Reduction of Wayside Noise from Shinkansen High-Speed Trains*

Takeshi KURITA**, Yuusuke WAKABAYASHI***, Haruo YAMADA**** and Masahiko HORIZUCHI*****

**R & D Center of JR East Group, East Japan Railway Company, 2-479 Nisshincho, Kita-ku, Saitama-shi, Saitama 331-8513, Japan
E-mail: t-kurita@jreast.co.jp

***Shinkansen General Rolling Stock Center, East Japan Railway Company, Aza-Sinyajiwaki Rifucho, Miyagi-gun, Miyagi 981-0112, Japan

****Transport and Rolling Stock Division, East Japan Railway Company, 2-2-2 Yoyogi, Shibuya-ku, Tokyo 151-8578, Japan

*****Knorr-Bremse Rail Systems Japan Ltd. (Former, East Japan Railway Company) 3-1-15 Nishi-Ikebukuro, Toshima-ku, Tokyo 171-0021, Japan

Abstract
We worked on the reduction of Shinkansen wayside noise at higher speeds using two experimental trains, namely "FASTECH360S" (running only on Shinkansen lines) and "FASTECH360Z" (running on both Shinkansen and conventional lines). Both of these feature several new types of equipment for reducing pantograph noise and noise from the lower part of cars, which have the greatest effect on overall noise level in series E2-1000, the newest commercial trains in JR-East. Low-noise pantographs and noise insulation plates were used with the intention of reducing pantograph noise. Sound-absorbing panels were installed to reduce noise emitted from the lower part of cars. We conducted running tests with the FASTECH360 trains to measure wayside noise. The results show that to operate at the same noise levels as current commercial trains (namely series E2 and E3 (coupled) running at 275 km/h), FASTECH360S and FASTECH360Z (coupled) would have to run at approximately 330 km/h, and FASTECH360S (alone) at approximately 340 km/h. We verified that the combination of certain measures for the reduction of pantograph noise and noise from the lower part of cars were rather successful in mitigating Shinkansen wayside noise.

Key words: Noise Reduction, High Speed Train, Pantograph Noise, Noise from Lower Part of Cars, Aerodynamic Noise

1. Introduction

Cutting Shinkansen travel time is the most effective way to increase market share. Increasing the maximum speed of Shinkansen trains is one way to shorten travel times. Since 2002, East Japan Railway Company has been working on the development of technologies to raise the maximum operating speed of Shinkansen to 360 km/h(1). This makes it much more important to reduce wayside noise, which necessarily increases with speed. In Europe, over the last decade, noise measurement and noise source analyses have been conducted using different trains at speeds up to around 350 km/h(2). In Japan, Shinkansen wayside noise has been mitigated gradually since it’s inauguration in 1964, while increasing the maximum operating speed to 300 km/h(3)(4). It has been acknowledged that the reduction of noise emitted from pantographs and the lower part of cars is one of the
most effective ways of reducing wayside noise\textsuperscript{(4)}. However, until now, the quantitative contributions of each noise source to overall noise levels at higher speeds have not been clear and thus few effective countermeasures have been proposed. Therefore, we have worked on reducing wayside noise at higher speeds using experimental trains.

First of all, we conducted running tests up to 360 km/h by using a series E2-1000 train, the newest commercial train in JR-East and then analyzed the noise measurement results to determine the contribution of each noise source to the overall noise level. Next, we developed two high-speed test trains (FASTECH 360S and 360Z) with a goal of operating at 360 km/h\textsuperscript{(5)} \textsuperscript{(6)}. FASTECH360S has eight cars and runs only on Shinkansen lines. FASTECH360Z has six cars and runs both on Shinkansen lines and on conventional lines converted to Shinkansen gauge. Running tests using the FASTECH360 trains were then carried out to measure wayside noise at a point 25 meters from the center of the track and 1.2 meters above the ground. Furthermore, we have introduced new corrective measures for noise reduction on the FASTECH360 as a result of the running tests. In this paper, the steps of development on the FASTECH360S are explained and the effectiveness of certain countermeasures for noise reduction is also discussed.

2. Running tests and noise analysis using series E2-1000

We conducted running tests by using a series E2-1000 train to ascertain what would be necessary to ensure successful operation at 360 km/h. As a result, it was found that the noise level of the E2-1000 train running at a speed of 360 km/h rises by approximately 6.5 dB over that of 275 km/h at a point 25 meters from the center of the track and 1.2 meters above the ground.

