To improve the riding comfort for high-speed running in Series E2 Shinkansen cars, a damper was mounted between car bodies and the change of installation height of the traction device was changed. Then we conducted tests to verify the effects of non-linear air spring performances. These tests clarified the following three points: (1) When a damper was mounted between cars, there was a maximum reducing effect of about 3 dB on the tail end car and about 4 dB on the middle cars in terms of the lateral riding comfort level, as compared to the case when it was not mounted. (2) When the traction device installation height was changed, the maximum reducing effect of about 1 dB was recorded in terms of the vertical riding comfort, as compared to the case when the current height of the traction device was not changed. (3) When a non-linear air spring was mounted, there was a maximum reducing effect of 0.07 m/s² in terms of the lateral stationary acceleration, as compared to the case when it was not mounted.

**Keyword**: Riding comfort, Shinkansen car, Acceleration of lateral vibration, Elastic vibration of car body

### 1 Introduction

A great number of projects have been launched to increase the speed and to improve the quality of the Shinkansen train. The riding comfort of the car is an important factor for improving high quality (comfort)

Efforts to develop technologies to improve the riding comfort include programs for improvement of the suspension system of the bogie, active vibration control measures, car body elastic vibration control measures, track system improvement measures, and many others.

Some of the achievements gained through these attempts have been reflected in subsequent commercial cars.

However, to meet the growing demands for faster commercial cars and greater passenger riding comfort, it has become necessary to study ways of further improving riding comfort.

For this purpose, in an effort to improve the riding comfort of Series E2 as a mainstay Shinkansen train in high-speed running mode, we mounted a damper between cars, and a non-linear air spring for reducing the acceleration in the lateral vibration at the time of cornering, and changed the installation height of the traction device for reducing vibration transmitted from bogie to car which might cause vibration of the car body. The effects of these measures were checked in performance verification tests.

This paper reports the overview of these tests and discusses the test results.

### 2 Overview of riding comfort

#### 2.1 Damper between car bodies

In a high-speed Shinkansen car, lateral vibration differs according to its position in the train composition, and the vibration is greater at the tail end in many cases.

To increase the speed of Shinkansen trains, it is necessary to improve the riding comfort by reducing the lateral vibration on the tail end side in the trainset. For this purpose, we have developed a damper between car bodies to prevent vibration between cars.

In the running test for this project, the car damper was installed between cars No. 1 and 2 and between cars No. 2 and 3, which are located at the tail end side when traveling in the outbound direction, thereby checking the effect of reducing the lateral vibration.

Fig. 1 shows the installation of the damper between car bodies.
2.2 Change of the traction height
The elastic vibration of the car body is thought to be caused by the vibration of the bogie transmitted to the car body through the traction device. Theoretically, if the center of bogie pitching is matched with the height of the traction device, the pitching of the bogie should not be transmitted to the car body. But it is difficult to set the appropriate position due to the configuration of the bogie.
In our test, we adjusted the height of the traction device to the level effective for reducing the elastic vibration of the car body, and checked the effect of reducing the vibration.
Fig. 2 shows the traction device whose height has been changed.

2.3 Non-linear air spring
When a rail car rounds a curve at a high speed, the car body tilts toward the outside of the curve due to centrifugal force. When the stopper for lateral movement of the car body is brought into contact, a severe vibration occurs, causing riding discomfort. In order to prevent this contact of the stopper, we mounted a non-linear air spring.
Fig. 3 shows an external view of the non-linear air spring. Fig. 4 shows its characteristics.
The non-linear air spring has its outer sleeve extended in the lateral direction to a larger degree. It does not contact the diaphragm at the neutral position, but the outer sleeve is brought into contact the diaphragm at the time of a large lateral displacement, for example, when rounding a curve. This will result in an increase in the lateral reaction, reducing the lateral displacement of the car body.
In this test, non-linear air springs were mounted on two bogies of car No.1 to check the effect of reducing the lateral stationary acceleration.

