Special edition paper

Development of Low-noise Air Conditioning Ducts


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When increasing Shinkansen speed, air conditioners need to be installed under the car floor from a perspective of wayside noise reduction. Present rolling stock for through service between conventional and Shinkansen lines has cabin units for the air conditioner on the roof due to limitations of underfloor space, so those cabin units will have to be relocated under the floor along with existing under-floor units for new rolling stock to be manufactured in the future. An all-in-one underfloor air conditioner is desirable in that relocation from a viewpoint of effectiveness in space conservation. On the other hand, such an air conditioning system has a disadvantage in terms of cabin noise because the two separate air conditioners and one ventilator have to be combined into one unit that generates more noise. We thus worked on reduction of cabin noise by the air conditioning system for the FASTECH360Z. In the development, we produced a mockup model of air conditioning ducts for actual cars and used that model to evaluate the noise generated by the air conditioning system and improve the ducts. As a result, we have successfully reduced the cabin noise by the air conditioning system of the FASTECH360Z by 3.4 dB.

●Keywords: Shinkansen, All-in-one underfloor air conditioning system, Mockup model of air conditioning duct, Airflow sound, Sound transmitted by air conditioning system

1 Introduction

The largest issue in Shinkansen speed increase is wayside noise reduction. Air conditioners for the rolling stock for through service between conventional and Shinkansen lines to be manufactured in the future must be installed under the car floor instead of on the roof as they are with the existing rolling stock to reduce noise along the line. But rolling stock for through service has less underfloor space than rolling stock exclusive for Shinkansen lines, so air conditioners also have to contribute to space saving. An all-in-one underfloor air conditioner including the ventilator is desirable from this point of view, so such air conditioners are used for FASTECH360. But, since the two separate air conditioners and one ventilator installed (both on roof and under floor, six units total) are combined in such a system, the required total air volume has to be supplied by the air conditioners alone. That leads to a disadvantage in terms of noise in the cabin, so improvement of quietness is an issue to overcome.

In this development, we created low-noise air conditioning ducts for the FASTECH360Z test train for through service, aiming to improve air conditioning ducts that are one of the causes of the cabin noise.

2 Identification of Noise Sources

2.1 Production of Mockup Model of Air Conditioning Ducts

The sources of air conditioning system noise are thought to be the air conditioner and the air conditioning ducts. But it is difficult to separately measure and evaluate those with actual cars. We thus produced a mockup model of air conditioning ducts of an actual car to measure and evaluated the noise by air conditioning ducts. In addition, we produced a blower to circulate air in the mockup model at a specified air volume. Those components made up a test system to evaluate the noise generated by the air conditioning ducts of FASTECH360Z and study measures to reduce noise. Fig. 1 shows the mockup model of the air conditioning ducts that recreates car No. 15 of the FASTECH360Z.

Connections with the air conditioner are located under the duct near the center of the mockup. The connections of the blower shown in Fig.2 connect to the ducts here. The blower has built-in supply and exhaust fans that can separately control the air volume using an inverter. In order to prevent transmission of fan noise, they are set in a sound insulating unit and silencers are installed in front of and behind the supply fan and to the intake side of the exhaust fan.

A speaker was installed to generate pink noise in the blower, and the amount of noise from the ducts was measured in the cabin. The level of sound absorption of the air conditioning noise of the ducts can thus be checked based on those measurement values.

Fig. 1 Air Conditioning Ducts in Car Body Mockup Model

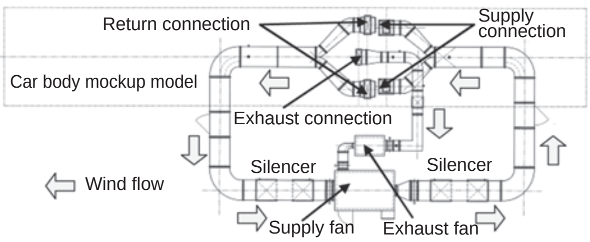

Fig. 2 Overview of the Blower

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2.2 Measurement of Noise in Mockup Model of Air Conditioning Ducts

Using the mockup model, we measured the airflow noise in the air conditioning ducts. The measurement point was set to a point equivalent to 1.2 m above the floor, the height at which an air conditioner is installed in an active duty car.

The airflow noise was measured by individual air conditioning duct system by changing the combination of ducts. Noise in the four systems measured was from ①air flow in the supply duct alone, ②air flow in the return duct alone, ③air flow in the exhaust duct alone and ④air flow in all duct systems.

