When Shinkansen trains run at high speed, noise is generated from between cars (hereafter “between-car section”). Since that noise increases wayside noise, it needs to be decreased. In order to solve the problem, we equipped the FASTECH360S Shinkansen high-speed test train with newly developed hard smooth covers between cars. The new smooth covers consist of combined linking mechanisms that absorb displacement at curves where intermediate sections become narrower. Running test results proved that those linking mechanisms worked properly, but also brought out that generation of the noise from the between-car sections (hereafter “between-car noise”) differs depending on the running direction. Accordingly, we have made improvement to the initial smooth covers between cars of the FASTECH360S to overcome that issue. Now we are evaluating durability, maintainability etc. in long running tests and other tests.

**Keywords**: Smooth cover between cars, Between-car noise, Wayside noise, Spiral array microphone

1. Introduction

As a tool for reducing wayside noise, the FASTECH360S has smooth covers between cars to reduce noise generated at the car coupling sections. Those smooth covers between cars have proved more effective for noise reduction than matching vestibule diaphragms (hereafter diaphragms) actually used for trains in operation; but we found that generation of the noise from smooth covers between cars differs depending on the direction the train is running.

Aiming for further noise reduction, we made improvements to the smooth covers between cars of the FASTECH360S. As shown in Fig. 1, the base upon which the improvements were made was the initial smooth cover between cars of the FASTECH360S. In order to solve the problem, we repeated development of new smooth cover between cars, static tests and tests using actual cars to determine the final shape. In the development this time, we repeated improvement in three prototypes to achieve the smooth cover between cars for durability tests.

![Fig. 1 Flow of the Improvement of the Smooth Cover between Cars](image1)

2. Initial Smooth Cover between Cars of FASTECH360S

2.1 Structure of the Initial Smooth Cover between Cars of FASTECH360S

Fig. 2 indicates the initial hard smooth cover between cars used when the FASTECH360S was completed. In order to enable easy decoupling, the smooth cover between cars has a cantilever structure where it is installed to just one side of a car and does not couple cars. The smooth cover between cars is not covered with just a single diaphragm, but rather separately covered with side diaphragms for the sides of the car body and a roof diaphragm for the top of the car body.

![Fig. 2 Initial Hard Smooth Cover between Cars of FASTECH360S](image2)
In order to avoid contact to extra-high-voltage cables laid through cars even when a difference in the height of cars is produced, the roof diaphragm has a flip-up structure using a linking mechanism.

The side diaphragm consists of three panels, each of which is installed to the surface of the car end with a linking mechanism. When the interval of the cars becomes narrower, that linking device folds the panels inside in sequence from the first panel (on the end of the opposite car).

2.2 Problems of the Initial Smooth Cover between Cars of FASTECH360S

Noise measurement results using a spiral array microphone in the running tests are shown in Fig. 3.

Fig. 3 shows the between-car space of cars No. 1 and 2 and cars No. 2 and 3. A smooth cover between cars is installed to the end of car No. 1 between cars No. 1 and 2 and to the end of the car No. 3 between cars No. 2 and 3. Comparing those, we can see that generation of noise is particularly different at the side diaphragms. It was conceivable that the gaps to fold the side diaphragms caused the difference. Fig. 4 illustrates the gap.

We provided the gaps between the first and second panels and the second and third panels so the panels could be folded without interfering each other. In the gaps, the panels were positioned slightly aslant, because the linking mechanism adjusted the gaps. Accordingly, the direction of flowing wind would cause a difference of generation of noise.

Fig. 5 shows the noise measurement results identified using a spiral array microphone in the running test after smoothing that part. Since the results showed an improvement in noise, we could expect that eliminating the gaps would solve the problem.

The roof diaphragm also had gaps in the flip-up mechanism. Since the roof diaphragm was curved along the roof, it was quite difficult to match the shape of the structure; so, we improved the structure.

Since the smooth cover between cars had a linking mechanism with many linkage contacts each for the first and the second panels, there were many movable parts and the smooth cover between cars consisted of many components. For easy maintenance, simplification was required too. Thus, in the improvement, we aimed to simplify the structure as well reduce noise. The roof diaphragm also had gaps in the flip-up mechanism. Since the roof diaphragm was curved to match the roof, it was quite difficult to match the shape of the structure.

