together, the peak level at the pantograph can be reduced by more than 2 dB compared to the peak level of the series E2 and by more than 5 dB compared to the peak noise of series E3.
3. By applying full-circumference smooth vestibule diaphragms and sound absorption at the lower part of the car body, the peak level between cars can be reduced by approx. 1 to 2 dB compared to that of the series E2 and by approx. 4 dB compared to the peak level of the series E3.
4. Considering the noise reduction performance of FASTECH360, the contribution of structure-borne noise to the total noise is not negligible.

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