Development of Technologies for Weight Reducing and More Efficient High-speed Trains

The development of Shinkansen rolling stock for use under a variety of different conditions and operating practices has continued over recent years, with a need to address technical challenges in ways that build on the research conducted into making rolling stock lighter weight and more energy-efficient, both crucial requirements for high-speed operation. Examples of the challenges associated with faster speeds include how to minimize internal and external noise and vibration levels during operation, and how to make trains more energy-efficient, smaller size, and lighter weight, and suitable for maintenance. These technologies contribute essential features to the Shinkansen trains used for long-distance travel in Japan, with significant progress being made on punctuality, comfort, and convenience. Among Hitachi's latest developments for use on the Shinkansen are technologies for reliable high-speed operation that include optimization of the aerodynamics of the leading shape, vehicle noise minimization, traction systems designed for energy efficiency, and improvements in ride comfort. This article describes these latest technologies for Shinkansen trains.

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1. Introduction

Railways have attracted attention in recent years as a form of public transportation with low energy consumption. Hitachi designs and manufactures rolling stock, traction systems, and switches and other signal and traction equipment for regional, commuter, high-speed, and monorail railway lines. Working in partnership with its production sites in Italy and the UK, it is able to offer a broad range of products.

This article focuses on technologies for reducing the weight of Shinkansen rolling stock and for making their traction systems more energy efficient.

The following section describes how the A-Train concept of double-skin construction using aluminum hollow sections provides a basis for making rolling stock lighter weight, and how the leading-shape design and noise-reduction techniques reduce train travel noise and make it more comfortable.

The subsequent section on traction systems describes the product technologies used in Shinkansen rolling stock, which include induction motors (IMs) with world-class efficiency and an inverter that features a new cooling system and silicon carbide (SiC) power devices that incorporate new materials. The article also presents technologies for making the interior of the train a more comfortable and pleasant place to be by reducing internal noise and improving bogies by enhancing ride comfort.

2. Required Technologies for Shinkansen

Among the technical challenges common to all Shinkansen rolling stock are the issues of how to suppress internal and external noise and vibration when trains are in operation, and how to make trains more energy-efficient, smaller size, lighter weight, and suitable for maintenance. Improvements in these areas help improve punctuality, comfort, and convenience. This section describes the latest technologies, focusing on those adopted on Japan's flagship Shinkansen trains.

2. 1 Environment-Conscious Development

On consideration for the environment, Hitachi has been working on areas such as rolling stock design, including improvements to the energy efficiency of the traction systems used on the Shinkansen and to the leading shape and external noise.

(1) Rolling stock design

Aluminum double-skin construction is used on Shinkansen rolling stock for rigidity and airtightness. This includes designing rolling stock to be strong enough to withstand the repeated air pressure stresses that occur when passing through tunnels and using lighter weight materials (aluminum) to reduce its weight.

(2) Leading shape

A three-dimensional shape simulation of Shinkansen rolling stock was performed using aerodynamics analysis to minimize the effects of the aerodynamics waves generated by passage through a tunnel and to improve interior comfort and reduce the noise of tunnel entry. This was used to reduce cross-sectional strain on the rolling stock and to optimize the aerodynamics of the leading shape.

This optimization was achieved by adopting a long-nose design with a total length of 15 m for the leading shape of the E5 and E6 Shinkansen that would allow a maximum speed of 320 km/h (see **Figure 1**).

The N700S Shinkansen has a leading shape design called a "dual supreme wing." This streamlining and reshaping successfully reduced air resistance compared to that of the N700A (see **Figure 2**).

(3) Traction system

The energy efficiency of the traction system was improved by adopting a higher-capacity drive circuit together with the use of SiC devices and highly efficient IMs.

The capacity of the traction system is sufficient enough to drive the 300-kW main motors needed to achieve the maximum speed of the E5 Shinkansen. Meanwhile, the E7 Shinkansen is fitted with equipment that can operate at both frequencies, 50 Hz and 60 Hz, as it runs on track supplied by Japan's two separate electricity grids (see **Figure 3**).

The power consumption of the N700S Shinkansen is approximately 6% less than its N700A predecessor thanks to use of an under-floor air cooling system and six-pole IMs like that shown in **Figure 4**. Moreover, reducing the weight and size of the drive system and the weight savings that come from using SiC devices have reduced the total trainset weight by approximately 10 t.

Figure 1 — Leading Shape of E5 Shinkansen
The leading shape of the E5 Shinkansen is designed for a maximum speed of 320 km/h.

Figure 2 — Leading Shape of N700S Shinkansen
The figure shows a photograph of the leading car of the N700S Shinkansen (left) and the results of an aerodynamics analysis (right).