In order to reduce Shinkansen noise more effectively, it is necessary to understand from where sound is generated and how much each noise contributes to overall noise. Therefore, we estimated the contribution of each noise source to overall noise in E2-1000 cars running at 275 km/h and at 360 km/h, as shown in the next paragraph.

We have divided Shinkansen noise into five components (Fig. 1): pantograph noise, noise from lower part of cars, aerodynamic noise from upper part of cars, aerodynamic noise from train nose, and structure-borne noise. Time history of A-weighted sound pressure level (SLOW) of structure-borne noise is estimated using the same method as Nagakura\textsuperscript{(7)} and those of the other four components are calculated as follows: Firstly, we replace the Shinkansen noise sources with twenty-one sound sources, using a time history measured by a linear microphone array (RION MY-10A, time constant: 35 ms), as shown in Fig. 2. Next, pantograph peak levels (levels of noise peak corresponding to pantograph located near the gap between cars) are divided into pantograph noise levels and inter-car peak levels (levels of noise peak corresponding to passage of inter-car gaps with no pantographs). Inter-car peak levels are then divided into levels of noise from the lower part of cars and those of aerodynamic noise from the upper part of cars, based on the method of Kitagawa \textit{et al.}\textsuperscript{(4)} using a time history measured by use of a linear microphone array at low speed (160 km/h) together. With one or more sources corresponding to each component, according to Nagakura's method\textsuperscript{(7)}, the time history of A-weighted sound pressure level (SLOW) of each component can be calculated. We obtained the results shown in Fig. 3; namely that pantograph noise and noise from the lower part of cars, in that order, have the greatest effect on overall noise level in series E2-1000 running at 360 km/h.
3. Overview of countermeasures for noise reduction on FASTECH360S

3.1 Countermeasures for pantograph noise

Two types of new low-noise pantographs were installed on FASTECH360S. The PS9037 type pantograph (Fig. 4 (a)) has the same main-arm-with-knee-joint as the PS207 type installed on series E2-1000 (Fig. 5 (a)), but with a cantilevered arm. The PS9038 type pantograph (Fig. 4 (b)) has a cantilevered main arm, and components below the knee joint are stored in a windproof cover to reduce noise from the joint. These pantographs have
succeeded in reducing aerodynamic noise, mainly emitting from the center of the base frame between the two windproof covers (Fig. 5 (b)). This is the most conspicuous source of noise from the PS207 pantograph.

To further reduce pantograph noise, noise insulation plates were used and one of the two pantographs installed on the trainset is folded. This makes it possible to reduce pantograph noise, as diffraction attenuation effect is obtained by hiding the folded pantograph behind the noise insulation plates seen from the point of noise measurement. With the aim of greater diffracting attenuation, we initially installed pantograph noise insulation plates with a Z-shaped cross section (Fig. 6)\(^5\)\(^6\).

\[\text{(a) Type PS9037} \quad \text{(b) Type PS9038}\]

**Fig. 4 New low-noise pantographs**

\[\text{(a) Type 207} \quad \text{(b) Center part of PS207 base frame}\]

**Fig. 5 PS207 type pantograph (series E2-1000)**

**Fig. 6 Pantograph noise insulation plates (Z-shaped type)**

Conventionally, a Shinkansen train collects current using two pantographs per trainset (four pantographs in a coupled operation) to prevent arc that might be caused by contact loss (pantographs of each section of a coupled trainset are not electrically connected to each other, while two pantographs in a trainset are electrically connected with a bus line). However, FASTECH360 is operated by folding one of the two pantographs, in other words, by using only one pantograph per trainset to collect current (Fig. 7, use of pantograph at rear of each trainset in operation); therefore, the pantograph for FASTECH360 must have significantly higher current collection performance than PS207 to ensure minimum contact loss. We developed a multi-segment slider\(^8\) (Fig. 8). The main contact strip is divided into
ten pieces in the new slider, and springs are inserted between the pieces. The structure reduces the amount of movable mass, which is quite effective in keeping the pantograph in contact with the overhead wire. Using this together with high tensile overhead contact lines helps achieve efficient current collection performance, and noise can be reduced by using only one pantograph per trainset.