3 Overview of the test
The following describes the overview of the test:
- Test schedule: April 4 to 18, 2001
- Test section: Between Sendai and Kitagami (outward bound train)
- Test car: Series E2 numbered in the 1000 range of J51 trains (composed of 8-car trainsets)
- Maximum test speed: 320 km per hour
- Positions provided with riding comfort improvement measures and measuring positions (Fig. 5)
4 Test result

4.1 Damper between car bodies
As mentioned above, the dampers between car bodies were installed between cars No. 1 and 2 located at the tail end in the running direction (outbound), and between cars No. 2 and 3. In the running test, measurement was made of the acceleration of lateral vibration on the floor surface of the first and second bogies between tail end car (No. 1) and middle car (No. 2). To examine the effect of the damper between car bodies, we compared the riding comfort levels in the lateral direction when the damper between car bodies was mounted, and when it was not mounted. Fig. 6 shows a comparison of the riding comfort levels in the lateral direction on the floor surface of the car body in the high-speed test section when the damper between car bodies was mounted and when it was not mounted.

Comparison of the riding comfort levels on the floor surface of the bogie at the same position shows a lower value when the damper between car bodies was mounted than when it was not mounted.

In the tail end car, the noise level was 89.8 dB without the damper between car bodies, and 86.8 dB (3 dB less) with the damper between car bodies. In the middle car, it was 86.7 dB without the damper between car bodies, and 82.7 dB with the damper between car bodies, resulting in reduction of 4db. However, the noise reduction was less effective at higher running speeds.

4.2 Change of the traction height
The traction height was changed in the first and second bogies of car No. 2. The traction height was set at 75 mm lower than the current level by simulation calculation.

In the running test, measurement was made of the acceleration in lateral vibration on the floor surface at the center of the car body. To check the effect of changing the height of the traction device, comparison was made of the vertical riding comfort on the car body floor surface according to the vibration data when the height of the traction device was changed and when it remained unchanged.

Fig. 7 shows a comparison of the vertical riding comfort in the high-speed test section when the height of the traction device was changed and when it remained unchanged.

When the height of the traction device was changed, there was a maximum reducing effect of about 1 dB in terms of the vertical riding comfort level, as compared to the case when it remained unchanged.

4.3 Non-linear air spring
The non-linear air springs were mounted on the first and second bogies of car No. 1, the tail end car.

In the running test, we measured the acceleration of lateral vibration on the floor surface of the car body. To examine the effect of the non-linear air spring, comparison was made of the lateral stationary acceleration when the non-linear air spring was used and when the current one was used.

Fig. 8 shows a comparison of the lateral stationary acceleration when rounding a curve having a radius of 4000 meters.

When the non-linear air spring was used, there was a maximum reducing effect of about 0.07 m/s² in terms of the lateral stationary acceleration, as compared to the case when the current one was used.
In this test, the spacing of the lateral movement stopper between the car and bogie was kept unchanged from that of the current Series E2. So stopper contact occurred at the time of high speed running. To further improve the effect of the non-linear air spring, it is necessary to study ways of increasing the spacing of the lateral stopper movement.

To improve the riding comfort in the running test of Series E2 cars numbered in the 1000 range, performance verification tests were conducted by mounting a damper mounted between car bodies and non-linear air spring, with the traction device installation height changed. These tests have provided the following results:

1) When a damper was mounted between car bodies, there was a maximum reducing effect of about 3 dB on the tail end car and about 4 dB on the middle car in terms of the lateral riding comfort level, as compared to the case when it was not mounted. This effect was reduced as the speed was increased.

2) When the traction device installation height was changed, the maximum reducing effect of about 1 dB was recorded in terms of the vertical riding comfort, as compared to the case when the current height of the traction device was not changed.

3) When a non-linear air spring was mounted, there was a maximum reducing effect of 0.07 m/s^2 B in terms of the lateral stationary acceleration, as compared to the case when it was not mounted. This requires the spacing of the lateral movement stopper to be re-examined.

**5 Conclusion**

To improve the riding comfort in the running test of Series E2 cars numbered in the 1000 range, performance verification tests were conducted by mounting a damper mounted between car bodies and non-linear air spring, with the traction device installation height changed. These tests have provided the following results:

1) When a damper was mounted between car bodies, there was a maximum reducing effect of about 3 dB on the tail end car and about 4 dB on the middle car in terms of the lateral riding comfort level, as compared to the case when it was not mounted. This effect was reduced as the speed was increased.

2) When the traction device installation height was changed, the maximum reducing effect of about 1 dB was recorded in terms of the vertical riding comfort, as compared to the case when the current height of the traction device was not changed.

3) When a non-linear air spring was mounted, there was a maximum reducing effect of 0.07 m/s^2 B in terms of the lateral stationary acceleration, as compared to the case when it was not mounted. This requires the spacing of the lateral movement stopper to be re-examined.