Figure 3 — Shinkansen Traction System

The photograph shows a 50/60 Hz converter/inverter (C/I) from the traction system of an E7 Shinkansen.

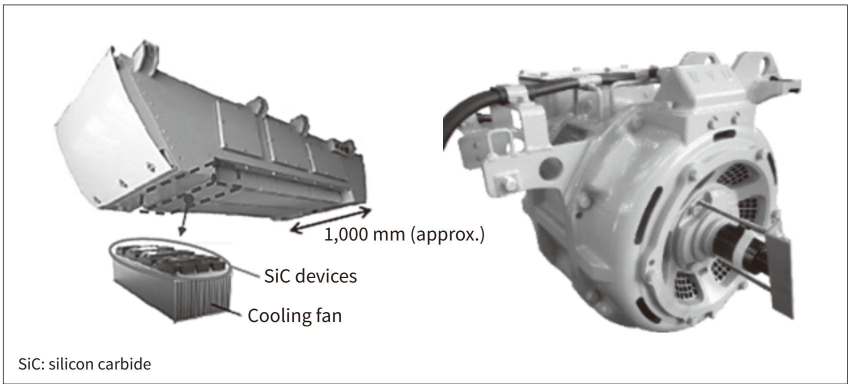


Figure 4 — Shinkansen Traction System

The photograph shows the C/I and main motor (MM) from an N700S Shinkansen.

(4) Reduction in external noise

Noise performance has been improved by smoothing the carbody to reduce external noise, the use of full-circumference hoods to eliminate the gaps between railcars, and the use of fully covered bogies.

New streamlining measures for the E5 and E6 Shinkansen include the use of flat door handles. Side covers that incorporate sound-absorbing material (see **Figure 5**) have also been fitted to reduce the level of noise that originates from under the train and is reflected back from the trackside soundproofing walls. To further reduce external noise, changes have also been made to the insulator covers and the shape of the double-skin walls to reduce the amount of wind noise from equipment on top of the train. Similarly, the propagation of noise from on-roof equipment has been reduced by the adoption of low-noise pantographs and fitting them with acoustic insulation panels.

As a result, the noise inside the E5 and E6 Shinkansen has been kept to a level equal to or better than that of an E3 traveling at 275 km/h.

(5) Improvements to operation at maximum speed

Brake performance has been enhanced and deceleration improved so that the train can stop more quickly than previous models in the event of an earthquake. In the case of the N700S Shinkansen, safety measures have been further enhanced by improvements to safety equipment and the braking system such that the braking distance in an earthquake is approximately 5% shorter than for an N700A when running at the maximum speed of 285 km/h.

2. 2 Comfort Improvements

Hitachi has sought to improve the ride comfort of its trains through measures that include reducing lateral forces in bogies and minimizing vibration in high-speed running conditions. Enhancements have also been made to the interior design of the Shinkansen rolling stock supplied to railway companies.

(1) Ride comfort improvement

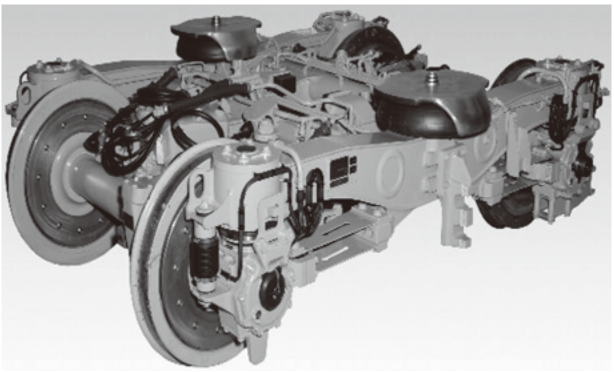
The suspension, dampers, and other bogie equipment have been optimized to improve safety at maximum speed.

Figure 5 — Measures for Minimizing External Noise from Shinkansen

The photographs show an E5 side cover incorporating sound-absorbing material (left), a sound-absorbing plate from an E5 (middle), and a sound-absorbing plate from an E6.

Figure 6 — High-speed Bogie for E6 Shinkansen

The bogie combines ride stability with a reduction in lateral forces when running on conventional railway lines.



A variable yaw damper has been adopted to minimize the lateral forces that cause problems for models such as the E6 when running on conventional non-high-speed track, combining this objective with that of stability on dedicated high-speed track (see **Figure 6**). This enables operation at high speed on dedicated Shinkansen track together with improvements to stability when traveling around small-radius curves on conventional track.

These improvements contribute to improving ride comfort performance by lowering noise to 80 dB or less for the E5 and E6 Shinkansen when running in a high-speed running condition of 320 km/h.