The measurement results are shown in Fig. 3. Looking at the overall value of the A-weighted sound pressure level per duct system, that of the supply ducts was 71.9 dB(A), the return ducts 65.1 dB(A) and the exhaust ducts 47.7 dB(A) in descending order. The fact that the airflow noise of the supply ducts was almost equal to the airflow noise of the all ducts (71.8 dB(A)) clarifies that the airflow noise by the supply ducts accounts for a large percentage of the total airflow noise by the air conditioning ducts.

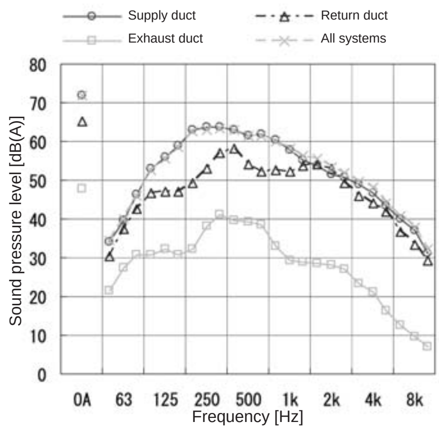

Fig. 3 Measurement Results for Wind Noise in Mockup Model

2.3 Noise Source Analysis

2.3.1 Airflow Noise Source Analysis

As a result of noise source analysis, we focused on the connecting supply air duct shown in Fig. 4 connecting the air conditioner and the in-floor duct. The supply fan of the air conditioner is located near the connection as shown in Fig. 5, and the effective air blow area is about half of the cross section of the connection. Accordingly, the cross section sharply increases toward the connecting supply air duct that is connected to the air conditioner, probably causing the increase in airflow noise[1]. Furthermore, guide vanes are installed where airflow around the cabin fan is disturbed, and that is considered a cause of wind noise. Based on those findings, we decided to take measures for airflow noise reduction to the connecting supply air duct.

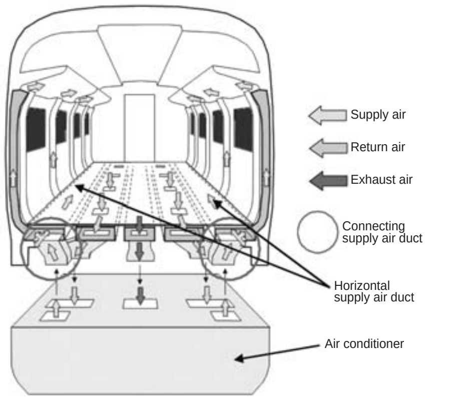

Fig. 4 Location of Airflow Noise Sources

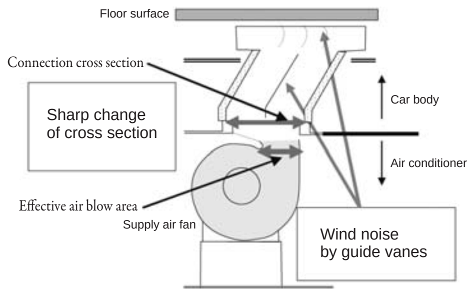

Fig. 5 Causes of Noise of the Connecting Supply Air Duct

2.3.2 Analysis of Transmission of Air Conditioner Noise

We know that in the air conditioning system, noise other than airflow noise generated by the conditioner is transmitted to the cabin through the air conditioning ducts (hereinafter "transmitted air conditioner noise"). Fig. 6 shows the estimated level of the transmitted air conditioner noise within the mockup model. Estimated values were calculated from the actual noise at the connections of each air conditioner measured separately and overall attenuation of each duct measured in the mockup model. The figure shows that the overall values of the A-weighted sound pressure level were 68.4 dB(A) at the exhaust connection, 62.5 dB(A) at the supply air connection and 52.4 dB(A) at the return connection, in descending order. Based on those results, we decided to reduce the transmitted air conditioner noise by improving the sound absorption performance of the connecting ducts for exhaust air and supply air.

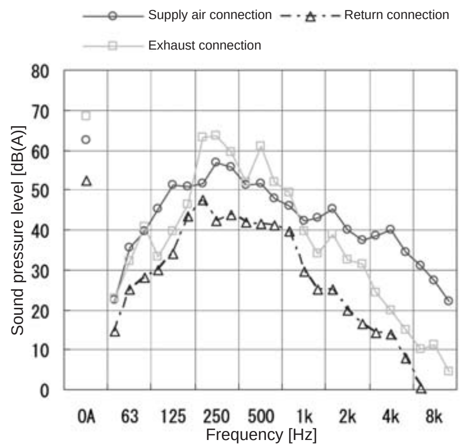

Fig. 6 Estimation of Transmitted Air Conditioner Noise in Mockup Model

3 Development of Low-noise Ducts

3.1 Improvement of the Connecting Supply Air Duct

We took measures for the connecting supply air duct both in terms of airflow noise and transmitted air conditioner noise. The probable cause of the airflow noise was a sharp increase of the duct cross section and wind noise by the guide vanes. Thus, in order to eliminate such sharp increase of the cross section, we changed the shape of that duct to a shape where the cross section gradually increases. We also simplified the structure by removing the guide vanes. The improved connecting supply air duct is shown in Fig. 7. As a measure to reduce transmitted air conditioner noise, we utilized the space created by changing the duct shape to attach sound absorbing material to the side of the duct. Sound absorbing material was also attached to the side of the horizontal supply air duct adjacent to the connecting supply air duct.

