Interpretive article

Outline of Shinkansen Research and Development

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Shinkansen research and development at JR East puts special emphasis on increasing operating speed. We also aim to employ our research and development activities to bring about improvements in all areas of Shinkansen operation, utilizing lessons learned in day-to-day operations and anticipating future issues in efficiency and services.
This issue of JR East Technical Review introduces a wide range of content in recent research and development.

1 Introduction

JR East is coming up on its 30th anniversary in April 2017. The company has built up a history of network expansion for the Shinkansen over this span (Fig. 1). The terminus of the Tohoku and Joetsu Shinkansen, which opened in 1982, was changed to Tokyo Station in 1991 with expansion between Ueno and Tokyo. The Yamagata Shinkansen opened and was later extended to Shinjo. The Akita Shinkansen opened. The Hokuriku Shinkansen (between Takasaki and Nagano) opened and later started through service with JR-West through extension to Kanazawa. The Tohoku Shinkansen was extended between Morioka and Hachinohe and then Hachinohe and Shin-Aomori, and it later started through service with JR Hokkaido with the opening of the Hokkaido Shinkansen.

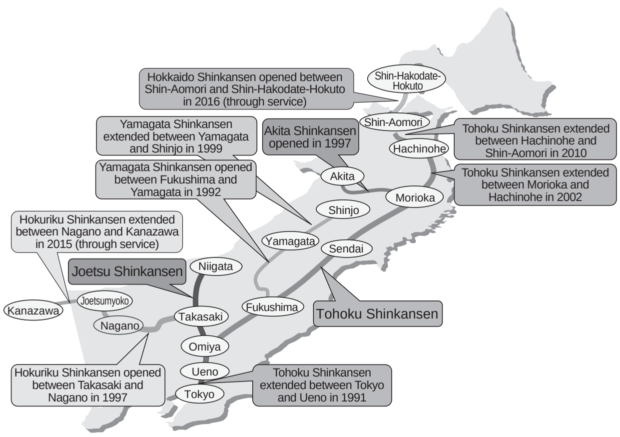

Fig. 1 History of Network Expansion

The Shinkansen in the JR East operating area has diverse operating sections and forms, giving it several distinct features. On the Yamagata and Akita Shinkansen, downsized Shinkansen rolling stock was made to run in their conventional line sections, achieving an original form of operation where those couple to and uncouple from full-sized Shinkansen cars at Fukushima and Morioka respectively, providing service without need to transfer. Shinkansen transport has also been achieved in conjunction with resort development, with Echigoyuzawa Station on the Joetsu Shinkansen being connected directly to GALA Yuzawa ski resort.

Research for increased speed makes up a major cornerstone of Shinkansen-related R&D at JR East. We also aim to further advance the Shinkansen including for issues that come from its distinct features, making efforts in R&D in a wide range of technical fields in order to overcome issues that come up in day-to-day operation and further improve efficiency and service levels.

This issue of JR East Technical Review introduces some of the R&D we have been working on recently.

2 Features of the JR East Shinkansen Network

The JR East Shinkansen network stretching in five directions has some features that lead to technical issues. The following introduces some of those.

2.1 Shortening Long-distance Travel Time

The line with the longest direct service in the network stretching in five directions is more than 800 km long between Tokyo and Shin-Hakodate-Hokuto stations, and the fastest “Hayabusa” trains connect those stations in 4 hours 2 minutes. People choose the means of transport to use according to factors such as travel time to destination, cost, and convenience. Therefore, they tend to choose airlines with their shorter travel time when traveling longer distances and cannot be persuaded to use railways unless travel time can be reduced. We have thus been promoting technical development for speed increases from 2002 with a technical objective of 360 km/h maximum commercial speed. And along with increasing speed, we are working to improve ride comfort and cabin amenity in order to make trips pleasant. Through R&D up to now, we have innovated cabin spaces and started providing service a level greater than that of previous first class cars (Fig. 2).

How to control the adverse affects of air vibration (noise, micro-pressure waves, etc.) and vehicle vibration has become a major theme in Shinkansen speed increases.

Fig. 2 Series E7 GranClass (From JR East Press Materials)

One major technical issue in speed increases is measures to reduce noise generated when running. Noise is classified by its source, and low-noise pantographs, pantograph noise insulating panels, smooth covers between cars, and the like were developed with past Shinkansen high-speed test trains (FASTECH) for aerodynamic noise where acoustic power increases proportional to the sixth to eighth power of speed.

