Development of new bogies for improved running safety/stability, ride comfort and reliability was performed in order to increase Shinkansen speed. In that, new configuration elements such as the driving device and axle bearings for the bogies have been adopted. A first prototype was made beforehand, and its performance and long-term durability were evaluated through bench tests. Then, bogies were installed on a FASTECH360 Shinkansen high-speed test train and running performance confirmed.

**Keywords:** High-speed Shinkansen bogie, Driving device, Shaft coupling, Axle bearing

1 Introduction

Ensuring reliability when running at high speeds, long term durability assuming use in operation and ease of maintenance must all be considered in conjunction with the development of a high-speed Shinkansen bogie, in addition to performance (running safety/stability and ride comfort) that can handle great increases in running speed. Therefore, configuration elements including use of new structural parts were reviewed for the main structural parts of the bogie. Significant investigation of the strength and performance through numerical analysis was done at the investigation stage. And a first prototype was built on which performance tests and long-term durability tests through bench testing were performed to confirm those factors.

Bogies for which development proceeded in this manner were installed on a FASTECH360 Shinkansen high-speed test train and performance confirmed through actual running tests. Here, we will mainly introduce the bogies and the main parts such as driving device and axle bearings with regard to the development details and development process for high-speed Shinkansen bogies.

2 Development Details

2.1 Configuration of the Developed Bogies

In order to achieve stable running at a maximum operating speed of 360 km/h, new elements were adopted for important configuration elements such as the driving device and axle bearings. Furthermore, for the bogie as a whole, enhanced running safety/stability and ride comfort as well as enhanced reliability, durability and maintainability were targeted during development. In order for the target speed to greatly exceed the current maximum operating speed, load conditions necessary for design were set based on data obtained using test train cars built in the past.

The primary characteristics of the developed bogies are as follows.

- (1) Optimized stiffness of primary suspension to enhance running safety and stability
- (2) Softened rigidity of the axle springs and air springs to enhance vertical ride comfort
- (3) Optimized lateral rigidity of the air springs to enhance lateral riding comfort
- (4) New active suspension control system to enhance lateral riding comfort
- (5) Air spring stroke type car body tilting control system to increase speed in curves
box (guide arm type), and it has a configuration whereby two electromagnetic actuators for active suspension control are arranged. A section (bolster) of the conventional train car body structural parts was switched over for use as structural parts of the bogie (car body connecting beam), enabling weight reduction for the train car as a whole and simplification of work required for attaching and detaching the bogie.

2.2 Driving Device

2.2.1 Gear Unit

The load on the driving device that transfers rotation of the motor to the wheels is intensified with the increase in running speed. We thus adopted double helical gears that do not generate force in the axial direction with the transfer of torque to the gear unit, with a goal of enhancing reliability and reducing noise. As conventional helical gears generate a force in the axial direction when torque is transferred, we were forced to use taper roller bearings that require fine clearance adjustment during assembly of the driving device. Adoption of double helical gears, however, relieved the force on bearings in the axial direction, enabling use of cylindrical roller bearings that do not require clearance adjustments. There is a temperature limit related to bearing seizure caused by contraction of the bearing clearance at lower temperature with helical gears that need delicate bearing clearance adjustment. But double helical gears enabling use of cylindrical roller bearings with larger bearing clearance have a shape that proves advantageous in cold regions.

![Fig. 2 Type A Development Bogie](image)

2.1.2 Type B Development Bogie

The axle box suspension for the Type B bogie uses the same guide arm type suspension system as for the Type A bogie, and it has a configuration whereby one electromagnetic actuator for active suspension control is arranged.

![Fig. 3 Type B Development Bogie](image)

2.1.3 Type C Development Bogie

The Type C bogie uses a system by which the bogie frame and axle boxes are linked using plate springs (leaf spring type), and it has a configuration whereby one roller screw type actuator for active suspension control is arranged.