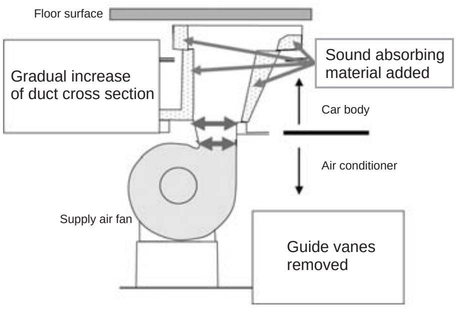

Fig. 7 Improvement of the Connecting Supply Air Duct

3.2 Improvement of the Connecting Exhaust Duct

Loud noise generated by the ventilator in the air conditioner was transmitted to the cabin through the connecting exhaust duct. Since that duct was straight in a vertical direction before, we made bends to extend the duct length and attached sound insulating material to those bends in an aim to reduce the transmitted ventilator noise. The improved connecting exhaust duct is as indicated in Fig. 8.

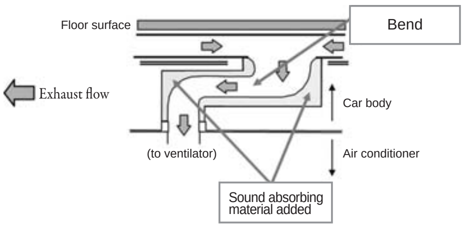

Fig. 8 Improvement of the Connecting Exhaust Duct

3.3 Verification of Effects Using the Mockup Model

3.3.1 Effect in Airflow Noise Reduction

We verified the effect in airflow noise reduction by connecting the improved ducts to the mockup model. Fig. 9 shows a comparison of the airflow noise of the all systems of air conditioning ducts before and after the improvement. The overall value of the A-weighted sound pressure level was reduced from 71.8 dB(A) to 63.7 dB(A), an 8.1 dB reduction.

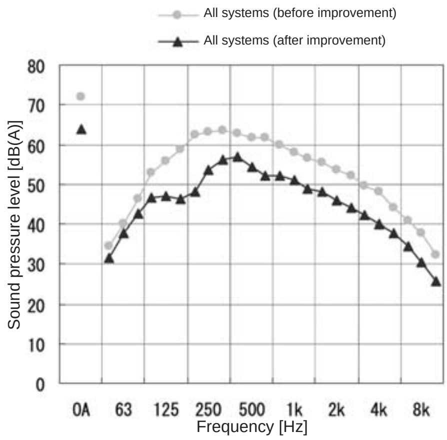

Fig. 9 Comparison of Wind Noise before and after Improvement (all systems)

3.3.2 Effect in Reduction of Transmitted Air Conditioner Noise

Next, we verified the effect of the improved ducts in reducing transmitted air conditioner noise. For verification purposes, we calculated the estimated level of the transmitted air conditioner noise in the mockup model. Calculations were based on the actual noise at the connections of each air conditioning unit separately measured and the overall attenuation of each duct measured in the mockup model. Fig. 10 shows the estimated level of the air conditioner noise in the mockup transmitted through the supply air connection, and Fig. 11 shows that through the exhaust connection. The transmitted air conditioner noise through the supply air connection was reduced by 1.1 dB from 62.5 dB(A) to 61.4 dB(A), and that noise through the exhaust connection was reduced by 6.3 dB from 68.4 dB(A) to 62.1 dB(A).

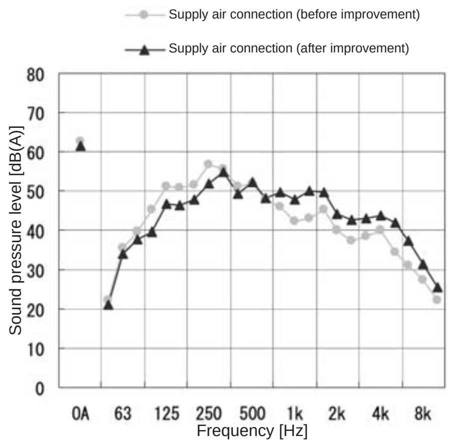

Fig. 10 Comparison of Estimated Transmitted Air Conditioner Noise (at exhaust connection)

