Noise Evaluation of Shinkansen High-speed Test Train (FASTECH360S,Z)

H.Yamada, Y.Wakabayashi, T.Kurita, M.Horiuchi
R&D Center of JR East Group, East Japan Railway Company, Saitama, Japan

Abstract

Noise reduction is one of the major technical challenges for further speed-up of the Shinkansen. FASTECH360S and Z, high-speed test trains developed by East Japan Railway Company for the purpose of verifying technologies for future practical trains, incorporate various countermeasures aiming at noise reduction at higher speed. Through 3 years' running tests since 2005, the performance of each countermeasure has been determined. In this paper, outlines of the tests designed to evaluate these countermeasures are explained and evaluations are made by referring to test results obtained by various microphone configurations. As a result of the tests, it has been concluded that the train speed at which the noise level is the same as current commercial trains running at the speed of 275 km/h is about 330 km/h for FASTECH360S+360Z (coupled), and is about 340km/h for FASTECH360S (alone).

1 Introduction

Noise reduction is one of the major technical challenges for further speed-up of the Shinkansen. In general, the noise level exponentially increases according to the train speed. However, in Japan, it is needed to prevent the noise level from rising even when the train speed is increased. In order to overcome this technical challenge, East Japan Railway Company has developed high-speed test trains FASTECH360S and Z which incorporate several countermeasures for noise reduction at higher speed, and has performed running tests up to 360 km/h. In this paper, outlines of the tests designed to evaluate these countermeasures are explained and evaluations are made by referring to test results obtained by some types of microphones. Furthermore, overall noise performance of FASTECH360 is also discussed in comparison with that of current commercial trains.

2 Test Trains and Noise Measurements

In this section, outlines of test trains and noise measurements used for noise evaluation are described.

2.1 High-speed Shinkansen Test Trains (FASTECH360S and 360Z)

East Japan Railway Company developed two types of high-speed test trains; FASTECH360S and 360Z, and has performed high-speed running tests since June 2005. FASTECH360S is a high-speed test train designed for running only on Shinkansen Lines, and has 8 cars numbered as shown in Fig.1 (a). FASTECH360Z is also a high-speed test train designed for through operation between Shinkansen lines and converted conventional lines, and has 6 cars numbered as shown in Fig.1 (b). That is, FASTECH360Z runs both on Shinkansen lines and on conventional lines converted to Shinkansen gauge. Because of the narrower clearances on conventional lines, the cross sectional area of FASTECH360Z is smaller than that of FASTECH360S.

Note that these trains can run with only one pantograph by adopting a multi-segment slider, while the currently operated Shinkansen trains use two pantographs to avoid arcs due to contact losses. [1] The pantograph nearer the front of the train is folded and could no longer be seen from the noise measurement point. It is also possible to couple these two test trains. With car No. 8 of FASTECH360S coupled to car No. 11 of FASTECH360Z, running tests were performed with Car No. 16 at the front in the down (north bound) direction.