In aiming for 360 km/h commercial operation and further noise reduction, methods of investigating measures to identify by simulation the mechanisms that are the source of noise are needed for more efficient development instead of past trial-and-error methods by experiments and the like. In efforts in reduction of pantograph aerodynamic noise using numerical simulation, sound pressure level around pantographs while running was predicted by numerical simulation, and accuracy of simulation was confirmed to be acceptable by comparisons in wind tunnel tests. By using simulations, sources of noise generation could be ascertained in detail, shapes to counter those investigated, and effects of shape changes evaluated by simulations.

In addition to the aforementioned noise as an effect of speed increases on the wayside environment, there is a problem with radiation of pressure waves generated in tunnels as trains enter them being radiated from tunnel exits (tunnel micro-pressure waves) and causing noise and vibration problems. If the lead car nose shape remains the same, tunnel micro-pressure waves become larger as speed increases. As rolling stock countermeasures against that in speed increases, we have reduced the cross sectional area and developed shapes where rapid changes in cross sectional area do not occur by increasing the area gradually from the nose. And as wayside countermeasures, we have set up at the entrances of the tunnels hoods with cross sectional areas larger that the tunnels (tunnel entrance hoods). Windows called "slits" are opened in those tunnel entrance hoods to release some of the compressed air to the outside in order to increase performance without lengthening the hoods (Fig. 3).

Slits are effective in countering micro-pressure waves, but sound leaks from those slits, worsening the noise level near tunnel entrances and exits. So in development of countermeasures against running noise for tunnel entrance hood slits, we are conducting development to achieve a mechanism to reduce sound while maintaining performance of slits in reducing micro-pressure waves. We have proposed devices of six different shapes and sizes and are conducing tests with models to confirm their effects.

Fig. 3 Tunnel Hood Slits

Next is the issue of ride comfort when running at high speed.

Ride comfort is greatly affected by acceleration received by passengers in lateral, vertical, and longitudinal directions. In confirming rolling stock performance, we weight and evaluate the degree of discomfort felt by people according to the frequency of vibration for measured values of body vibration acceleration. However, in recent years, the frequency of vehicle vibration that is a problem in terms of ride comfort has come to be in a higher range.

When developing new rolling stock, only finding out the body vibration that affects ride comfort by actually running it delays advancement of improvement in ride comfort. So, we believe that if we could accurately simulate in advance the vibration of rolling stock when it is running, we will be able to examine various items at the design phase. In "Construction of a Vibration Analysis Model for Railway Vehicles Used for Examination in the Design Phase to Improve Ride Comfort" introduced in this issue, we constructed a simulation model taking into account high-frequency vibration with an aim of simulating vibration for future rolling stock development. In order to reproduce vibration of running vehicles, we made a full-vehicle model of one car combining a bogie model with a body model made up of models of body structure, interior, and under-floor equipment. With a running model where the full-vehicle model is run using track data and running conditions, we were able to simulate body vibration when running. We verified the accuracy of simulations by comparing that simulation data with measurement data.

2.2 Heavy Snow Regions and Through Service between Shinkansen and Conventional Lines

The network stretching in five directions from Tokyo branches at stations along the way. Even if a line branches, we make an effort to achieve through service so passengers to not have to change trains. But most trains going in those five directions start from or end at Tokyo Station, so trains from all directions concentrate between Tokyo and Omiya stations. Currently, trains depart from Tokyo Station in intervals of as short as 4 minutes, and running trains separately for each direction makes the section between Tokyo and Omiya a bottleneck to train traffic, preventing us from setting the required number of train runs. For that reason, Yamagata Shinkansen "Tsubasa" trains are coupled with Tohoku Shinkansen "Yamabiko" trains and Akita Shinkansen "Komachi" trains are coupled with Tohoku Shinkansen "Hayabusa" trains. Running two trains as one and uncoupling those at the junction stations reduces the number of runs between Tokyo and Omiya, allowing us to set the required number of train runs.

"Tsubasa" trains run on conventional line sections between Fukushima and Shinjo and "Komachi" trains run on conventional line sections between Morioka and Akita, so the rolling stock must be compliant with wayside equipment standards differing from those for Shinkansen sections. This is more than just an issue of size differences, as signal systems and other functions differing between Shinkansen and conventional lines must be able to handle both line types. We therefore face the issue of a need to fit much equipment into small size bodies. There are also difficult-to-overcome issues in terms of running performance in achieving both high-speed stability performance in Shinkansen sections and curving performance in conventional line sections as performance emphasized differs by line type.

Moreover, conventional line sections are in areas that see much snowfall in winter. Thus we are struggling with many technical issues in terms of severe winter environmental conditions.

Rolling stock for through service between Shinkansen and conventional lines operating in conventional sections with much snowfall saw snow accumulating on cars due to factors such as snow being thrown up when a train passes (Fig. 4). Snow accumulates particularly around the bogies where the body is recessed. If blocks of snow fall off while running at high speed in Shinkansen sections, that may damage wayside equipment and the like.