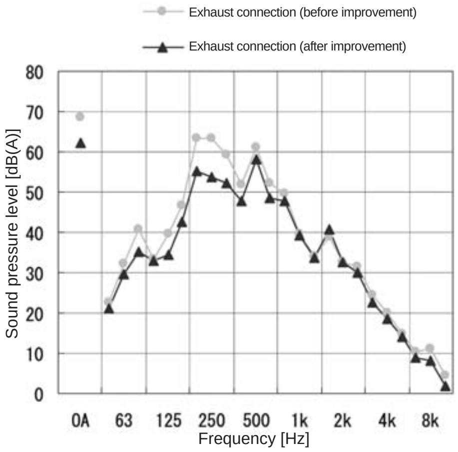

Fig. 11 Comparison of Estimated Transmitted Air Conditioner Noise Before and After Improvement (at exhaust connection)

4 Verification Using an Active Duty Car

We installed the low-noise ducts to car No. 15 in order to confirm with an active duty car the noise reduction effect of the duct improvement and compared the noise before and after the duct improvement. To reduce weight in other development tests not related to air conditioning, most of the interior of this car had been removed at the time of verification and the vertical supply air duct cut at its bottom. Those measures would make cabin noise larger than usual.

Fig. 12 shows the measurement results. The overall value of the A-weighted sound pressure level of cabin noise was 74.2 dB(A) before the improvement and 70.8 dB(A) after the improvement. Those results demonstrated that duct improvement could reduce cabin noise by the air conditioning system by 3.4 dB. However, the effect was not as large as in the mockup model test. The reason was probably the difference of fan conditions between the mockup model and the actual car. While straight flowing air was blown into the air conditioning ducts in the mockup, disturbed air immediately around the room fan is blown in the active duty car. Furthermore, air conditioner noise may be transmitted through routes other than the ducts due to the effect of the removal of the interior.

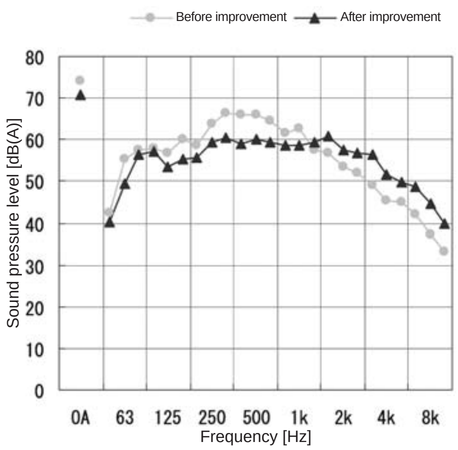

Fig. 12 Cabin Noise Before and After Improvement (Car No. 15)

5 Conclusion

We have obtained the following findings from low-noise duct development to reduce air conditioning system noise in the FASTECH360Z.

① The predominant airflow noise of the air conditioning system of the FASTECH360Z is noise by the connecting supply air duct. The probable cause of that noise is airflow noise caused by a sharp increase of the cross section of the connecting supply air duct and the wind noise by the guide vanes.

② Transmitted air conditioner noise of the FASTECH360Z is loudest at the exhaust connection, and that is followed by noise at the supply air connection and at the return connection. Noise at the exhaust connection and the supply air connection in particular is large. Noise at the return connection is relatively small.

③ We have changed the shape of the connecting supply air duct to the one where the cross section gradually increases, and have simplified the structure by removing guide vanes. Furthermore, we have attached sound absorbing material to the side of the connecting supply air duct in the new space created by changing the duct shape. With those measures, we were able to reduce the overall value of the A-weighted sound pressure level of the airflow noise in the mockup from 71.8 dB(A) to 63.7 dB(A). The sound absorbing material has also reduced the transmitted air conditioner noise by 1.1 dB.

④ We made bends in the vertically-straight connecting exhaust duct to extend its length and attached sound absorbing material in the bends to reduce the transmitted noise of the ventilator in the air conditioner. That reduced transmitted ventilator noise by 6.3 dB.

⑤ Verification using car No. 15 after weight reduction modification has demonstrated a 3.4 dB reduction of the overall value of the A-weighted sound pressure level of the cabin noise from 74.2 dB(A) to 70.8 dB(A).

⑥ Noise was not reduced in the active duty car test as much as in the mockup model test. The reason could be that disturbed air immediately around the supply fan was blown into the air conditioning ducts in the actual car while straight flowing air was blown in the mockup. Another possibility is that air conditioner noise was transmitted through routes other than the ducts due to the effect of the removal of the interior.

Reference:

1) Norio Ando, "Practical Techniques for Designing and Construction of Air Conditioning Ducts", Rikoh Tosho Publishing Co., Ltd., pp. 105 - 114, 1999