3 Improvement of Smooth Covers between Cars

3.1 First Prototype

For the main purpose of maximizing noise reduction effect, we made improvement to the initial smooth cover between cars of FASTECH360S, while simplifying the structure. The aims of the improvement were as follows:

1. To make noise generation equal in any running direction, and
2. To reduce the weight to under 200 kg by simplifying the structure (the weight of the initial smooth cover between cars of FASTECH360S was approx. 400 kg).

The first prototype with those as a target is shown in Fig. 6 and 7. Fig. 6 shows the newly developed roof diaphragm. Roof diaphragms up to that point had a flip-up structure; but we applied
the developed lateral storage to the test sample using the space at the low roof for joints of extra-high-voltage cables. The purpose of that was to eliminate the structural gaps as much as possible. In order to simplify the structure, the test sample diaphragm consisted of a linear guide and a linking mechanism.

As shown in Fig. 7, we changed the side diaphragm with three panels (a fixed panel and two movable panels) to the one with two panels (a fixed panel and a movable panel), with the aim of reducing two gaps to one. By applying the structure with two panels, two sets of linking mechanisms for the structure with three panels could be reduced to a set for the structure with two panels. The aim of that was structural simplification and weight reduction.

In order to achieve a structure that enables flat contact between a fixed diaphragm and a movable diaphragm, we selected aluminum material. But that could not absorb all of the displacement when the between-car section became narrow. So, we supported the base aluminum panel and the aluminum panel on the contact surface with triangular rubber because rubber does not affect the surrounding linking devices or the end of the car body when contacting those. The triangular rubber component was compressed when the between-car section became narrower, and that brought about the structure where no damage was caused even when contacting other components. For those functions, we achieved a structure where the movable diaphragm was inserted under the fixed diaphragm using a linear guide and the linking device. Applying the linear guide also simplified the structure of the linking device, and that resulted in weight reduction.

### 3.2 Static Test of the First Prototype of the Improved Smooth Cover between Cars

In the static test, we carried out the displacement test considering crossing turnouts in the Shinkansen car depot. Fig. 8 shows the test conditions. The test results proved that the prototype worked without interference and the functional mechanism had no problems.

Based on the first prototype, we worked to identify problems in installing to FASTECH360S, and found two problems.

1. The rigidity of the rubber plate of the side diaphragm was not secured.
2. The structure of the sliding roof diaphragm became more complicated.

As for (1), the rigidity of the rubber plate was not sufficient to meet the stress by the wind and the pressure change considering the wind that flows against the smooth cover between cars during high-speed running and the pressure change in tunnels. Regarding (2), while the new structure had no gaps, it became more complicated and heavier than the original flip-up diaphragm. The weight of the diaphragm only (without the base) was 291.24 kg, heavier by 90 kg than the target weight.

Accordingly, we made further review of the structure to solve those structural problems and developed the second prototype.
3.3 Second Prototype of the Improved Smooth Cover between Cars

Based on the results of the first prototype, we examined a structure where the first panel (movable) and the second panel (fixed) of the first test sample were linked with a rubber plate. In that examination, we reviewed the specs of the material of the rubber plate, so that no large displacement occurred in the pull direction of the rubber plate.

We previously made many developments on the side diaphragm using rubber plates for STAR21 etc., but those were not actually introduced. Reviewing the problem of the diaphragm using rubber plates, we found that usage where tensile force was applied to the rubber plates (extending the rubber) when the train went through small curves caused troubles. There were many incidents where the rubber plates that were deteriorated by the tensile force were torn. Thus, we tested a structure using the linking mechanism developed in the first prototype that kept only the smoothness without large tensile force to the rubber plates. In the tests, we found two promising types of rubber plates, which would enable a structure linking two panels with a rubber plate. The rubber plate, however, could not be folded on the shoulder of the car body as shown in Fig. 9, while that could be folded in an S-shape on the side of the car body. So, we planned to check the durability of that part in the durability tests, including conditions about displacement.

Since the roof diaphragm of the first prototype became more complicated and heavier than the flip-up roof diaphragm (sliding type of first prototype: 75.52 kg > flip-up type: 55.7 kg), we decided to improve the conventional flip-up type diaphragm. In the improvement, we enlarged the roof panel and covered the fixed diaphragm on the end of the car and the side diaphragm with that roof panel to bridge gaps. And furthermore, as shown in Fig. 10, we introduced a lining panel on the rear surface to achieve a structure that could minimize noise.

The function test of the combination of the second prototype with a side diaphragm and a roof diaphragm demonstrated good results, so, we installed the smooth cover between cars No. 1 and 2 to check the performance.