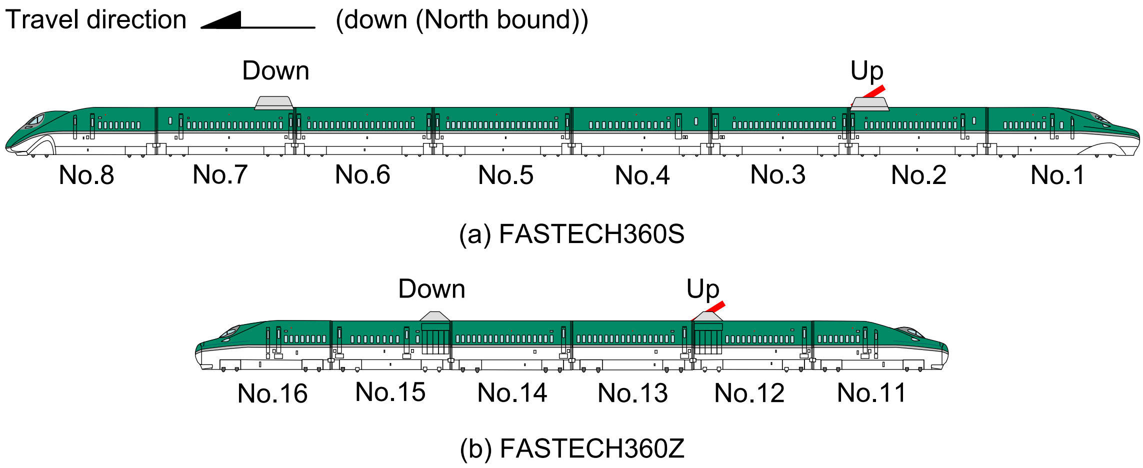


Fig. 1 FASTECH360S, 360Z, and their pantograph positions

2.2 Countermeasures of FASTECH360 for Noise Reduction

Both FASTECH360S and 360Z have several countermeasures to reduce wayside noise in the five categories of Shinkansen noise; (1) Pantograph noise, (2) Aerodynamic noise from the train nose, (3) Aerodynamic noise from the upper parts, (4) Noise from the lower parts, (5) Structure-borne noise. [2] Table 1 shows primary countermeasures applied on the test trains. Note that some of the countermeasures are different between 360S and 360Z due to the smaller size of 360Z as mentioned above. One example of this difference is pantograph noise insulation plates of FASTECH360Z. They are built to be vertically movable to allow FASTECH360Z to run on the converted conventional lines which have narrower clearance, while those of FASTECH360S are fixed to the car body.

Table 1: Primary countermeasure applied on FASTECH360S and 360Z

Noise Classification	Countermeasures
(1) Pantograph noise	(a) Low-noise pantographs (b) Pantograph noise insulation plates
(2) Aerodynamic noise from the train nose	(a) Bogie covers (b) Smoothed door to the drivers' cab (c) Snowplow cover
(3) Aerodynamic noise from the upper parts	(a) Circumferential bellows (b) Smoothed roof without cables
(4) Noise from the lower parts	(a) Bogie covers (b) Sound absorbing panels
(5) Structure-borne noise	(a) Lighter axle load

2.3 Noise Measurements

Three types of microphones were used to evaluate noise performance of test trains, and measurements were taken of trains running in the down direction. In this section, outlines of the measurements are explained.

2.3.1 Measurement using a Spiral Microphone Array

A spiral microphone array was used to capture noise distribution of moving trains. [2] Fig. 2 shows a schematic diagram of the measurement. This enables us not only to specify locations of noise sources in the car body but to know whether countermeasures are effective or not by comparing results taken in various conditions.

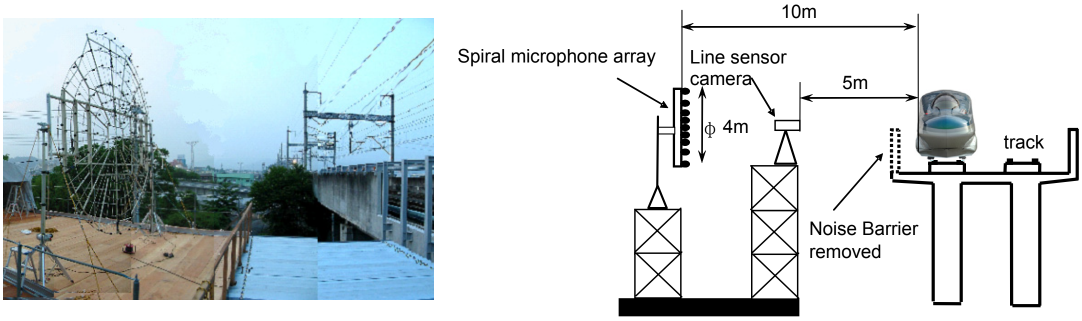


Fig. 2 Schematic diagram of measurement using spiral microphone array

2.3.2 Measurements using a Non-directional Microphone and a Microphone Array

Both a non-directional microphone (dynamic characteristic: slow) and microphone array (time constant: 35msec) were placed 25m away from the nearest track where the wayside Shinkansen noise was evaluated. The schematic diagram of measurement using these microphones is shown in Fig. 3. An example of measurement result using the microphone array is shown in Fig. 4. Peak and low levels of sound pressure level can be seen for each car, and these are good indicators of noise performance of trains.