3.2 Countermeasures for noise from lower part of cars

As described in § 2, noise from the lower part of cars is the next largest source of noise in series E2-1000 running at 360 km/h. Hence, reduction of noise from this area is an important issue in reducing overall noise. We thus installed bogie side covers which shielded underfloor equipment and wheels on FASTECH360S, as shown in Fig. 9. With the aim of absorbing the noise from the lower part of car body through a process of multiple sound reflections between car body and noise barrier, we also applied sound-absorbing panels to the car bodies (Figs. 10 (a) and (b), Fig. 11). The structure of the sound-absorbing panel is shown in Fig. 12.
3.3 Countermeasures for other noise sources

The measures employed in noise reduction include circumferential diaphragms to smooth inter-car gaps in the upper part of cars (Fig. 13), snowplow covers and bogie side covers for aerodynamic noise from train nose (Fig. 14), lessening average axle load from approximately 13 tons to 11.5 tons to mitigate structure-borne noise.

4. Improvements resulting from running tests of FASTECH360S

Figure 15 shows the schematic diagram of noise measurement for FASTECH360 using a spiral microphone array. Figures 16 (a) and (b) show measurement results of noise source distribution of FASTECH360S at 340 km/h in the early stage of the running tests and
after improvement, respectively. Figure 16 (a) shows that much noise is generated from the pantograph noise insulation plates, certain wheels and circumferential diaphragms. Therefore, we studied corrective measures for these noise sources.

Concerning pantograph noise insulation plates, Fig. 16 (a) shows that there are large noise sources at the front and rear ends of the plates in addition to the noise source around the pantograph head at the center of the plate. We also conducted running tests by installing the flat insulation plates with 45-degree angles at both ends of the plate in the side view (“conventional noise insulation plates”). These had shown good performance in past running tests of series E2-1000(10). Figure 17 shows the conventional noise insulation plates installed on FASTECH360S. Figure 16 (b) shows the result of measuring noise source distribution with conventional noise insulation plates. The figure shows that the noise at both ends of the insulation plates is greatly reduced. Regarding noise from the wheels (front half of the trainset), we carried out running tests blocking the ventilation route for the cooling fins on the back of the brake disk on the side of the wheel (Fig. 18). The test results proved that the noise could be reduced to the level of the other wheels, as shown in Fig. 16 (b). Namely, the source of the noise from wheels was found to be aerodynamic noise from the cooling fins of brake disks. Regarding noise from the circumferential diaphragms, we found that much noise was generated when air flowed into thin gaps between diaphragm plates. Thus, the noise could be reduced by blocking the gaps, as shown in Fig. 16 (b).

Fig. 15 Schematic diagram of measurement using spiral microphone array

Fig. 16 Noise source distribution of FASTECH360S using spiral microphone array (340 km/h, without noise barrier)
Based on the study explained above, we were able to further reduce noise on FASTECH360S. We also conducted a wind tunnel test using a 1/10 scale model to find ways to reduce noise from pantograph noise insulation plates\(^{(6)}\). Based on the results, we replaced the conventional noise insulation plates on FASTECH360S with new noise insulation plates with 30-degree angles at both ends of the plate in the side view (Fig. 19). At the same time, we changed both pantographs in the trainset to PS9038, which has better noise reduction performance as well. To reduce the noise from the wheels and the circumferential diaphragms, we improved the shape of the cooling fins on the back of the brake disk on the side of the wheel (Fig. 20, added ribs on the inner periphery of the disk to reduce air flow through the fins) and changed the structure of the circumferential diaphragms (Fig. 21, 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), respectively. We applied almost the same improvements to FASTECH360Z as FASTECH360S.
5. Noise Reduction Performance of FASTECH360

5.1 Running Test Results

After making the improvements explained in the previous section, we measured wayside noise from the FASTECH360 trains running at the high speeds. Figure 22 shows the noise measurement overview. Figures 23 and 24 show the pantograph peak levels and inter-car peak levels that were measured using the liner microphone array (time constant: 35 ms), respectively. Figure 25 shows the measurement results with a non-directional microphone (dynamic characteristic: SLOW).

The lines in the figures represent linear regression. Note that in Figs. 23 and 24, in order to calculate the average value of series E2 running at around 270 km/h, each average line of series E2 was drawn, for the sake of convenience, using the slope of each linear regression line of series E3. This is because it is difficult to determine the speed-dependent degree of the data of series E2 due to concentration of data at around 270 km/h caused by the train schedule to which series E2 (not coupled with series E3) is assigned. And there is a large amount of variation in the data of commercial trains (series E2 and E3) compared to the test trains (FASTECH360S and FASTECH360Z). The reason for this is that although the number of FASTECH360S and FASTECH360Z trainsets is only one each, by contrast, the number of both series E2 and E3 trains reaches several dozen each. Thus, individual difference among the commercial trainsets in operation may be one cause of the large variation in the data.