(2) Improvements to interior environment

The interior of the latest Shinkansen trains has been enhanced to maintain comfort during long journeys. In addition to placing highly sound-absorbing materials between the railcar body and interior fittings to make the railcars quieter inside, lateral sway at maximum speed and ride comfort on curves have also been improved through the use of vibration damping and train tilting systems.

New GranClass* rolling stock has been introduced, initially on the E5, to make the train a comfortable place to spend a long journey. Exclusive use of light-emitting diode (LED) internal lighting creates a pleasant environment through a mix of personal lighting with multiple indirect light sources, and this is accompanied by a novel backshell seating design (see **Figure 7**). Attention has also been paid to the interior fittings and to providing a quiet environment, with an internal noise level of 70 dB or less at the maximum speed of 320 km/h.

2. 3 Equipment Reliability Improvements

To enable Shinkansen trains to operate at higher speeds, measures have been adopted to improve operating performance and to ensure reliability in high-speed running conditions. The traction system has also been made suitable for maintenance, with improvements to the reliability and durability of the parts used in the different items of equipment. As a result, the system is smaller and quieter than previous models while still delivering the required output. A shift is also underway to condition-based maintenance (CBM) based on the actual operational status of equipment rather than the past practice of time-based maintenance (TBM) whereby elapsed time or distance traveled were the criteria for when to perform work.

2. 4 Barrier-free Accessibility

Steps are also being taken to provide facilities suitable for the physically disabled to improve barrier-free accessibility. Braille signage is located in the deck area to provide information about the interior layout and progress is being made on installing highly convenient equipment designed with accessibility in mind, including many Shinkansen trains being fitted with multi-function wheelchair-accessible toilets (see **Figure 8**).

(1) Use of LED interior lighting

LED ceiling lights are used in the passenger compartments to improve energy efficiency and reduce maintenance

* GranClass is a registered trademark of East Japan Railway Company in Japan.

Figure 7 — Interior of GranClass Rolling Stock

The photographs show the car interior (left) and a front and rear view of the seating (middle and right).

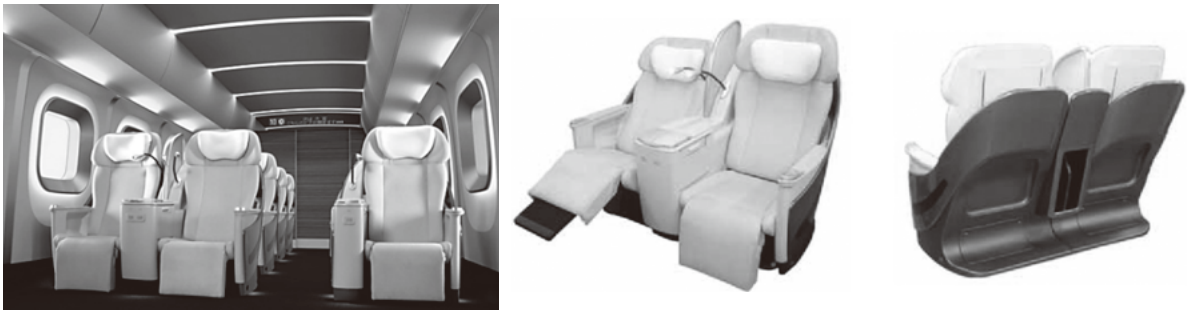


Figure 8 — Improvements to Shinkansen Comfort

The photographs show light-emitting diode (LED) lighting (left), braille signage (middle), and large toilet (right) on an E7 Shinkansen.

Figure 9 — Shinkansen Barrier-free Accessibility

The E7 and N700S Shinkansen provide space for wheelchairs.

costs. These consume less electric power than previous light fittings while still providing the required illumination. They also require less maintenance because of their longer life.

(2) Power sockets available on all seats

Power sockets provided on almost all passenger seating, including those in standard-class cars.

(3) Hot-water bidet toilets

To improve comfort, all toilets are equipped with a hot-water bidet. The design also seeks to prevent people from mistakenly pressing the emergency (SOS) button instead of the toilet buttons, including through the use of clear labeling.

(4) Security

Security has been improved by installing cameras in the deck area and passenger compartments and by providing an emergency call function in the passenger compartments and toilets.

(5) Wheelchair accessibility

Convenience for wheelchair users has been improved by providing space in the seating area (see **Figure 9**). New N700S Shinkansen trains supplied from FY2021 onwards will have six such spaces.

3. Conclusions

This article has described technologies for reducing weight and improving energy efficiency, both essential requirements for Shinkansen trains.

Hitachi intends to continue in its pursuit of technical innovation as it seeks to further improve the performance of Shinkansen rolling stock.

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Rolling Stock Engineering Department, Rolling Stock Engineering Division, Railway Systems Business Unit, Hitachi, Ltd. *Current work and research:* Sales engineering on high-speed trains.