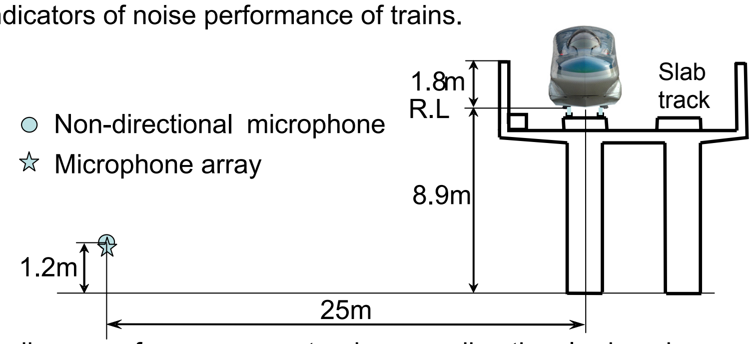


Fig. 3 Schematic diagram of measurement using non-directional microphone and microphone array

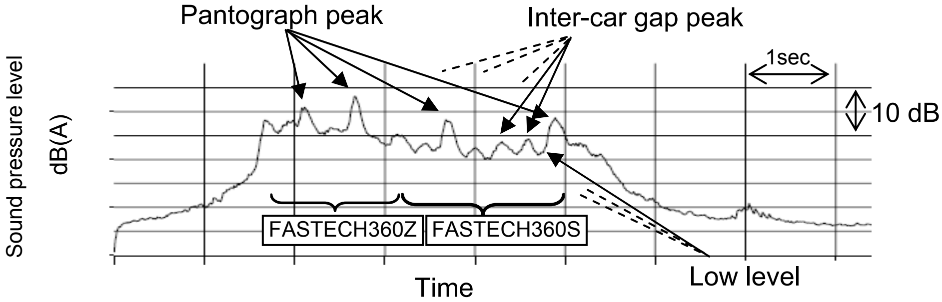


Fig. 4 An example of measurement result using microphone array (360S and Z coupled)

3 Testing the Effect of Each Countermeasure

In order to evaluate the effect of each countermeasure for noise reduction, deterioration tests were performed by replacing countermeasures with conventional structures, and measurement results are compared among cases. In this chapter, details of deterioration tests for some of the main countermeasures and the test results are described.

3.1 Pantograph Noise Insulation Plates

Pantograph noise insulation plates were installed to reduce pantograph noise, which is the most dominant among all noise sources. In order to evaluate their effectiveness, movable pantograph noise insulation plates of FASTECH360Z shown in Fig. 5 were used. Noise levels were compared with those plates in the up and in the down position.

Noise distributions of both cases are shown in Table 2. As seen in the table, the noise distributions of “w/o Plates” are remarkably worse. Fig. 6 indicates pantograph peak level with and without pantograph noise insulation plates. In these graphs, it is confirmed that peak level increases by 4.4 dB for a down pantograph and 2.6 dB for an up pantograph, which agree with the tendency seen in noise distributions. The greater increase in noise from the down pantograph is attributed to the wider hidden area of this pantograph. Since the down pantograph is folded and could no longer be seen from the measurement point, while the head of the up pantograph could be seen from the same point, it is considered that the insulation effect of the plates is greater. In Fig. 7, sound pressure level (SPL) at 25m from the track is shown. As can be seen, the increase reaches about 1.5 dB. That means achievable train speed is decreased by about 20 km/h if pantograph noise insulation plates are not used.