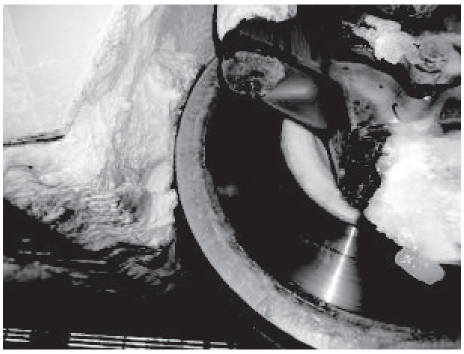

Fig. 4 Snow Accumulated on Bogie End Cover (From paper in this Issue)

Snow was knocked off manually at Morioka Station so as not to bring it into Shinkansen sections where trains travel at high speed, but heaters to prevent snow from accumulating had been developed in the past as a rolling stock-side countermeasure. But even with the series E6 equipped with the developed heaters, snow would still accumulate on cars when the amount of snowfall was large, so we worked on development for further improvements. In "Improvement of Bogie End Covers with Heater System for Shinkansen Rolling Stock" introduced in this issue, we introduced measures that did not involve increasing the amount of heat from the heaters. We studied and built prototypes to enable heat to be effectively used by improving the covers, and we confirmed the effects.

Ground coils of signal equipment is one example of wayside equipment damaged by blocks of snow falling while running (Fig. 5).

In "New Shinkansen Position Correcting Ground Coil for Further Speed Increases" in this issue, we introduce development of ground coils installed on the rail side to transmit to cars information for correcting position. Development centers on ensuring instantaneous transfer of data between the train and wayside when a train running at high speed passes over a ground coil so as to be able to handle further speed increases. However, to avoid of risk of snow accumulated on rolling stock falling and striking wayside equipment, a risk that becomes larger with speed increases, we also examined lowering the height of ground coils in relation to top of concrete slabs. Along with that, we investigated the impact on wireless transmission quality between ground coil and onboard antenna that rebar in slabs has as distance between slab face and ground coil become shorter.

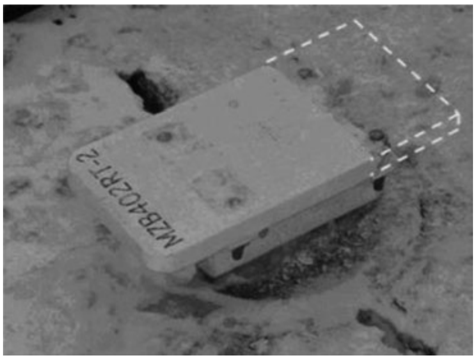

Fig. 5 Damaged Ground Coi (From paper in this Issue)

In Shinkansen sections with much snowfall, sprinkler snow melting equipment is installed at time of construction to prevent buildup of snow. Water for sprinklers is heated to about 10 ºC, and fuel (kerosene), consumption by heaters becomes enormous, so reducing running costs and CO_2 emissions becomes an issue. In basic investigation for energy conservation by sprinkler snow melting equipment, we measured temperature at individual parts of a viaduct at sprinkling, and confirmed items such as where the heat is consumed. As a result, we were able to gain findings that will prove to be useful reference information in making sprinkler snow melting equipment more energy efficient.

Along with snow, rolling stock needs to be able to handle a wide range of temperatures. Rolling stock has much equipment that requires lubrication, and that is becoming even more important particularly for bogie equipment related to running of trains. We are aiming for further improvement of functionality of that machine lubrication oil as well. In development of gear oil for the Shinkansen compatible with low temperatures, we assumed speed increases while striving for further compatibility with low temperatures and set an objective of keeping cost increases under control. Results of functional tests have been good, and verification of durability is currently underway.

3 Striving for Improved Efficiency and Service Levels

In addition to the technical issues covered up to this point caused by sections and forms of operation, we are also working on R&D for improving efficiency and service levels. The following introduces some of those efforts.

3.1 More Efficient Maintenance of Rolling Stock Equipment

To keep passengers from feeling discomfort such as popping ears when a train passes through tunnels, Shinkansen rolling stock has a structure where air is confined in the cabin (airtight structure) in order to alleviate abrupt pressure fluctuation. Cabin ventilation is necessary, however, so forced ventilation is done by ventilation equipment.

Filters are installed on the air intakes of ventilation equipment to prevent dust intrusion. But they become clogged with continuous use, causing problems such as reduction in cabin pressure, so they need periodic maintenance. In "Development of Cyclone Dust Collector for Shinkansen Trains" introduced in this issue, we developed a dust collector that uses a cyclone system (Fig. 6) similar to that commonly used in home vacuum cleaners recently.

