Developing a Gauge-Changing EMU

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Summary
The Japan Railways network comprises two track gauges: narrow gauge (1,067 mm) and standard gauge (1,435 mm). Due to this difference in gauge, Shinkansen trains and conventional trains cannot run on the same tracks, and, consequently, passengers are forced to transfer at intermediate junctions.

A Gauge-Changing Train currently being developed changes its wheel gauge automatically while passing through a tapered track section, the Gauge-Change Equipment. All axles of the Gauge-Changing Train are powered; thus it can transit between the two gauges completely under its own power, without even having to stop.

A prototype three-car test train was built in 1998, and is now in its feasibility test phase. High-speed performance tests and endurance tests have been done overseas, attaining a maximum speed of 246 km/h and a cumulative running distance of about 600,000 km. From the autumn of 2001, the train is continuing with performance and endurance tests on Shinkansen and narrow gauge lines in Japan.

This paper explains the main features of the test train, how the gauge changing works, and the test results to date.

1. Background
There are several ways to achieve through-operation between differing track gauges, without passengers having to change trains. The obstacle could be removed altogether by rebuilding the tracks to just one gauge, or by adding a third rail to form dual-gauge track. Unfortunately, converting narrow to standard gauge track by either of these methods would be both slow and very costly. Furthermore, train services would be disrupted during the construction period, causing a great deal of inconvenience to passengers. Elsewhere in the world, locomotive-hauled, gauge-changing passenger trains were introduced over 30 years ago.
The principle selected for development in Japan is a Gauge-Changing Train that automatically changes its wheel gauge while passing through a special transition section, named the Gauge-Change Equipment. It is designed as an electric multiple-unit train, which is able to make the gauge transition completely under its own power, i.e. without having to connect or disconnect any locomotive, and without even having to stop.

### Development schedule

2. **Principles of Automatic Gauge Changing**

2.1 **Gauge-Change Equipment**

The Gauge-Change Equipment is 49 m long. Car support rails with conveyor-type rollers (linear bearings) are arranged parallel with and on each side of the track, at a level just below the bogie axleboxes. Between these car support rails, the track is constructed as four distinct sections: standard gauge approach section, contingency braking section, transition section, and narrow gauge approach section.
Whereas the car support rails remain level along their entire length, the running rails of each approach section gradually slope downward toward the braking and transition sections, reaching a level 55 mm below the nominal. Through the transition section there is a 5 m long gap between the narrow gauge and standard gauge running rails. Instead of running rails, inner and outer guide rails are fitted, which engage the wheel sides laterally and push them together to narrow gauge – or apart to standard gauge – depending on the direction of travel. The train speed through the Gauge-Change Equipment is about 7 km/h.

2.2 Hub Motor Bogies (A-Type)

2.2.1 Bogie features

Each wheel is installed with a bearing onto a two-part outer sleeve, which envelops the axle end. A traction motor is attached directly to each wheel, driving the wheel without any intermediate gear (i.e. hub-motor, independent-wheel configuration). Gauge changing is accomplished by the wheel and traction motor sliding laterally together as a unit along the fixed axle, thus forming a very simple dual-gauge bogie configuration.

The bogie has superior high-speed stability. To improve its curving performance, forced steering of the wheelsets is used. This bogie type is designated the Type-A dual-gauge bogie, to distinguish it from the axle-gear driven dual-gauge bogie described below.

Cross section through the wheel assembly of the Type-A dual-gauge bogie
2.2.2 Gauge changing process

On the outboard side of each outer sleeve is a mechanism to lock the wheel gauge securely in place. This consists of two pins at distinct lateral positions on the sleeve and a corresponding receiver in the axlebox. When the Gauge-Changing Train passes through the Gauge-Change Equipment, the carbody weight is supported by the axleboxes on the carbody support rails along each side of the Gauge-Change Equipment. The running rails slope gradually downwards toward the transition section, their top of rails reaching a level 55 mm below the nominal, so that an entering wheelset will descend initially, its locking pins disengaging their receivers, thereby enabling the wheels to shift. As the train proceeds, the unlocked wheels are now guided laterally by the guide rails, thus effecting the gauge change.

After the gauge has been changed to its new value, the wheelset, still proceeding in the forward direction, rolls onto the gradually rising running rails. As the wheelset rises, the other set of locking pins engages the axlebox receivers, thereby securely locking the wheel gauge at its new value. The gauge change is now completed.