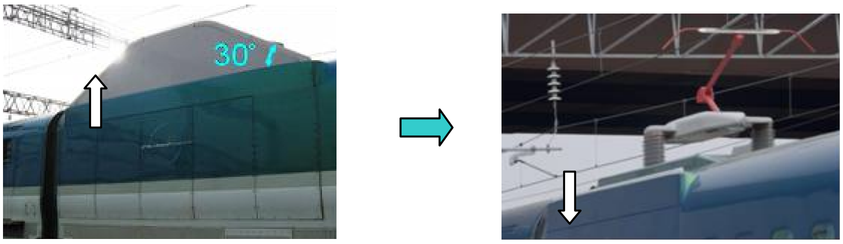
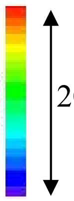
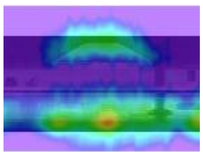
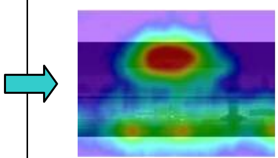
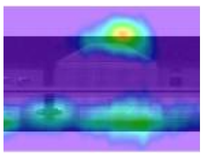
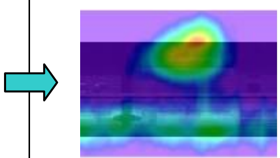
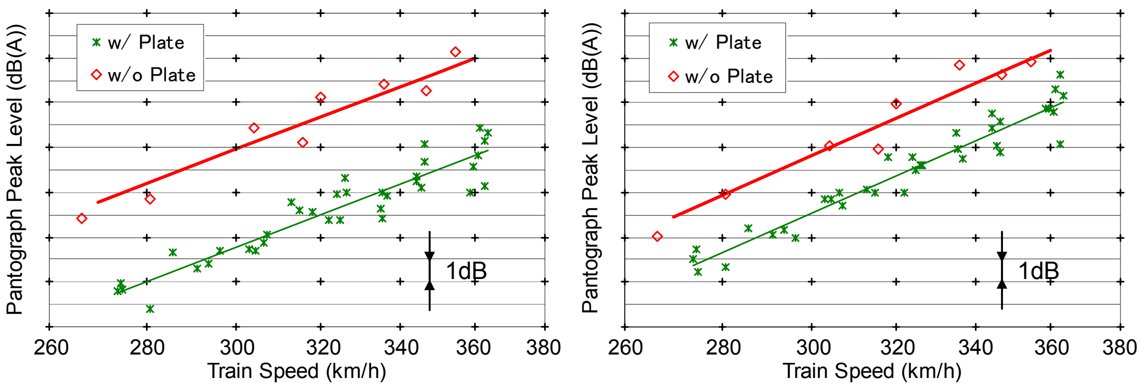


Fig. 5 Pantograph noise insulation plates on FASTECH360Z (in Up and Down position)

Table 2. Noise distribution of pantographs with and without pantograph noise insulation plates

		w/ Plates	w/o Plates
Down Pantograph	 20 dB		
Up Pantograph			



(a) Down pantograph (between No. 14 & 15) (b) Up pantograph (between No. 12 & 13)

Fig. 6 Comparison of pantograph peak level with and without pantograph noise insulation plates (microphone array)

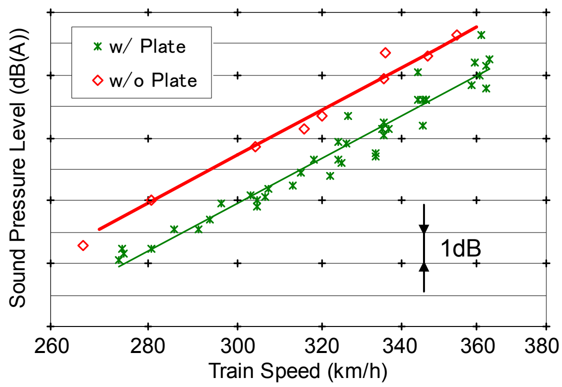


Fig. 7 SPL at 25m with and without pantograph noise insulation plates
(non-directional microphone)

3.2 Smoothed Roof

FASTECH360 has a smoothed roof on which there are no cables for high-voltage like those on the roofs of current commercial trains such as series E2. The value of this countermeasure was investigated by placing dummy cables on the top of the roof as shown in Fig. 8. Cables were placed from car No.13 through No. 15. Straight joints were placed between car No. 15 and No. 16, and a cable head was also placed between car No. 13 and No. 14, which was replaced by a straight joint during the tests to compare noise performance.

The comparison of noise distributions with and without cables is in Fig. 9. In (b) of this figure, noticeable noise can be observed on the roof where cables are attached. In particular, the noise level is greater around the straight joint and the cable head than around the cables because of aerodynamic noise caused by the configulation. Fig. 10 shows lowest and peak levels measured by microphone array with and without cables. In these graphs, it is confirmed that the lowest noise level of car No. 15 is increased by 2.7 dB when cables are added, while the peak level between car No. 13 and No. 14 is increased by 2.7 dB when the cable head is added. When the cable head was replaced by a straight joint, noise level was decreased by 0.7 dB compared to the case of cable head. But noise level was still 2 dB greater when there were no cables. In Fig. 11, sound pressure level (SPL) at 25m from the track is shown. As can be seen, it increases by 0.4 dB. According to further calculation it was revealed that the cable head was one of the greatest contributors to overall noise, and increased the sound pressure level by almost 0.3 dB.