Before installing to actual cars, we carried out function tests 30,000 times in static tests to check the durability of sliding parts and components. 30,000 times was obtained by a rough calculation of four times/day (assuming small curves in the yard) X 300 days X 15 years X 1.5.

3.4 Tests of the Second Prototype of the Improved Smooth Cover between Cars Using Actual Cars

As indicated in Fig. 11, the tests using actual cars showed very good results in terms of noise. But, an incident occurred where the roof diaphragm was lifted up from the time a car at over 300 km/h entered a tunnel to the time it came out of the tunnel.

The cause of the lifting of the roof diaphragm could be pressure change in the tunnel. So, we measured the pressure change when entering the tunnel at the point where the initial diaphragm was installed. The results are shown in Fig. 12. We found the following...
The test results proved that a gap like the slit of the smooth cover between cars of FASTECH360Z would not increase noise. The slit would not affect much on noise because the slit is made in the direction of wind flow. Accordingly, we changed the length in the direction of the sleepers and decided to introduce the structure with a gap in the direction of the rails (wind flow direction). And we also determined the structure to minimize the effect of pressure change by applying the flip-up diaphragm of the same structure as the initial smooth cover between cars (about a half size of the between-cars section). Based on the noise from the side diaphragm, we found that a gap in the direction of sleepers, which is at a right angle to the wind direction, increases noise; so, we attached a lining panel to the rear side to bridge that gap. Fig. 15 shows the third prototype of the smooth cover between cars to which those improvements are applied.

As the third prototype uses the side diaphragm of the second prototype, the number of components was reduced. While the target weight 200 kg could not be achieved, the reduction of the number of components could lead to a weight of 243 kg, approx. 150 kg less than the initial smooth cover between cars.

3.6 Tests of the Third Prototype of the Improved Smooth Cover between Cars Using Actual Cars

We carried out the tests of the third prototype using actual cars. In the tests, we found no lifting of the roof diaphragm at cars entering a tunnel.

Fig. 16 shows the measurement results using a spiral array microphone. The results proved that the slit of the roof diaphragm in the direction of rails to release the pressure had no unfavorable effect on noise. The results also proved that the difference of the noise generation depending on running directions, which had been initially observed with the FASTEC360S, was solved too.
We identified the problems with the smooth cover between cars initially installed on the FASTECH360S and made improvements to that smooth cover between cars learning from the development successes for STAR21. As a result, we were able to improve on the problem of the noise generation depending on the difference in running direction.

We were also able to simplify the structure and reduce the two linking mechanisms to one. This simplification reduced the number of components and that resulted in a reduction of the weight of the section between cars by approx. 150 kg from 400 kg to 243 kg, even though that reduction did not reach the target.

Based on the strength check etc. in night running tests, we determined that the third prototype of the smooth cover between cars was capable of withstanding durability tests. Now we are conducting durability tests by installing the same smooth cover between cars as the third prototype to all between-car sections of the FASTECH360S. As of November 30 2007, the distance covered with the third prototype was approx. 150,000 km; yet no serious failures have occurred.

In the durability tests mentioned above, we installed two types of rubber plates on the third prototype to check the deterioration per type.

We are planning to conduct 600,000 km of durability tests by the end of FY 2008. The plan is to proceed with the tests while periodically checking the items shown in Table 1. After the tests, we will disassemble the diaphragms to finalize the replacement periods per component and the method of the periodic inspection.

In this development, we aimed at noise reduction by sealing the sections between cars with smooth covers; but there could be another way to reduce noise by analyzing and controlling the air flow in the intermediate section. Now we are studying a way to change the shape of the section between cars to control the air flow and reduce noise, together with the development of the smooth cover between cars.

<table>
<thead>
<tr>
<th>Item</th>
<th>Side diaphragm rubber plate</th>
<th>Linear guide</th>
<th>Cam</th>
<th>Bushes</th>
<th>Springs</th>
<th>Linking components</th>
<th>Abrasion of sliding panels</th>
<th>Roof panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content of check</td>
<td>Cracking</td>
<td>Sticking and breakage</td>
<td>Sticking and breakage</td>
<td>Sticking and breakage</td>
<td>Breakage</td>
<td>Cracking</td>
<td>Abrasion and condition of sliding surfaces</td>
<td>Deformation</td>
</tr>
</tbody>
</table>

Table 1 Durability Check Items for the Durability Tests

Fig. 16 Measurement Result Using a Spiral Array Microphone (Third Prototype)