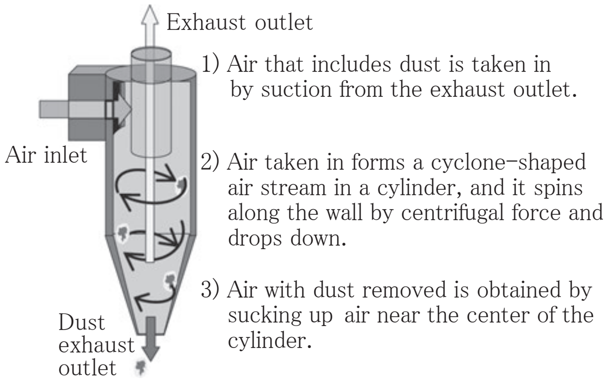

Fig. 6 Mechanism of Ordinary Cyclone Dust Collector
(From paper in this Issue)

3.2 Simplification of Structure and Renewal of Aged Equipment

Handling renewal of equipment has also become an issue. Civil engineering structures are scheduled for major renovation from 2031, but overhead contact lines supplying electricity to rolling stock via pantographs too are approaching timing for updates, and the method of updating those is being studied.

Compound catenary equipment (Fig. 7) consisting of three wires has been the standard type of overhead contact line structure for Shinkansen trains running at high speed. But with changes such as advances in wire materials and reduction in number of pantographs per car, simple catenary equipment that is simplified to a two-wire composition can now be selected. In "Simplification of Structure of Shinkansen Overhead Contact Lines" efforts introduced in this issue, we selected wire materials and made desktop studies such as simulations with an aim of changing to simple catenary equipment at time of renewal. And from running tests at 320 km/h, we obtained results similar to those of simulations and otherwise confirmed that there would be no problems in terms of performance. Maintenance reduction effects such as simplification of renewal work and equipment can be expected with this technology, and will work to further development.

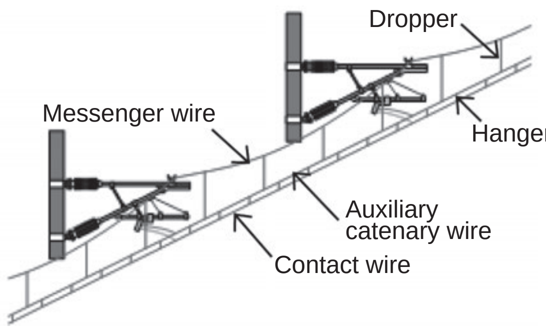

Fig. 7 Compound Catenary Equipment
(From paper in this Issue)

3.3 Identification of Detailed Transport Needs

A variety of customer needs are considered for timetables of the Shinkansen handling high-speed and large-volume transport in planning such as timetable updates done about once a year and setting of special seasonal trains. Results of usage per train is important data in addition to transport capacity per day for planning taking into account needs according to time of day. For this, we have identified the number of people per cross-section of transport using passenger volume reports where conductors count the maximum number of people in a predefined section.

Meanwhile, automatic ticket gates have been introduced at JR East Shinkansen stations where data read when judging validity of tickets is stored, and that data is utilized in a Shinkansen onboard ticket examination system to eliminate the need to check tickets for reserved seats. Research has been conducted since fiscal 2002 on a method to ascertain stations where passengers board and debark and the trains they use. This is done by consolidating and analyzing data of automatic ticket gates at each station. Estimation by a method using this data allows us to obtain data on where a passenger rides the train to and from and enables more detailed analysis than with passenger volume reports.

In "Study on Improvement of Estimation Accuracy of a Shinkansen Passenger Simulator" introduced in this issue, we identified train cancelations and delays that could not be reflected by past methods and otherwise increased the data used and improved the algorithm. Furthermore, we compared estimations with measurement data in order to verify accuracy. Possibilities are expanding for improving service by utilizing estimation data, such as combining outside data to predict the future and utilizing data to provide various data to customers.

4 Conclusion

Here we have introduced some of the R&D at JR East related to the Shinkansen. We would like to express our gratitude to related research agencies, manufacturers, and others who have been cooperating with our R&D efforts. And we would like to continue to promote open innovation while working in partnership with others.

2017 marks a commemorative year for JR East's Shinkansen services starting with the 20th anniversary of the opening of the Akita Shinkansen on March 22 and followed by the 35th anniversary of the opening of the Tohoku and Joetsu Shinkansen. Those involved in Shinkansen development will continue to improve on the technologies we have realized up to now as well as pursue new possibilities and go forward with R&D for the next generation of Shinkansen in order that customers use the Shinkansen for years to come as a valuable means of mobility.