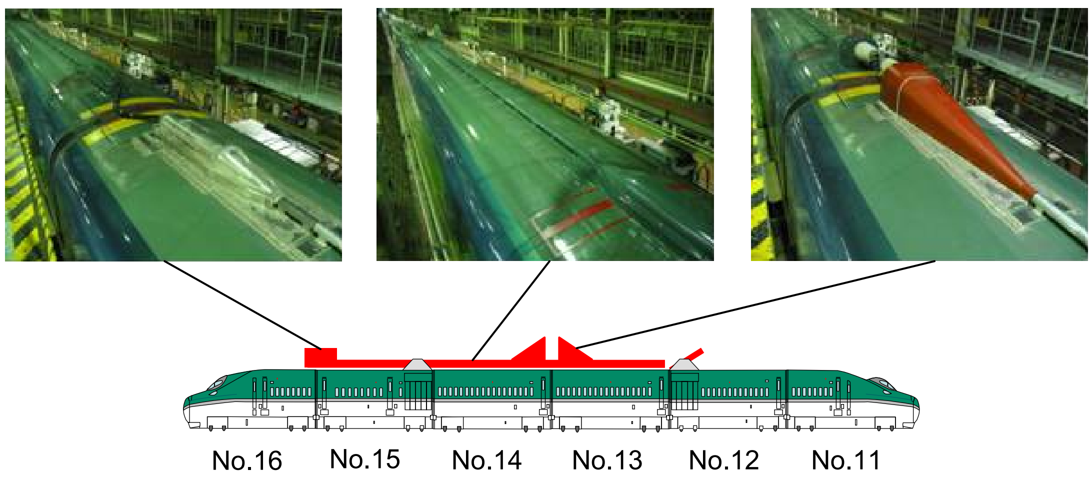


Fig. 8 An outline of deterioration tests for smoothed roof (cable size is exaggerated in the figure)

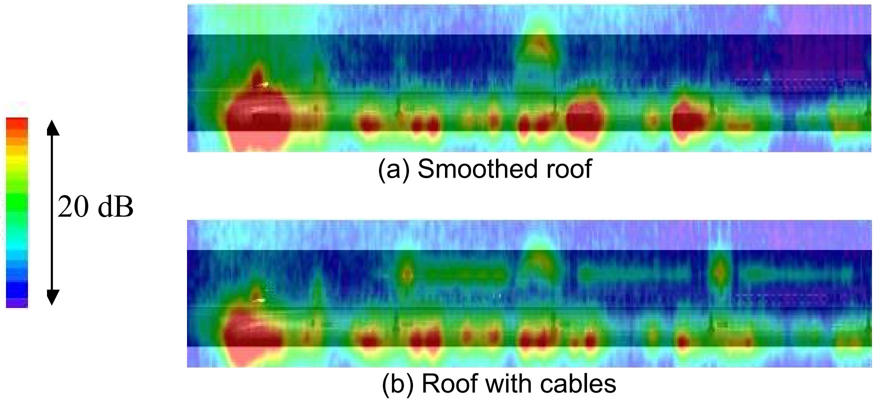
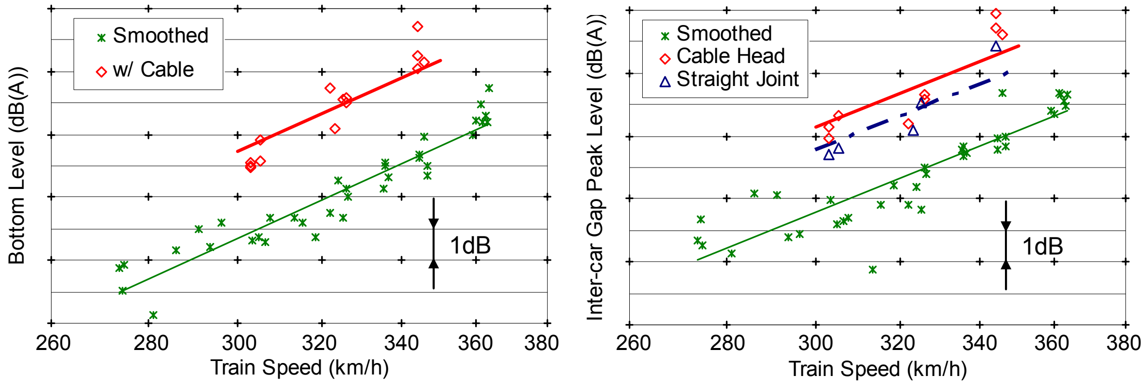


