Technological overview of the next generation Shinkansen high-speed train Series N700

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Abstract

In March 2005, Central Japan Railway Company (JR Central) has completed prototype trainset of the Series N700, the next generation Shinkansen high-speed rolling stock, developed jointly with West Japan Railway Company (JR West) since June 2002. The Series N700 was based on further evolution of the Series 700 to create the fastest high-speed rolling stock for the Tokaido and Sanyo Shinkansen. The Series N700 has been designed to improve riding quality, reduce noise, and consume less energy, and thereby be more environmentally friendly.

To achieve these design concepts, the Series N700 incorporates the latest technologies, such as a body inclining system, a train control and communication network, a new type hood covering the spaces between cars entirely, a nose shape with superior aerodynamic performance, and a high-performance semi-active suspension system.

The Series N700 is the first high-speed rolling stock with a body inclining system. The inclining system was achieved by controlling air pressure sent into the air springs, in combination with a new ATC system and the train control and communication network. When traveling around 2500m-radius curves that are standard on the Tokaido Shinkansen, the system inclines the car bodies toward the inside of the curves at an angle of 1 degree. As a result, it is possible to run through these curves at 270km/h, the maximum operation speed on the Tokaido Shinkansen, instead of 250km/h, speed restriction for other types of rolling stock.

Generally, when the maximum speed of trains is increased, riding comfort and noise level of the passenger environment deteriorate. However, as to the Series N700, passenger comfort was improved even further, by using the latest technologies. Riding comfort has been improved by installing an innovative high-performance semi-active suspension system in all cars. Longitudinal vibration has been suppressed by employing a combination of smooth braking through the use of the new ATC system, and reducing the number of accelerations and decelerations necessary at curves through the use of the body inclining system. To reduce noise in not only passenger’s cabins but also the vestibules, a number of innovated technologies have been introduced, for example, the use of the double skin structure has been expanded to reduce noise from the outside, a new type of hood has been adopted to decrease the aerodynamic noise coming from spaces between cars, noise reducing flooring materials have been used, noise from electrical equipment under the floors has been reduced, and a new type of link fitted between the bogie and the car body absorbs noise proliferating from bogies to bodies.

To increase cruising speed, total output power has been increased by 30% in comparison to the Series 700, and yet energy consumption has been reduced by about 19%. This was achieved by the superior aerodynamics of the nose, the complete smoothing of the body to minimize air friction, and an increase in the number of motored cars with the effective use of regenerative braking.
1. Introduction
Since June 2002, JR Central and JR West have jointly promoted the development of the Series N700 for through-operation between the Tokaido and Sanyo Shinkansen. Fundamental performance of the Series N700 was confirmed to determine specifications for the mass production trainset through running tests using the prototype since April 2005. Along with starting new services that introduce the latest technology the Series N700 is offering an “even more comfortable interior space” that meets the various needs of our customers. This paper describes the features of the Series N700 entered commercial service on July 1, 2007.

2. Concepts behind development
The Series N700 is a new improved version of the Series 700, and features the three developmental concepts outlined below (Fig. 1).

(1) High-tech (cutting edge) rolling stock that run on the Tokaido and Sanyo Shinkansen lines at the highest possible speeds
(2) Further improvements to comfort in passenger cabins
(3) Compatibility with the environment and improvement of energy-saving features

To achieve these concepts, the Series N700 incorporates a number of advanced technologies. These include systems for body inclining system and train control and communication system, the adoption of cover-all hoods between cars, an optimum nose shape with excellent aerodynamic characteristics, and advanced semi-active suspension system. The name N700 represents “a new Series 700” or “the next Series 700” after the Series 700, to imply its evolution and development from conventional cars.

3. Measures taken to achieve the concepts of development
(1) High-tech (cutting edge) rolling stock that run on the Tokaido and Sanyo Shinkansen lines at the highest possible speeds

The most outstanding feature of the Series N700 is the introduction of a body inclining system (Fig. 2). This inclines the car body 1° toward the inner rail to reduce the stationary acceleration force on the outer rail when running on curves, thereby increasing the operating speed at curves without compromising the high level of riding comfort. On the Tokaido Shinkansen line, the operating speed at curves (currently 250km/h on standard curves with a radius of 2,500m) has been raised to 270km/h for Series N700 cars.
Series N700 cars are equipped with a simple lightweight air spring uplift system to tilt the car body using the force of air sent into the air springs. The car body inclination is controlled by high-precision digital speed and position signals transmitted from the new ATC to the body inclining control device in each car through the train control and communication system. The body inclining control device is equipped with a highly reliable CPU. This provides an optimum system featuring diversified software and redundant sensors that are ideal for high-performance, high-reliability Shinkansen cars.
The starting acceleration of the Series N700 is raised to 2.6km/h/s, which is far higher than that of the Series 700. This substantially cuts the time taken to reach maximum speed, which for Series N700 cars is 270km/h on the Tokaido Shinkansen line and 300km/h on the Sanyo Shinkansen line.

Series N700 cars therefore make up the fastest rolling stock between Tokyo and Hakata, and it enables to reduce travel time between Tokyo and Shin-Osaka by five minutes. [2]

(2) Further improvements to comfort in passenger cabins
Higher train speeds normally cause a deterioration in riding comfort or increase the noise in passenger cabins. However, the new technologies incorporated into the Series N700 have improved riding comfort further, regardless of the increase in speed.

To improve riding comfort, each Series N700 car is mounted with a newly developed advanced semi-active suspension system to control lateral vibration. This is in addition to the non-linear air springs and dampers between cars whose effectiveness has already been proven with Series 700 cars. Riding comfort, both overall and in the longitudinal direction, has also been improved through the introduction of two measures: one is the single-step braking provided by the new ATC system, and the other is a reduction in the frequency of train acceleration/deceleration thanks to the body inclining system’s effect of expanding sections where trains run at a constant speed (270km/h).

The low-noise feature is ensured both in passenger cabins and on entrance/exit decks. Series N700 cars are constructed using the high noise-insulation double-skin skeletons used for the car body end plates and the floor above trucks in Series 700 cars. They are also equipped with newly developed cover-all hoods between cars, and are constructed with low-noise floors. Additionally, the cars adopt a number of new technologies, including quiet under-floor electric equipment and driving units, and low-noise single link traction devices.

(3) Compatibility with the environment and improvement of energy-saving features
As Series N700 cars run at a higher maximum speed on normal sections and on curves by utilizing the body inclining system, they are subjected to the problem of tunnel micro-pressure waves and other issues related to environmental compatibility such as external noise. To combat this, an aero double-wing-type has been adopted for nose shape (Fig. 3). This nose shape, which boasts the most appropriate aerodynamic performance, has been newly developed for railway rolling stock using the latest analytical technique (i.e. genetic algorithms) used to develop the main wings of airplanes. The shape resembles a bird in flight, suggesting a feeling of boldness and speed.
To reduce the noise emitted to adjoining areas, Series N700 cars feature the products of results obtained from a number of wind tunnel tests at the JR Tokai Komaki Research Complex. These include cover-all hoods between cars, bogie skirts, passenger cabin window panels that lay flush with the car body surface, noise-preventing insulator covers and pantographs designed to suppress aerodynamic noise. [1]

On the Tokaido Shinkansen line, Series N700 cars save 19% energy than Series 700 cars, despite a 30% increase in the output of their traction equipment for higher-speed operation (Fig. 4).

Compared with the very first Shinkansen, the Series 0, the Series N700 is 32% more energy efficient, not to mention that speed has been improved by 50km/h from 220km/h to 270km/h. If this comparison is based on a speed of 220km/h, there is 49% more energy efficient than the Series 0.

This is a result of adopting the aerodynamically excellent nose shape, reduced running resistance thanks to the drastically smoothened car body and under-floor equipment, effective utilization of regenerative braking by increasing the motor cars (M-cars), and a decrease in the number of acceleration/deceleration operations as a result of higher operating speed at curves. When compared at the speed of 220km/h, the Series N700 is 49% more energy efficient than the Series 0.

4. Main specifications

(1) Unit composition
Series N700 trains are composed in the same way as Series 700 trains, comprising 16 cars with four cars as a unit. To increase the output of the train, two more M-cars are added to each train set. As a result, the first and fourth units are composed of three motor cars and a trailing car (or leading car), while the second and third units are made up of four motor cars, constituting a 14M2T composition.

(2) Passenger capacity
To enable train sets to be made up of Series N700 cars mixed with existing Series 300 and 700 cars, N700 cars are allotted the same passenger capacity as each Series 300 or 700 cars. This capacity is set at 1,123 for regular cars and 200 for green cars, making the total passenger capacity of the train set 1,323.

(3) Main dimensions
The lengths of leading and middle cars are the same as those of the corresponding Series 700 cars, while car body width is reduced by 20mm to 3,360mm in consideration of car body inclination. To contribute to environmental preservation, the roof height is also reduced to 3,600mm, 50mm lower than that of Series 700 cars. The nose length of leading cars is extended to 10.7m (compared to the 9.2m value of Series 700 cars), with the roof height on the driver seat side reduced to 3,500mm to make a two-level roof structure. The leading car therefore features different cross-sections at the nose, the low-roof part, the two-level section and the remaining section (i.e. where the cross-section is the same as that of middle cars).

(4) Main power circuit system
To minimize increases in the size and weight of equipment in conjunction with higher total power
output, the main power circuit system of the Series N700 is designed to be compact and highly efficient. This makes the output/mass ratio about 20% higher than that of the Series 700. In a train set, some units are composed of four motor cars (M cars), while others are composed of three. Two types of main transformer are therefore used in a train set (i.e. one for each of the four- and three-M car units), while the main power converter and traction motor are common to all motor cars. The output of the main transformer for the four-M car unit is 5,600kVA, which is the highest of its kind in the country. The main power converter, which uses large-capacity IGBT power device, performs three-level control to reduce noise and raises the intermediate DC voltage to decrease conversion loss. The traction motor, which features improved rotor bar and stator, also reduces loss and noise, thereby suppressing rises in temperature.

(5) Train control and communication system
Series N700 cars use the train control and communication system using a new digital transmission system to reduce car weight and correspond to highly functional rolling stock systems. The system transmits the commands for powering, braking, remote control and power source guiding to the main converter and brake output control units, while inheriting the conventional circuits for emergency braking, door closing operation and other important security devices. Since a very high level of reliability is required, the train control and communication system uses the same hardware as that of the new ATC system, as well as full dual-control on transmission routes, power sources, connectors and software.

(6) Monitor system
The Series N700 has raised the basic transmission speed to 100Mbps from the 2.5Mbps of the Series 700, and has an improved CPU and memory capacity. This enables the integration of operation information units and strengthening of the status monitor function. To improve the quality of rolling stock, Series N700 cars continuously monitor the status of the power source circuit and contact conditions of various cocks.

(7) Brake system
Like the Series 700, the Series N700 uses an air brake system in tandem with a regenerative brake system. During service brake operation, the 14 motor cars can generate the brake force required for a total train set composed of 16 cars, thus eliminating the need for the eddy current brake (ECB) otherwise required for trailing cars. Trailing cars are therefore equipped with only a mechanical brake system (without the dynamic brake function). The N700 Series has also adopted an air pressure skid control system of each bogie, replacing the conventional hydraulic skid control system for skid prevention of each axle. This decreases the number of pressure intensifier cylinders needed to one per bogie, subsequently reducing car weight.

(8) Bogie
The bogie of the Series N700 has succeeded the 700 Series’ dip-feed lubrication-type tapered roller bearings and the wing-type axle box suspension system using coil springs and laminated rubber. The bogie was reviewed in terms of the structure and strength at various points to deal with the higher maximum speed. To prevent interference between different parts when the car body tilts, the body is composed of shorter cross-members.
Pantograph and insulator cover
To reduce aerodynamic noise, a single-arm pantograph with shorter bottom frames has been developed. This is different from those used for Series 300 and 700 cars, completely covering the structure below the top frame's middle point with windshields to reduce aerodynamic noise. Whereas four supporting insulators were used for pantographs in the past, the pantograph of the Series N700 uses only three, with a smaller cavity length inside the insulator cover. As a synergetic effect of these measures and larger sidewalls, noise has been reduced further from that of the Series 700. Pantographs are mounted on car numbers 5 and 12 (the same car numbers as those in a Series 700 train set).

5. Interior and exterior
(1) Interior
Series N700 cars improve even on the spacious interior of Series 700 cars, with upgrades to all aspects of space and equipment in the passenger cabin.
Green cars (Figs. 5, 6 and 7) have achieved an elegant, peaceful and quiet passenger cabin atmosphere appropriate for accommodating VIPs. The entrance/exit decks give a sense of decency and high-quality, with the quality materials and curved surfaces reminiscent of a hotel lobby. To provide ergonomically optimal seating comfort, the cars use newly developed synchronized comfort seats featuring an inclined seat base interlocked with reclining operation. The seats accommodate a range of passenger requirements, and are each equipped with an easy-to-use high-intensity LED reading light, a foot rest, a large seat-back table, a handy side table and a leg warmer to be used by individual passengers to prevent chilly feet. Toilet and lavatory facilities are also designed to high quality, luxurious specifications.
Regular cars (Fig. 8) also feature bright and spacious passenger cabins, developed further from those of Series 700 cars. Apart from B seats (i.e. the center seats of the three-seat block) which are already wider, all seats are designed 10mm wider than those of conventional cars, with a newly developed cushion featuring a compound spring structure for improved seating ride comfort.
As well, we start new services such as “all seats non-smoking”, establishment of new smoking room, increasing the number of outlets for mobile devices, starting an “Internet Service” (after spring, 2009), multipurpose toilet space established facilities for ostomates, and an enlargement of seat-back tables to meet the various needs of our customers.
Additionally, a number of common facilities are installed in Series N700 cars such as western-style toilets with diaper changing stands, plug sockets for personal computers, and other auxiliary facilities. In view of the importance of universal design, pictograms are used consistently for signs, along with large color TELOPS to improve the visibility and content of information to guide passengers.
<table>
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<tr>
<th>Specifications</th>
<th>Series N700</th>
<th>Series 700</th>
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<tbody>
<tr>
<td>Formation</td>
<td>14M2T</td>
<td>12M4T</td>
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<tr>
<td>Unit configuration</td>
<td>4 cars per unit</td>
<td>(Same)</td>
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<td>Seating capacity</td>
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<td>Maximum speed</td>
<td>Tokaido: 270km/h, Sanyo: 300km/h</td>
<td>Tokaido: 270km/h, Sanyo: 285km/h</td>
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<tr>
<td>Operating speed at curve (R2500m)</td>
<td>270km/h</td>
<td>250km/h</td>
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<tr>
<td>Starting acceleration</td>
<td>2.6km/h/s (Tokaido / Sanyo)</td>
<td>1.6km/h/s (Tokaido), 2.0km/h/s (Sanyo)</td>
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<tr>
<td>Weight (at capacity)</td>
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<tr>
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<td>Car length</td>
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<tr>
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<td>Car height</td>
<td>Front end of the leading car: 3,500mm</td>
<td>Rear end of the leading car: 3,600mm</td>
</tr>
<tr>
<td></td>
<td>Middle cars: 3,600mm</td>
<td>3,650mm</td>
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| Total power output           | 17,080kW    | 13,200kW   |
| Nose shape                   | Aero Double-wing (10.7m) | Aero Stream (9.2m) |
| Bogie structure              | Bolsterless bogie | (Same) |
| Equipment for riding comfort  | Advanced semi-active suspension system for all cars | Semi-active suspension system for seven cars |
| Body inclining system        | Air spring mechanism (1"inclining) | - |
| Hood between cars            | Cover-all type | Sides only (partitioned) |

Table 1: Main specifications of the Series N700

Fig. 5: Green car passenger cabin
Fig. 6: Green car vestibule
Fig. 7: Green car lavatory space
Fig. 8: Regular car passenger cabin
(2) Exterior
Series N700 cars blend the bold nose profile with the traditional design of Tokaido and Sanyo Shinkansen cars, achieving a highly advanced, sleek exterior with a 21st century feel. The exterior painting succeeds the blue belts on a white background that have been a tradition since the inauguration of the Tokaido Shinkansen, and gives the effect of the "fastest rolling stock" as a concept of Series N700 cars. The outside of the car body features six highly streamlined stickers placed in a blue-based color scheme on both sides of cars 1, 3, 7, 11, 13 and 15, creating a speedy effect.

Full-color LEDs are used as destination indicators to provide passengers with a range of information such as the train number, midway stations where the train stops and reserved seat zones, in addition to the terminus and train nickname that are already displayed on conventional trains.

6. Conclusion
Series N700 is a result of development of the latest technologies to be used for passenger service on the Tokaido and Sanyo lines in the 21st century. After prototype cars manufactured in March 2005, Basic performance tests, speed-increasing tests and a long-term durability test were performed over a period of 18 months. After acquisition various data and confirm and verify, Series N700 debut and commenced commercial operation on July 1, 2007. Speed which passenger required a high level of ride comfort and diversified services of Series N700 which achieved the "latest, fastest and best rolling stock" has received very favorable comments from our customers.

References