![Fig. 4 Type C Development Bogie](image)

![Fig. 5 Configuration of the Driving Device](image)

![Fig. 6 Gear Structure 1](image)
2.2.2 Shaft Coupling
As previously described, the stiffness of the axle spring for the developed bogies was reduced to improve vertical direction ride comfort. Thus, the displacement between the traction motor shaft and the pinion shaft became large. Two types of shaft couplings (gear type shaft coupling and TD coupling) that reduced rotation noise and that can handle this amount of displacement were thus developed.

![Shaft Couplings](image)

Fig. 7 Shaft Couplings

2.3 Axle Bearings
Vibration acceleration acting on the axle bearings roughly doubles when increasing running speed from 275 km/h to 360 km/h. As that causes reduction in durability if using conventional bearings, enhancing reliability and durability of the bearings is essential for enabling increase in speed. It is thus important to confirm performance beforehand.

Several types of bearings including oil bath lubrication type and grease lubrication type were created in this development, and performance tests described later were implemented with a bench test device. As a result of the tests, grease lubrication type bearings were selected because there are issues with temperature rise and sealing for the lubricating oil with the oil bath lubrication type. In addition, a structure that suppresses aggression on the axle was adopted.

Using grease lubrication type bearings, we tested two types of retainer material—metal and polyamide—to check control of ferrous content increase in grease as shown in Fig. 8. Fig. 9 illustrates the structure of the adopted bearing.

![Axle Bearing Structure](image)

Fig. 9 Axle Bearing Structure

3 Performance Tests
Conventionally, performance testing by individual part such as for the driving device and axle bearings was implemented using a bench test device. However, performance testing for the bogies as a whole has often been performed through actual running of rolling stock. In recent years, however, running performance confirmation (prior confirmation) implemented using bench tests with a bogie or rolling stock has increased. In this bogie development also, a first prototype was built and focus put on performance testing on bench tests as running speed will be increased greatly. Performance testing results for bench tests are as explained below.

3.1 Bogie Performance Test Results
Evaluation of bogie characteristics was primarily implemented on the rolling stock test stand at the Railway Technical Research Institute. With that, we confirmed running stability and riding comfort.

As a result, we confirmed that all of the developed bogies were able to run without stability issues at speeds higher than 400 km/h. Furthermore, confirmation concerning ride comfort was also obtained, and items where improvement was needed were reflected in the specifications of the bogies for the test train.

![Test on Rolling Stock Test Stand](image)

Fig. 10 Test on Rolling Stock Test Stand (Railway Technical Research Institute)

3.2 Driving Device Performance Test Results
Tests related to temperature (high acceleration test at low temperature and driving test at room temperature) and near-field noise measurements were performed. We found that the driving device of new rolling stock has characteristics that are equivalent to or more favorable than those of present rolling stock even at 360 km/h in tests related to temperature. With respect to near-
To achieve high-speed running with safety and certainty in long-term rolling stock use, it is necessary to sufficiently confirm reliability and durability for each of the parts beforehand in addition to bogie performance. However, until recently, test devices that could implement long term testing under loads seen during actual running for the most part did not exist, and durability evaluation required installation on actual rolling stock and running it for a certain period.

Since many new parts were adopted for the high-speed bogies developed this time, they have to be verified thoroughly in advance of actual running tests. The Research and Development Center of JR East Group thus used the bogie testing device newly installed at our Omiya facility shown in Fig. 13, where a 650,000 km durability test was implemented on a prototype bogie to evaluate reliability and durability. That was performed under the conditions of traction motor drive using flywheel energy and vibration excitation of actual track irregularity. It was a round the clock test with maximum speeds of 400 km/h for 124 days, making it an extremely severe test.

The driving device and axle bearings were disassembled and studied after the completion of the endurance test, and we found that there were no flaws that would affect safety.

3.3 Axle Bearing Performance Test Results
We made a bearing test device shown in Fig. 12 to compare temperature characteristics for oil bath lubrication type and grease lubrication type bearings. As a result of comparisons, we found that the oil temperature for the oil bath lubrication type bearings when running at 400 km/h became 120°C, the temperature where the oil starts to deteriorate. On the other hand, the grease lubrication type bearings were roughly half that temperature. Furthermore, there was an oil leak (at equivalent of 30,000 km operation) with the oil bath lubrication type bearings, showing that the seal structure has trouble with high speed running. We did improve the bearing structure and adopted new sealing in later development, and those enabled running at 320 km/h using oil bath lubrication type bearings.