Fig. 9 Comparison of noise distributions with or without cables



(a) Intermediate car (No. 15) (b) Inter-car gap (between No. 13 & 14)

Fig. 10 Comparison of bottom and peak level with and without cables (microphone array)

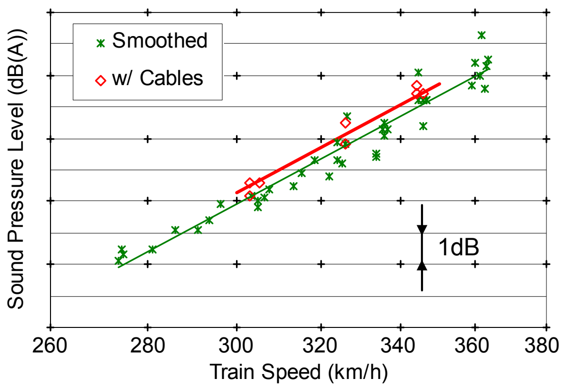


Fig. 11 SPL at 25m with and without plates (non-directional microphone)

3.3 Circumferential Bellows

Gaps between cars of FASTECH360 are entirely covered with circumferential bellows. Comparison was made to measure their effect by replacing them with conventional bellows of the type used on series E3, a current commercial train used for through operation. (shown in Fig. 12)

Noise distributions of both circumferential bellows and conventional bellows are in Fig. 13. As in (b) of this figure, noise level was higher with conventional bellows. Fig. 14 shows the comparison of peak level measured by the microphone array. The peak level between car No.

15 and No. 16 was increased by 1.4 dB in the conventional bellows case. Sound pressure level (SPL) at 25m from the track is shown in Fig. 14. As can be seen, the level is increased by 0.3 dB.

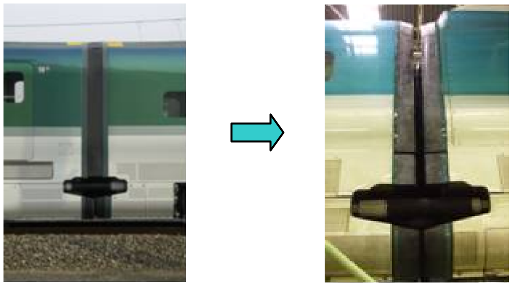
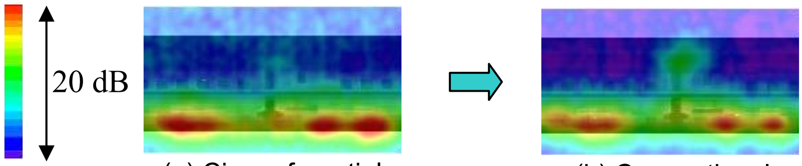


Fig. 12 Circumferential bellows and conventional bellows



(a) Circumferential (b) Conventional

Fig. 13 Comparison of noise distributions with circumferential bellows and conventional bellows

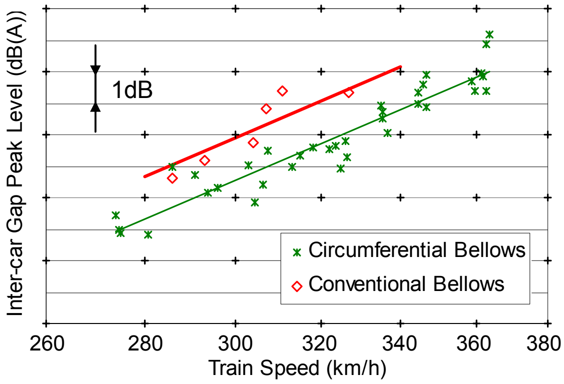


Fig. 14 Comparison of peak level with circumferential and conventional bellows

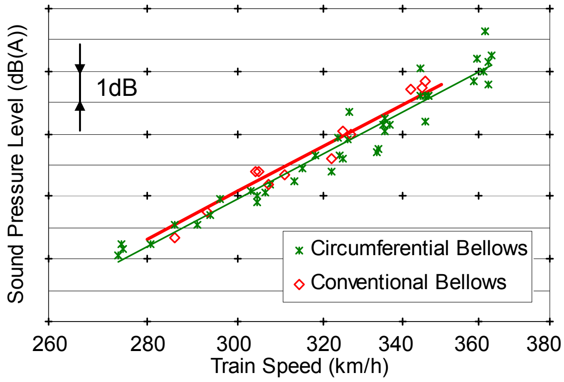


Fig. 15 Comparison of SPL at 25m with circumferential and conventional bellows

3.4 Sound Absorbing Panels

Sound absorbing panels are applied to the lower sides and bottom of the car body to absorb the noise reflected by the roadbed and noise barriers in order to reduce noise from the lower parts, which makes a comparatively greater contribution to the overall noise level of the test trains because of their reduced pantograph noise. [1] As shown in Fig. 16, comparison was made by replacing these panels with panels that don't have sound absorbing material. The panel pattern was changed in order to find which parts of sound absorbing panels are more effective in overall noise reduction as indicated in Table 3.

Fig. 17 shows sound pressure level at 25m in each case. About 0.9 dB increase was observed when all the sound absorbing material was removed. From the detailed analysis, it was also found that sound absorbing panels attached to the side skirts contribute greatest to overall noise level, reducing overall noise by 0.8 dB. This is because sound absorbing panels attached to side skirts greatly diminish noise from the lower parts in a multi-reflection process between car bodies and sound barriers as shown in Fig. 18. As for contributions of other parts, it was found that panels attached under the floor reduced noise slightly ,while panels attached to side beams and front and back sides of bogies didn't contribute to reduce overall noise beyond that achieved with other parts of panels.

Fig. 16 Deterioration tests for sound absorbing panels

Table 3 Panel Pattern for the tests

	Side beam	Side skirts	F/B of bogies	Under the floor
case1	O	O	O	O
case2	O	O	X	O
case3	X	X	X	X
case4	X	O	O	X
case5	X	O	O	O

(O: Sound absorbing panel X: No sound absorbing panel)

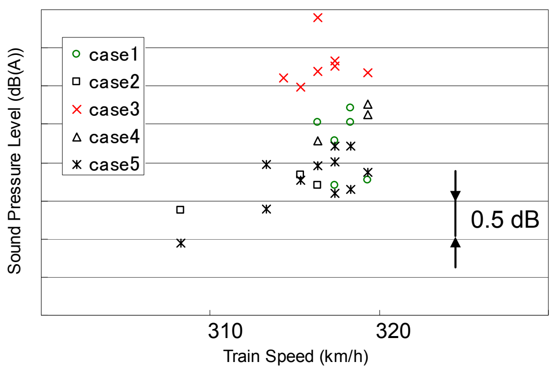


Fig. 17 SPL at 25m in 5 cases (non-directional microphone)

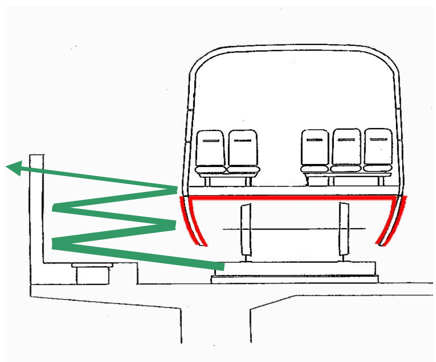


Fig. 18 Multi-reflection process

4 Overall Performance

In this chapter, overall noise performance of FASTECH360 is explained. Pantograph peak level, inter-car gap peak level, and sound pressure level at 25m of FASTECH360 are compared with those of commercial trains. Note that series E2 trains are used on Shinkansen lines ,series E3 trains are used for through operations onto converted conventional lines, and trains of both types can also be coupled as FASTECH360S and 360Z can.

