Research and Development on Reducing Interior Noise in Shinkansen Vehicles

Noise inside Shinkansen cars increases with increase in train speed. We have conducted considerable development to reduce this interior noise and successfully developed new rolling stock with interior noise levels that are equal to or less than that in previous trains even when the maximum speed increased from 275 km/h to 320 km/h. In this paper, we discuss the direction of development to further increase the speed of Shinkansen trains by reviewing past developments such as the effects of various types of products developed and noise measurement results obtained through running tests.

Keywords: Shinkansen rolling stock, High-speed train, Interior noise

1 Introduction

Energy of noise in a train car generally increases in proportion to the square to sixth power of running speed of that train. Also, sound insulation performance required to reduce that noise is proportional to mass of car body, floor, and windows. In other words, an effective measure to control increase of interior noise due to train speed increase is to increase rolling stock weight by making materials of car body and windows thicker. On the other hand, high-speed Shinkansen rolling stock must increasingly be faster (arrive at destinations in shorter time), operate with less power, and have less ground vibration; and we have been aiming to reduce body weight as an effective measures for those. Reducing interior noise and reducing rolling stock weight are contrary to each other; however, we need to achieve both of those to increase Shinkansen running speed. In light of that, much research and development on technology to reduce interior noise without increasing rolling stock weight has been considered and that technology introduced to actual trains in commercial operation.

In this paper, we review the results of research and development the Research and Development Center of JR East Group has conducted on reducing interior noise.

2 Causes of and Countermeasures for Interior Noise

There are various sources of interior noise, including aerodynamic noise from the car body, rolling noise from wheels, and noise caused by bogie vibration that is propagated to and vibrates the floor panel and interior. Noise generated from different sources enters the cabin to become interior noise, so interior noise can be categorized by transfer path into "air-borne noise (transmitted noise)," "structure-borne noise," and "duct noise (direct noise)." Fig. 1 shows causes and measure examples of interior noise.

Fig. 1 Causes and Measure Examples of Interior Noise

By identifying the noise source and transfer path, we can take specific measures to reduce interior noise. Particularly, in efforts to reduce noise caused by speed increase, we need to minimize increases in car body weight. Correctly identifying the noise transfer path from source to cabin and degree of contribution of individual noises to the total noise and taking measures focusing on individual targets based on that knowledge are requirements for achieving interior noise reduction and car body weight reduction at the same time.

3 Interior Noise Reduction Method

3.1 Flow of Development of Interior Noise Reduction Methods

There are many possible methods of reducing interior noise. Fig. 2 shows an example of flow of development of a method we have actually carried out. First, we measure noise and vibration in stationary tests and running tests to identify actual noise in detail. Then, according to the measurement results, we analyze and evaluate degree of contribution to total noise and transfer paths from sources of individual noises. Based on the analysis and evaluation results, we focus on the target noises and develop technical elements appropriate to the part and method that need to be dealt with, and we then examine how to actually introduce the items developed to rolling stock while taking into account weight, cost, and the like. Finally, we return to the first step and check the effect of the equipped items developed by measuring noise and vibration in stationary and running tests again. By repeating this cycle, we have been working on refining interior noise reduction methods.
the vibration measurement results. Vibration level of floor and wainscot panels that are greatly affected by structure-borne noise did not increase so much in tunnels. In contrast, vibration level of windows and ceilings increased greatly. The reason is that airborne noise (transmitted noise) increased due to noise reflection in a tunnel, and this is a characteristic of the part that is affected by that transmitted noise.

In addition to those running test results, we also gained noise and vibration data by acoustic vibration and impact excitation methods in stationary tests.

3.2.2 Results of Acoustic Analysis (Analysis of Degree of Contribution to Total Interior Noise)

From the running and stationary test data, we calculated transfer path functions that are the rates of outside noise and vibration propagated inside to become interior noise, and we also calculated degree of contribution to the total interior noise by transfer paths using a noise prediction model by statistical energy analysis (SEA) and boundary element method (BEM). Here, Fig. 5 shows the calculation results of degree of contribution to total interior noise per part.

In the figure, values are the degree of contribution to the total interior noise in an open section per part, and values in brackets those in a tunnel section. The results revealed that nearly 90% of interior noise is transmitted noise and structure-borne noise from the floor and windows increased greatly. The reason is that airborne noise (transmitted noise) increased due to noise reflection in a tunnel, and this is a characteristic of the part that is affected by that transmitted noise.

3.3 Verification of Interior Noise Reduction Measures Using FASTECH 360

Based on the measurement results using a series E2 Shinkansen train, we further worked on development of elements focusing on some specific noises. Since June 2005, we carried out running tests using the FASTECH 360 Shinkansen high-speed test train to verify noise reduction effects of individual elements developed.

Fig. 2 Example of Development of Interior Noise Reduction Method

3.2 Case Example of Noise Measurement and Analysis Using Series E2 Shinkansen Train

3.2.1 Test and Measurement

Fig. 3 shows as the results of interior noise measurement carried out in running tests from March to June 2003 using a series E2 Shinkansen train. Interior noise increased as train speed increased. It increased by approx. 2 dB(A) in an open section and approx. 3 dB(A) in a tunnel section as the train speed increased by 40 km/h from 280 km/h.