Figure 23 shows that the pantograph peak levels of FASTECH360S and FASTECH360Z with new low-noise pantographs and 30-degree noise insulation plates are reduced by 2 to 3 dB compared to that of series E2 and 5.5 to 6.5 dB compared to that of series E3, respectively. We also confirmed that, with 30-degree noise insulation plates, the peak level at the folded pantograph could be further reduced compared to that of the lifted pantograph.

Figure 24 shows that the inter-car peak levels of FASTECH360S and FASTECH360Z are lower by approximately 1.5 dB compared to that of series E2 and by approximately 4 dB compared to that of series E3. That is the effect of noise reduction with circumferential smooth diaphragms and sound-absorbing panels at the lower part of the car body. Since Shinkansen trains in the JR East operational area run on slab track, sound absorption around the lower part of the car body is more effective.

Figure 25, the noise measurement results at 25 meters from the center of the track, shows that the improvements of rolling stock explained in § 4 have reduced noise in the coupled operation of FASTECH360Z and FASTECH360S by approximately 4.5 dB compared to that of the present coupled operation of series E3 and E2 at 275 km/h. Red lines in Fig. 25 are shown to find speeds at which FASTECH360 trains can run at the same noise level as the present coupled operation (series E3 and E2 at 275 km/h). While we could not achieve operation at 360 km/h keeping the noise at the current level, we were able to...
achieve 330 km/h keeping the noise level equal to the present coupled operation and 340 km/h for the FASTECH360S train running alone. The reason for the difference is that FASTECH360Z has smaller noise reduction effect than FASTECH360S because the former must operate within the rolling stock gauge of conventional lines.

Fig. 22 Schematic diagram of measurement using non-directional microphone and linear microphone array

Fig. 23 Pantograph peak level using microphone array

Fig. 24 Inter-car peak level (between first and second cars) using microphone array
5.2 Amount of contribution of each noise component to overall noise

We estimated the contribution of each component to overall noise in FASTECH360S cars running at 360 km/h in the same way as described in § 2. Figures 26 (a) and (b) show the calculated results in the case of series E2-1000 running at 360 km/h and in the case of FASTECH360S at 360 km/h, respectively. As shown in Figs. 26 (a) and (b), we estimated that pantograph noise contribution to the overall noise level was reduced by roughly 7 dB compared to that of E2-1000 at 360 km/h and the contribution of noise from the lower part of cars to the overall noise level was reduced by roughly 1 dB as well. The levels of the other components to the overall noise are also considered to be reduced as a result of the countermeasures mentioned in § 3.3.

6. Conclusions

We clarified the contribution of each noise component to the overall noise levels through measurements and analysis of E2-1000 running at 275 km/h and then at 360 km/h. Based on the results of this analysis, we have developed two experimental trains, FASTECH360S and FASTECH360Z, with a number of countermeasures for pantograph noise and noise from lower part of cars, and conducted running tests using these trains. As a result, we verified that the combination of certain measures described in this paper was rather successful in mitigating Shinkansen wayside noise. The results of this development are summarized as follows:
(1) The noise level of E2-1000 running at 360 km/h rises by approximately 6.5 dB over that of 275 km/h. Pantograph noise and noise from the lower part of cars, in that order, have the greatest effect on the overall noise level of E2-1000 at 360 km/h.

(2) To operate at the same noise levels as current commercial trains, FASTECH360S and FASTECH360Z (coupled) would have to run at approximately 330 km/h, and FASTECH360S (alone) at approximately 340 km/h.

(3) The combination of certain measures for noise reduction described in this paper reduces the contribution of pantograph noise within the overall noise level by roughly 7 dB and that of noise from the lower part of cars within the overall noise level by roughly 1 dB, compared to that of E2-1000 at 360 km/h.

Noise reduction techniques for Shinkansen high-speed trains such as new low-noise pantographs, pantograph noise insulation plates, sound-absorbing panels and circumferential diaphragms, as described in this paper, will be used for the next generation Shinkansen trains, to be called series E5. Series E5, with a maximum speed of 300 km/h, will be introduced in March 2011 after the completion of the Tohoku Shinkansen extension to Shin-Aomori, after which we will increase the maximum speed to 320 km/h, the highest Shinkansen speed in operation in Japan, by March 2013.

References