4.1 Pantograph Peak Level and Inter-gap Peak Level

Pantograph peak level and inter-car gap peak level measured by the microphone array are shown in Fig. 19 and Fig. 20 respectively. Fig. 19 shows that the pantograph peak level of FASTECH360 is reduced by more than 2dB compared to series E2, and is reduced by more than 5dB compared to series E3. This reduction is achieved not only by pantograph noise insulation plates but also by low-noise pantographs [1]. It is also noted that the peak level of the folded pantograph is less than for the unfolded one. This is because hidden areas of the folded pantograph behind noise insulation plates are greater than those of the unfolded pantograph. Fig. 20 shows that the inter-car gap peak level of FASTECH360 is reduced by 1 to 2 dB compared to series E2, and is reduced by approximately 4dB compared to series E3. This is attributed to the noise reduction effect of smoothed roof, circumferential bellows, and sound absorbing panels as described in chapter 3. Sound absorbing panels were especially effective when running on slab track. It is also remarkable that the noise reduction effect of FASTECH360S is greater than that of FASTECH360Z. This is due to the larger size of countermeasures applied on FASTECH360S as described above.

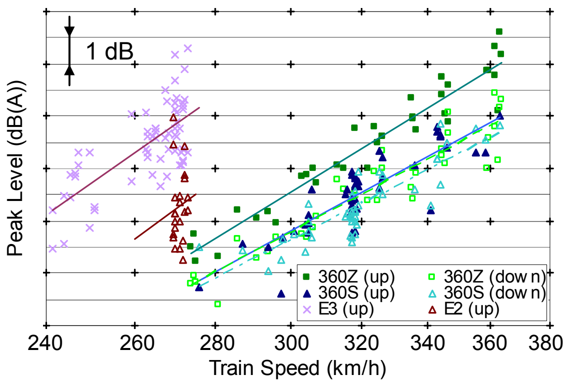


Fig.19 Pantograph peak level (microphone array)

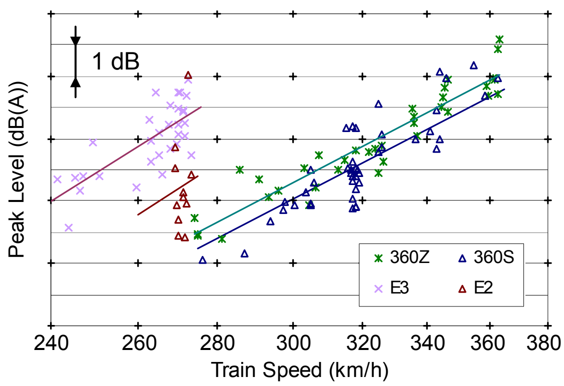


Fig. 20 Inter-car gap peak level (microphone array)

4.2 Sound Pressure Level at 25m

Fig. 21 shows sound pressure level measured by non-directional microphone. The noise level of FASTECH360S+360Z (coupled) is 4 to 5 dB less than that of E3+E2 (coupled), and the difference reaches 6 dB when it comes to FASTECH360S (alone). In other words, the train speed at which the noise level is the same as current commercial trains running at the speed of 275 km/h is about 330 km/h for FASTECH360S+360Z (coupled), and is about 340km/h for FASTECH360S (alone). Although the goal “360km/h” is still ahead, it was confirmed that countermeasures incorporated in FASTECH360 greatly reduce wayside noise and contribute to environmental friendliness.

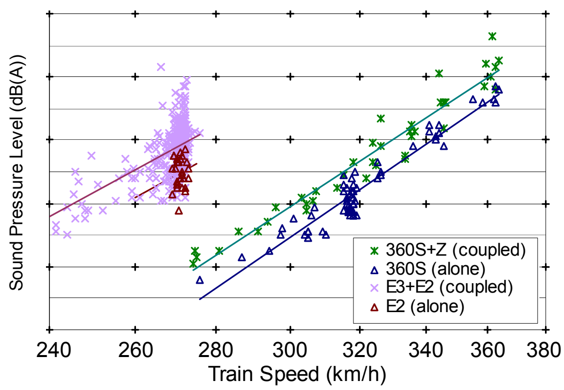


Fig. 21 SPL at 25m (non-directional microphone)

5. Conclusions

(1) The train speed at which the noise level is the same as current commercial trains running at the speed of 275 km/h is about 330 km/h for FASTECH360S+360Z (coupled), and is about 340km/h for FASTECH360S (alone).

(2) Pantograph noise insulation plates reduce wayside noise by about 1.5 dB. In combination with low-noise pantographs, they reduce pantograph peak level by about 2 to 5 dB compared to current commercial trains.

(3) Smoothed roof, circumferential bellows, and sound absorbing panels are also of use to reduce wayside noise. Combined together, inter-car gap peak level is reduced by about 2 to 4 dB compared to current commercial trains.

References

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