We also measured vibration of floor panels, interior panels, windows and the like in addition to noise values. Fig. 4 shows...
3.3.1 Measures for Noise from Floor

Fig. 6 shows the measures for noise from floor verified using FASTECH 360. We found that the measures were effective on transmitted noise for the floor panel structure. For comparison, we carried out tests by installing aluminum honeycomb floor panels also used in series E2 trains, newly developed aluminum honeycomb floor panels with a rubber plate, and aluminum floor panels with resin foam as the core material. As a countermeasure against noise structure-borne noise, we adopted a floating floor structure where floor panels were supported by two types of rubber supports. Moreover, we made a cutout at the end of a joist to make a structure where little vibration is propagated between airtight floor panels and floor panels.

Fig. 6  Countermeasures for Noise from Floor

The evaluation results in the running tests showed that using aluminum floor panels with resin foam was most effective of the three floor structures on reducing transmitted noise. They also confirmed that elastic support and cutout on the joist greatly reduced structure-borne noise.

3.3.2 Countermeasures for Noise from Walls and Ceiling

Fig. 7 shows the countermeasures for noise from walls and ceiling. The effect on transmitted noise of attaching sound absorbing material was known from before, but using more sound absorbing material leads to increase of car body weight and cost. In light of that, we checked on the FASTECH 360 the effects of different types and thickness of sound absorbing material that also works as heat insulation. We also verified elastic supporting of interior material that was conventionally fixed to the car body frame of Shinkansen rolling stock.

The evaluation results in the running tests gave us information on type and thickness of sound absorbing material required and part to which it is attached as a measure for reducing transmitted noise. In contrast, we could confirm almost no effect of the method of elastic support of interior material.

3.3.3 Countermeasures for Noise from Windows

We adopted a cabin window structure with an air layer between the outer glass and inner glass, and based on the element development results, we installed three types of outer glass to the FASTECH 360 for verification. Those were multi-layer glass with and without an air layer in between and polycarbonate glass. Fig. 8 shows the structures of conventional and tested window types. To expand the frequency band where sound can be insulated, the air layer was made thicker. Window size itself was made smaller while maintaining cabin comfort.

Fig. 8  Countermeasures for Noise from Windows

The running test results confirmed the effects of each type of multi-layer glass and polycarbonate glass on reducing transmitted noise. From that, we gained insight on the appropriate structure and thickness of multi-layer glass windows in installing to rolling stock in commercial use.

3.3.4 Other Measures

In addition to the measures explained above, we verified the following measures using the FASTECH 360 based on the element development results.

(1) Quiet air-conditioner ducts

In reviewing the structure of air-conditioner ducts, one of the interior noise sources, we developed a quiet air-conditioner duct with a simple structure and to which sound absorbing material was added and confirmed its effects.

(2) Elastic support of underfloor equipment (main transformer)

As a measure to reduce harmonic vibration and noise, we tested a structure where main transformers area supported with rubber. The results of verification using FASTECH 360 confirmed vibration insulation and noise reduction.
We employed interior noise reduction measures confirmed effective using the FASTECH 360 on the series E5 and E6 Shinkansen rolling stock that runs at 320 km/h in commercial operation, taking into consideration noise reduction effects, weight, cost, and the like. Fig. 9 shows the noise reduction measures introduced.

Fig. 9 Development Results Employed on Series E5 and E6 Rolling Stock

Fig. 10 shows a comparison of total interior noise level between series E2 and E5 rolling stock. This confirms that interior noise could be kept to a level equal to or less than before both in open and tunnel sections by introducing the items developed even when speed was increased from 275 km/h to 320 km/h.

Fig. 10 Comparison of Interior Noise Levels (directly above bogie)

Next, Fig. 11 shows frequency analysis results. With the series E5 train, A-weighted sound pressure level of around the 100 to 200 Hz frequency band, which determines total noise level, is kept low both in open and tunnel sections. As it is known that structure-borne noise such as from bogies is predominant in this frequency band, we could confirm that measures for reducing structure-borne noise keep total noise level down. In the 300 to 1,000 Hz frequency band, noise level difference with the series E5 train is 6 dB(A) between open and tunnel sections, while that is 10 dB(A) with the series E2 train. As transmitted noise is predominant in this frequency band, this result shows that measures for reducing transmitted noise are effective. We could reduce both structure- and air-borne noise in a well-balanced manner, resulting in total interior noise reduction.

Fig. 11 Comparison of Frequency Analysis Results (at 275 km/h, directly above bogie)

We could reduce interior noise by the technologies developed as described herein even with train speed increase from 275 km/h to 320 km/h while minimizing increase of rolling stock weight. However, with further speed increase, rolling stock weight and production cost will increase and cabin space will be smaller by using current technologies only.

Aiming to reduce interior noise for the next generation of high-speed Shinkansen rolling stock, we will work on developing new analysis methods to identify noise transfer paths and degrees of contribution to total noise in more detail and completely new interior noise reduction methods that are not simply an extension of conventional rolling stock technologies. We will seek an ideal rolling stock structure that has a good balance between the effects of such new interior noise reduction measures and the constraints of rolling stock design in weight, cost, space, and the like.

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