The driving device and axle bearings were disassembled and studied after the completion of the endurance test, and we found that there were no flaws that would affect safety.

5 Running Tests
We installed the three types of bogies with new elements on the Shinkansen high-speed test train. Using that, we evaluated performance in actual running tests.

5.1 Running Safety of the Type E954 Shinkansen High Speed Test Train
We measured lateral force, wheel load and derailment quotient with the type E954 Shinkansen high speed test train as items related to running safety. Each of those showed favorable results, being less than the target values for judging speed increase in the
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speed range up to 398 km/h.

In order to check running safety if the yaw damper fails, we carried out a yaw damper failure tests. In the tests, we deactivated one of the two yaw dampers per bogie (no damping force provided) and monitored whether or not hunting motion would occur by the measurement results of wheel/rail contact force and bogie frame vibration. As a result, we found that no hunting motion occurred with any type of development bogies in the speed range up to 360 km/h.

5.2 Running Safety of the Type E955 Shinkansen High Speed Test Train

We adopted for the type E955 Shinkansen high speed test train switching yaw dampers that can switch between damping force for Shinkansen sections and conventional line sections to ensure the curving performance of the train in conventional line sections. For running safety in Shinkansen sections, we measured lateral force, wheel load and derailment quotient, each of which showed favorable results less than the target values for judging speed increase in the range up to 398 km/h. Then we changed bogie specifications to reduce the lateral force at running in small curves of conventional line sections and checked running safety up to 365 km/h.

To confirm running safety in yaw damper failure, we carried out yaw damper failure tests for the three types of development bogies after the bogie specification change. As a result, unstable vibration occurred with one of the bogies, so we concluded that we must select a yaw damper configuration that could ensure appropriate damping even if one of the yaw dampers fails for bogies used in through service on Shinkansen and conventional lines.

Changing suspension stiffness was proved effective as a measure to reduce lateral force when running in small curves of conventional line sections, while no effect was found by changing the coupling between cars.

We also confirmed that correcting the height at which yaw dampers are installed was effective as a measure to reduce vertical vibration of the car body.

5.3 Durability of the Type E954 Shinkansen High-speed Test Train

We carried out an approx. 600,000 km durability running test of the type E954 Shinkansen high-speed test train to verify the durability of the development bogies. After the test, we studied the conditions of new components, parts and components with the structure changed from the present one and parts and components on which larger load was expected in conjunction with speed increase. Major condition study results are as follows.

(1) Bogie frame
Dimension measurement and magnetic particle testing showed no problems with durability.

(2) Wheelset
Visual inspection and magnetic particle testing of all mating components disassembled showed no problems with durability.

(3) Axle bearings
Studies of sliding parts and grease property analysis showed no problems with durability.

(4) Double helical gear type driving device
Magnetic particle testing of gears, lubricant oil property analysis and condition studies of bearings and the like showed no problems with durability.

(5) Shaft couplings
Magnetic particle testing of gears of the gear type coupling, grease property analysis and condition studies of the flexible plate of the TD coupling showed no problems with durability.

(6) Dampers
Sampling measurement of damping characteristics of axle dampers, yaw dampers and switching lateral dampers showed no problems with durability.

(7) Rubber parts
Appearance studies and sampling measurement of static spring constants of rubber elements of single links, guide arms and yaw dampers showed no problems with durability.

(8) Air spring
Appearance studies and sampling measurement of spring constant showed no problems with durability.

(9) Axle spring
Magnetic particle testing and sampling measurement of height at no load and spring constant showed no problems with durability.

6 Conclusion

This article has introduced the details of high-speed bogie development. The configuration elements of the developed bogies are applied to the bogie specifications for the next generation of Shinkansen EMU (series E5).

With an aim of further Shinkansen speed increase, we are planning to continue development of bogies and configuration elements with excellent safety, reliability, maintainability as well as high-speed performance.

Reference: