Efforts to save energy for the Tokaido Shinkansen

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Summary

Central Japan Railway Company (JR Central) has promoted various efforts to save energy for the Tokaido Shinkansen related both to ground installations and on-board equipment. The 2014 Environment Minister's Award for Global Warming Prevention Activity was presented for further improvement of environmental performance realized by the latest N700A (N700 Advanced). This paper outlines evolution of environmental performance as to the traction system of the Shinkansen rolling stock from the Series 300 to the latest N700A, especially on technological development for reduction in size and weight of power converters.

1. Traction system for lower energy consumption

Continual upgrade and replacement of the Tokaido Shinkansen rolling stock have realized energy saving. In the Shinkansen rolling stock, key technological elements for energy saving are as follows: (1) reducing running resistance, (2) using the regenerative braking system, (3) improving efficiency of traction system and (4) reducing weight of the rolling stock.

Among these, (1) and (4) are taken as the main effective measures to suppress the wayside noise and vibration accompanied with increased train speed. Improved aerodynamic performance by the smoothed car body and the optimized nose shape greatly contributed to reduction in running resistance. On the other hand, this weakens braking performance, requiring enhanced thermal capacity of brake disks and improved regenerative braking performance. The traction system to drive the Shinkansen trains has made great advances through realizing key elements like (2), (3) and (4).

The Series 300 developed in 1990, after the establishment of JR Central, represents the great turning point in the traction system of the Shinkansen rolling stock. We have pioneered practical application of the AC regenerative braking system and drastically reduced the weight of the traction system taking advantage of the evolved power devices. Squirrel-cage asynchronous motors featuring high-speed rotation and simple structure without wearing parts, such as commutator brushes, are efficient for traction motors for the Shinkansen rolling stock, satisfying the requirements of lightweight structure and high capacity. The rated output and weight of the asynchronous motor for the Series 300 were 300kW and 390kg, respectively, which means that the weight per unit output is 1.3kg/kW.

The regenerative braking system is to transform kinetic energy during deceleration into electric power that is fed back to the overhead contact wires. As to the Shinkansen rolling stock, traction motors are used as generators for the power conversion in braking. In the Series 0 and the Series 100, electric power generated by traction motors was transformed into thermal energy and consumed by the main resistors equipped under the floor. The main resistors occupied large part of the space for equipment under the floor, to consume kinetic energy from 220km/h to 0km/h, however, by the practical use of the regenerative brake, the main resistors became unnecessary, which contributed to drastic reduction in weight. Thus, the asynchronous motor driving system with the regenerative brake has been a standard in the later Shinkansen rolling stock, and since then, is to evolve continuously.

2. Progress of power converter

The weight of equipment constituting the traction system is dominant in the whole rolling stock. Technological development related to power electronics makes a greater contribution to decrease in size and weight, compared to those in mechanical components like the car body or the bogie. For this reason, development to reduce size and weight of the traction system has been still important since the introduction of the Series 300. Especially, the power converter to drive the AC motors, a core in the traction system, is one of the largest components because of high-capacity power semiconductor devices inside and their dedicated cooling system for the heat dissipated in their switching.

Progress of power semiconductor devices and development of the cooling system are closely related to the power converter.

As to the power converter for the Series 300, we applied 4.5kV-2.5kA Gate Turn-Off (GTO) thyristors, the maximum class at that time. After that, power semiconductor devices have made rapid progress. In the middle of 1990s, 1kA class Insulated Gate Bipolar Transistors (IGBT) became applicable to the power converters for the Shinkansen rolling stock.

In 1994, we started trial use of the power converter with the IGBT attached to the Series 300. For the prototype of the Series 700, the successor to the Series 300, we brought the power converters fully adopting the IGBT into practical application, which was the first time for the high-speed rolling stock (Photo1). The power converter for the Series 700 features further lightweight, higher efficiency and smaller size than that for the Series 300 by reducing loss and simplifying electric circuit thanks to adopting next-generation power devices.

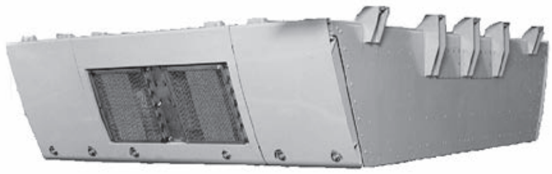

Photo 1: Power converter for the Series 700

The power converter for the Series 700 employs the forced-air-cooling system, in which the air is taken from one side, cools down the power devices inside and is thrown out to another side (Figure 1). The 3.3kV-1.2kA module type IGBTs have been in the mainstream as

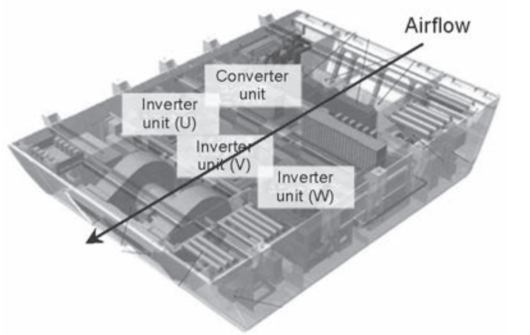

Fig.1: Airflow in the forced-air-cooling system

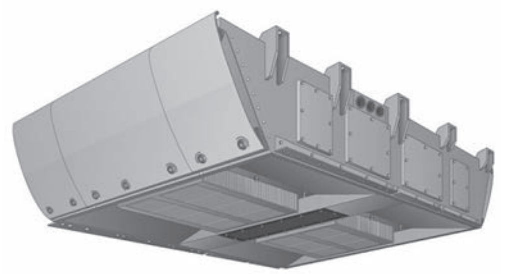

Fig.2 Train-draft-cooling power converter for the Series N700

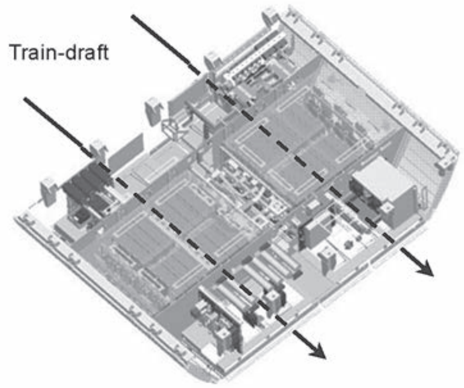

Fig.3 Airflow in the train-draft-cooling system

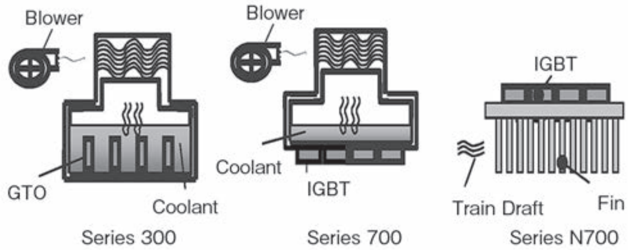

Fig.4 Comparison of the cooling system for power converters

a power semiconductor device for the Shinkansen power converters since then.

Using the IGBTs, we newly developed the train-draft-cooling power converter with the cooling fins on the bottom. The validity to cool the power devices only by train-draft instead of forced ventilation was verified through running tests using the prototype of the Series N700 completed in 2005. We examined characteristics of the train-draft-cooling power converter through long-term running tests to optimize the bottom shape of the converter and distance to neighboring under-floor equipment required for adequate airflow. The results of running tests showed that the cooling performance was not affected by the position in a train set of 16 cars (in the head, the tail and also the middle). This train-draft-cooling system needs no blower motors, no air ducts and no liquid cooling mediums. We have practically applied this type of power converter to the Series N700 commercial fleet later, increasing gradually in number. The traction system of the Series N700 features output 30% higher than that of the Series 700 due to enhanced performance such as maximum speed, acceleration and deceleration. The train-draft-cooling power converter realizes reduction in weight regardless of increased power output.

Concerning the traction system, the trend of reduction in weight per unit output from the Series 0 to the Series N700 explicitly represents our uninterrupted efforts to cut down overall weight. We have lessened the weight per unit output of the Series N700 to be around 30% that of the Series 0 (Figure 5). Environmental performance can be maintained as we endeavor to cancel increase in weight due to pursuing further improvement of safety and riding comfort.

In 2013, eight years after introduction of the Series N700, we put the latest N700A into commercial service with enhanced safety, reliability, riding comfort and environmental performance. Further reduction in size and weight of the power converter was also pursued through reviewing arrangement of internal components and slopes which guide train draft to the intakes for cooling power devices. The power converter for the Series N700 has slopes on both longitudinal sides. As to the power converter for the N700A, a slope on one side is eliminated because the body covers under the floor adjacent to the converter on another side is designed to fulfill the same role (Figure 6). Various compositions were examined to optimize mounting position of the power converter and condition of the car body in repeated running tests using the N700 prototype (16-car train set, used solely for technological developments). As to the power converter for the N700A, which has the same power output as the Series N700, the longitudinal length is shortened by 25% and the weight is reduced by 17% compared to that of the Series N700.

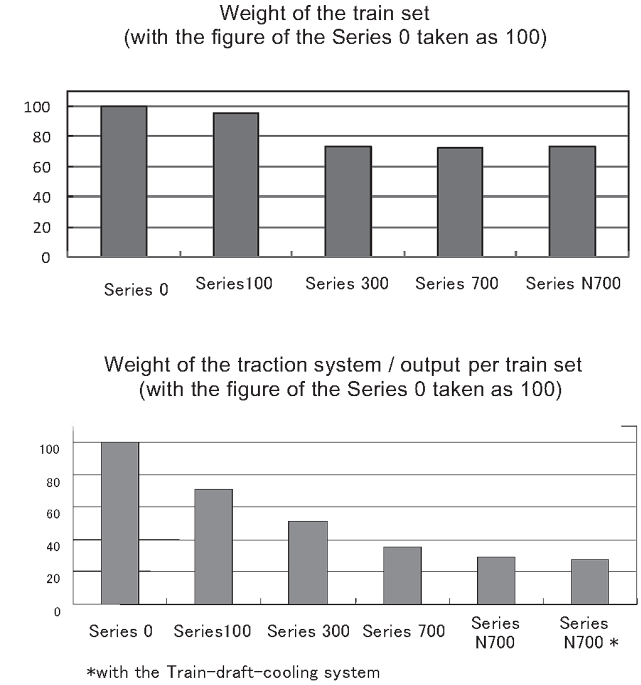

Fig.5 Trend of reduction in weight of the traction system

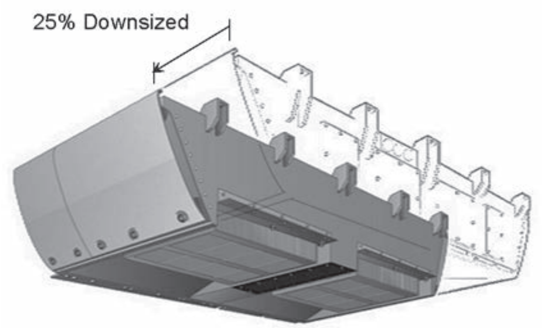

Fig.6 Train-draft-cooling power converter for the N700A

3. Practical application of regenerative braking system

Given that the brake is applied from the speed faster than 200km/h, the rheostatic braking system was basically used as the service brake to avoid wear on brake disks or pads for the Series 0, since its development stage. This philosophy is firmly maintained since then. When we introduced trailers partly in the Series 100, we adopted eddy-current brakes a kind of electric brake for the trailers. Regarding the

16-car train set, the Series 300 has 10 motored cars and 6 trailers, the Series 700 has 12 motored cars and 4 trailers. All of the trailers of the Series 100, the Series 300 and the Series 700 have eddy-current brakes. Part of the braking energy cannot be fed back to the overhead contact wires because the eddy-current brake is to dissipate braking energy as heat caused by eddy currents induced on axle-mounted disks.

Braking energy handled by trailers was reduced to be less than half in the Series 700 train set compared to the Series 100 or the Series 300. The rest of the braking energy is complemented by the reinforced regenerative brakes on motored cars. The use of electricity by the Series 700 is superior to forerunners in terms of energy saving.

From the Series N700, the train set is composed of 14 motored intermediate cars and 2 driving trailers. The two driving trailers, leading cars on both ends, are not equipped with the eddy-current brakes. The service brake is not applied in the axels on the leading cars to secure axels that are free from skidding. Higher ratio of motored cars compared to the Series 700 enables the regenerative brakes to handle overall braking energy including 2 driving trailer. The Shinkansen rolling stock has attained advanced environmental friendliness owing to further enhancing its regenerative ratio.

4. Contribution to energy saving

Reduction in running resistance greatly contributes to lowering energy consumption. As to the Series N700, cover-all hoods at all coupling sections between cars and bogie skirts (Photo 2) at all bogies drastically decreased running resistance (Figure 7). Concerning the traction system, not only improved efficiency mainly of power converters but also efficient use of regenerative energy and lightened equipment under the floor play important roles for energy saving. Energy consumption by different types of the Tokaido Shinkansen rolling stock is compared in Figure 8. Energy consumption by the Series 300 is reduced compared to the Series 0 even though the maximum speed was raised from 220km/h to 270km/h. The Series N700 (including N700A) consumes energy equivalent to approximately half of that consumed by the Series 0 in running at 220km/h between Tokyo and Shin-Osaka. Introduction of rolling stock with higher efficiency for replacements leads to reduction in energy consumption as a whole in the Tokaido Shinkansen.

We have strived to develop traction systems with higher efficiency for the Shinkansen rolling stock focusing not only on reduction in size and weight but also on cutting down on manufacturing and operational costs. Thanks greatly to continuous and consistent technological development, environmental performance has been improved without any interruption since the drastic breakthrough was attained in the traction system for the Series 300. Our promise is making energy efficiency of the Tokaido Shinkansen even higher through technological development to contribute to prevention of global warming.

5. Receiving the Environment Minister's Award

Our commitment to develop the N700A was awarded environment-related honorable prizes in succession. In December 2013, we received the 2014 Environment Minister's Award for Global Warming Prevention Activity (Figure 3). This award is presented yearly by the Ministry of the Environment to honor individuals or groups that have made significant contributions toward preventing global warming in December, designated as Global Warming Prevention Month, as a part of efforts to promote measures against global warming. JR Central also received this award in 2003 and 2007 (Table 1).

We also won the Gold Prize of the 10th Aichi Environmental Commendation in February 2014. This commendation rewards companies, foundations and other groups that work on pioneering and effective technology, business, activities or education programs to promote recycling of resources and reduction in environmental impact annually since 2005. The Gold Prize is the highest rank of the commendation.

Encouraged by these honors, we continue to prioritize safe and reliable transportation, which is the foundation of the railway business, and strive steadily to contribute to protection of the global environment.

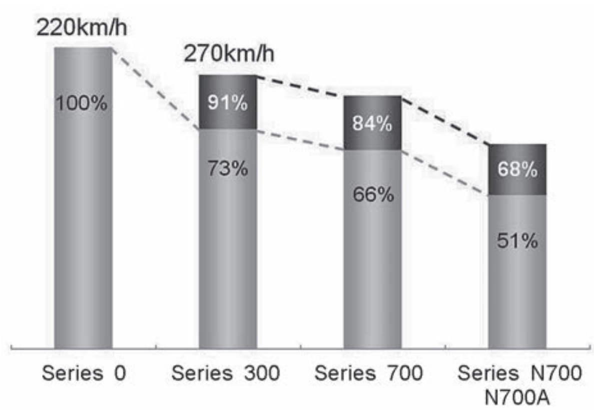

Fig.8 Comparison of energy consumption by different types of the Tokaido Shinkansen rolling stock (with the figure of the Series 0 taken as 100)

Photo 2 Bogie skirt (Series N700)

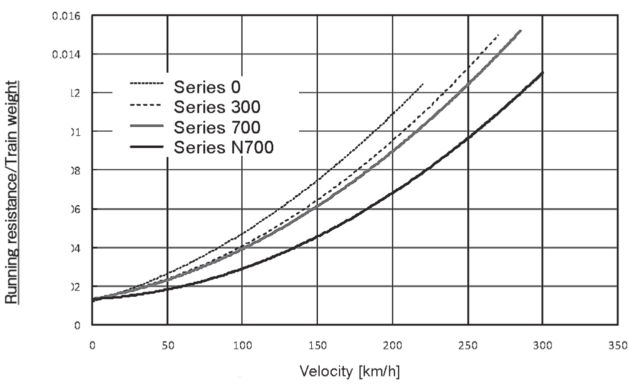

Fig.7 Comparison of the running resistance in Shinkansen train

Photo 3 Environment Minister's Award for Global Warming Prevention Activity

Table 1 Past records of Environment Minister's Award for Global Warming Prevention Activity

FY2003	Development and introducing energy saving rolling stock mainly for the Tokaido Shinkansen and accomplishment of saving operational energy.
FY2007	Development of the Series 700 achieving both speed-up and energy saving.
FY2013	Development of the N700A achieving further enhanced environmental performance.

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NEWS

○Introduction of the world's first wireless crossings

On December 14, JR East began to use the crossing control function of the ATACS wireless train control system that has been in use since 2011 for a 17.2-km section of the Senseki Line between the stations of Aoba-dori and Higashi-Shiogama. ATACS replaced the conventional train control procedure used for ground facilities, and allows trains to wirelessly exchange information based on the detection of their locations. It eliminates the need for devices such as track circuits and ground signals, thereby enabling facility scale reduction, improving reliability and allowing maintenance cost savings.

The company first installed ATACS on October 10, 2011, for the section in question, initially starting with the minimum functions necessary for train operation (e.g., train interval control). On December 16, 2012, it began to use a temporary speed control function disaster situations and similar.

The recently introduced crossing control function pre-calculates a train's arrival time at a crossing based on its current speed and the performance of trailer vehicles, wirelessly commands the train to request a warning issuance, and drives a control device to sound an alarm at the crossing and lower the gate bar. After the train passes the crossing, the function stops the alarm and raises the gate bar. The system reduces the load for equipment at crossing-related facilities, thereby enhancing safety and reliability, simplifying maintenance, and sometimes shortening the shutdown time of crossings.

This first-ever application of wireless crossing control was begun on December 14 at the Furuyado Crossing between Nigatake and Kozuru-shinden stations and at the Numagata Crossing between Kozuru-shinden and Fukuda-machi stations. It will also be applied to the 12 other crossings from now on between Aoba-dori and Higashi-Shiogama stations spending half a year in the first half of 2015.

○Start of central maglev train route construction

On December 17, JR Central began the construction of facilities for a maglev train route. On that day, staff at Nagoya and Shinagawa stations (the route's east and west terminals) started preparations for construction work after a ceremony at which prayers were said for the safety of the project. This marked a shift in the route's development from the planning stage to the construction stage and a new step toward the expected start of operation between Shinagawa and Nagoya in 2027.

Trains on the central maglev train route will be driven by a magnetic levitation mechanism supported by superconductivity at speeds up to 505 km/h, carrying passengers from Shinagawa to Nagoya (a distance of about 286 km) in as little as 40 minutes along the Southern Alpine route and to Osaka (about 438 km) in 1 hour 7 minutes. Actual commercial operation is expected to start in 2027 between Shinagawa and Nagoya and in 2045 between Shinagawa and Osaka. Total expenditure is estimated at 5,524 billion yen (excluding the cost of the pilot line previously built in Yamanashi Prefecture) for the Shinagawa-Nagoya route and 9,300 billion yen for the Shinagawa-Osaka route.

After receiving a decision on the deployment plan and an order for construction from Japan's Ministry of Land, Infrastructure, Transport and Tourism, JR Central assessed related environmental effects over a period of about three years from June 2011 onward. The issuance of a report detailing the results on August 26, 2014, marked the completion of the environmental due diligence required of the company before construction could be started. At the same time, JR Central submitted its construction plan to the Ministry of Land, Infrastructure, Transport and Tourism for approval, and on October 17 received permission to go ahead with Phase 1 (subject to the development of structures included in the plan). Approval for Phase-2 plans regarding related facilities such as station buildings and electrical infrastructure will also be requested.

JR Central President Koei Tsuge and 18 other local representatives attended the Shinto ceremony for construction safety at a site owned by the company to the west of Nagoya Station. After the ceremony, Mr. Tsuge said, "I'm very pleased that we've now progressed to the construction stage, and fully understand the scale of the responsibility placed upon us. Although we may face a variety of challenges during the construction period over the next 10 years and beyond, we remain committed to construction safety, due care for environmental maintenance, and in full cooperation with local areas." On behalf of the attendees, Hiroyasu Goto, Chairman of the Political Cooperative Committee for the Nakamura District, said, "We positively support the construction work for the prosperity of the prefecture, city and locality."

A new facility for the line will be built at Nagoya Station. The construction will involve open-cut tunneling 30 m underground over a distance of more than 1 km to the east and west. At JR Central sites (such as those used for the Tokaido Shinkansen and other conventional lines) where the center of the new station will be, structures such as viaducts and tracks will be built before the main construction begins in the fall of 2015 accompanied by ground surveying and land acquisition. Presentations currently being made to local autonomies along the planned line will be followed by guidance meetings on ground surveying, structural design, site acquisition, and its contracts for construction, details of construction, and results of discussions with local representatives. The series of planned construction tasks will then begin.

At Shinagawa Station, 21 representatives including JR Central Chairman Yoshiomi Yamada attended the construction safety ceremony, which included the offering of a sprig by a representative. Mr. Yamada said, "Although we expect a number of challenges during the long construction period, we plan to move along with a consistent and steadfast approach to problem resolution." Representing other attendees at the ceremony, Minato Ward Mayor Masaaki Takei said, "The maglev train route, with its full use of innovative high-speed railway technology, is ideal for Shinagawa as a city undergoing reconstruction for a new town. We support this project as a local base for the work involved, and pray for safety in the line's construction."

Construction at Shinagawa Station will now go ahead starting with yards for materials and construction work.

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