Axle boxes ride on the support rollers, carrying the carbody

Wheels and motors converge

Wheels and axles drop

Locking pins disengage

Wheels and axles rise

Locking pins engage

Gauge changing of the Type-A dual-gauge bogie

2.3 Gear-Driven Bogies (B-Type)

2.3.1 Bogie features

The Type-A dual-gauge bogie described above has a simple propulsion system and runs with superior high-speed stability, but its unsprung mass is comparatively high and its curving performance dependent on steering. Therefore, to get a baseline comparison for the hub motor Type-A bogie, another dual-gauge bogie design was produced with its traction motors mounted on the bogie frame and driving the wheelset via a gear, as on conventional bogies. The wheelset rotates together as one unit, similarly to conventional (i.e. non-gauge changing) wheelsets. This gear-driven bogie is designated the Type-B dual-gauge bogie. Since the two wheels on each axle rotate together, a steering mechanism to enhance curving, as on the Type-A bogie, is not necessary.
Cross section through the wheelset of the Type-B dual-gauge bogie

2.3.2 Gauge changing process

On the Type-B dual-gauge bogie, each wheel is pressed onto an outer sleeve, which can move laterally on the axle by way of pin splines, thus enabling the wheel gauge to be changed. Locking and unlocking of the wheel gauge are accomplished by a locking mechanism, which consists of a key-shaped slide stopper located on the journal box and a corresponding slide stopper receiver on the bogie frame. Cams extending along the car support rails of the Gauge-Change Equipment control the vertical movement of the slide stopper.
3. Running Tests

3.1 Initial Running Tests in Japan (Narrow Gauge)

After an initial three years of basic development and component testing in Japan, a three-car test train was built in 1998. Initial gauge-changing tests were done in December 1998 at the Railway Technical Research Institute’s test facilities in Kunitachi. Shortly thereafter, in January 1999, car performance tests at speeds up to 100 km/h were done on a narrow gauge section about 9 km long on JR West between Yonago and Yasugi stations. The test section is electrified with 1500 V DC, and has tangent sections as well as curves down to 400 m radius. This was the first time that powered, independent-wheel bogies were tested in Japan. The tests confirmed good running performance at speeds up to 100 km/h.

![The Gauge-Changing Train approaching the Gauge-Change Equipment](image)

**Transition speed:** 7 km/h  
**Equipment length:** 49 m  
**Transition length:** 5 m

3.2 Running Tests Overseas (Standard Gauge)

3.2.1 Test facilities

Due to the long time required to confirm durability and the limited access to mainline tracks in Japan for testing purposes, safety assurance as well as reliability and durability growth tests were conducted at the Transportation Technology Center at Pueblo, Colorado (U.S.A.). Here, the GCT ran on a dedicated test loop, the Railroad Test Track (RTT), having a total length of 22 km, minimum curve radius of 1400 m, highest superelevation of 152 mm, and catenary voltage of 25 kV AC. A train maintenance building housing the Gauge-Change Equipment and a short narrow gauge track were newly constructed near the core area of the test center. All turnouts on the RTT had moveable-point frogs installed to enable high continuous test speeds.
3.2.2 Operation support

During the testing at TTC, the train was operated solely by TTCI staff, with Japanese engineering staff taking part in the performance and speed-up tests only. For the high-speed endurance test, test data was recorded automatically by an on-board data acquisition system, and the data tapes were sent to Japan. When necessary to study the train function and performance, data was replayed, analyzed, and stored; otherwise the tapes were erased, shipped back to the U.S., and reused.

During the first part of the endurance test, operation was limited to 8 hours per day, as use of the RTT had to be shared with other projects. From March 2000, however, the GCT got exclusive access to the RTT at night, and could then run as much as 16 hours per day, dramatically raising the efficiency of the testing.

The GCT train was inspected and maintained regularly, organized into five different types of inspections: daily, 3-day, 10,000-km, 25,000-km and 100,000-km inspections; each with a different scope of content.
Inspection intervals during the endurance test

3.2.3 Test results

Performance and durability testing began in April 1999, and was completed in January 2001. The highest speed attained was 246 km/h, as determined by the existing track geometry and applicable safety limits. At the completion of this test phase, the Type-A bogies had run a total of 591,949 km (target 600,000 km) and the Type-B bogies 229,687 km (target 300,000 km). The average test speed maintained was over 200 km/h and the running performance very stable. Gauge change durability testing was also done, completing a total of 2,084 train passes.
3.3 Running Tests in Japan (Standard and Narrow Gauge)

3.3.1 Train modifications

After the endurance testing in the USA, the cars were shipped back to Japan, and detailed inspections and necessary modifications were made. Key modification items include:

1. Adaptation for higher-speed operation, including the fitting of noise-suppression covers, track clearers and aerodynamically optimized pantographs.
2. Installation of signaling equipment for Shinkansen, such as ATC and train radio.
3. Installation of certain high voltage electrical equipment, such as an AC/DC line selector.

3.3.2 Test facilities

A GCT Test Center was established at the Shin-Shimonoseki maintenance depot of JR West and in the Kokura Works of JR Kyushu. The Shin-Shimonoseki Test Center includes a GCT maintenance depot, the Gauge-Change Equipment, and an access ramp to the Sanyo Shinkansen Line, which passes overhead.
3.3.3 Test program

From the autumn of 2001, testing continues with high-speed performance tests on the standard gauge Sanyo Shinkansen line, and endurance tests including sharp curves on the narrow gauge Nippo line. By the end of March 2003 performance tests up to 300km/h on Shinkansen and endurance tests of over 100,000 km on narrow gauge will be completed.

4. Future plans

Even though the development process is still under way, many parties are enthusiastically looking forward to the GCT being put into service. Before starting revenue service, however, there are still many challenges to meet. Foremost among these are safety assurance and the improvement of reliability and durability.

5. Acknowledgements

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