Technical Development for Shinkansen Speed Increases

Minoru Ogasawara
Director, Advanced Railway System Development Center, Research and Development Center of JR East Group

JR East launched the Shinkansen High-speed Project in April 2002, aiming at improvement of service in the expanded Shinkansen network, improvement of competitiveness with airlines and achieving world-class high-speed rail technology. To achieve those goals, we are carrying out technical development for faster Shinkansen trains under the themes of higher running speed, assurance of safety and reliability, comfort improvement and environmental compatibility, with a goal of the world’s fastest operation speed of 360 km/h. We have built the Shinkansen high-speed test car sets FASTECH360S (exclusive for Shinkansen) and FASTECH360Z (for through service on Shinkansen and conventional lines) and also improved wayside equipment to implement comprehensive verification of rolling stock and wayside equipment under actual load in the actual operating environment. High-speed running tests have continued since June 2005, mainly in the section between Sendai and Kitakami on the Tohoku Shinkansen line. Based on assessment of the technical development and cost performance achieved up to 2007 against the operation start of Shin-Aomori station planned at the end of FY 2010, we have announced that we will gradually increase speeds from the end of FY 2010 to operate all Hayate and Komachi type Shinkansen at 320 km/h at the end of FY 2013. In this paper, I will introduce the past developments and the issues for further speed increase.

1 Introduction

The Shinkansen of the JR East network extends from Tokyo in five directions with the Tohoku, Joetsu, Nagano, Yamagata/Shinjo and Akita Shinkansen linking main cities in our operational area. We are planning to open Shin-Aomori station in FY 2010 and Shin-Hakodate station in FY 2015 on the Tohoku Shinkansen and Toyama and Kanazawa stations on the Hokuriku Shinkansen in FY 2014. Looking at world high-speed railways, ICE in Germany and TGV in France started running at 300 km/h some years ago, and TGV Est Europeene that opened in June 2007 runs at 320km/h. So, it is safe to say that world’s high-speed railways have entered in the area of over-300 km/h operation.

Under these circumstances, we are aiming at improvement of service in the expanded Shinkansen network, improvement of competitiveness with airlines and the top level of high-speed technology in the world. To achieve that we are carrying out technical developments for faster Shinkansen trains centering on higher running speed, assurance of safety and reliability, comfort improvement and environmental compatibility, with a target of a top operation speed of 360 km/h.

Fig. 1 Development Subjects for Shinkansen Speed Increase

In April 2002, we launched the Shinkansen High-speed Project. Specifically, we have built FASTECH360S and FASTECH360Z Shinkansen high-speed test trains and also improved wayside equipment to implement comprehensive verification of rolling stock and wayside equipment under actual load in the actual environment. The high-speed running tests with those trains have been ongoing since June 2005.

Fig. 2 Development Process of Shinkansen Speed Increase

Test running is now underway mainly in the section between Sendai and Kitakami on the Tohoku Shinkansen. We are conducting tests with FASTECH360S, exclusive for the Shinkansen, also in the section between Morioka and Hachinohe and tests with FASTECH360Z for through service on Shinkansen and conventional lines on the Akita Shinkansen. The test items are running performance evaluation, environmental assessment, passing tests, coupling tests and durability assessment.

FASTECH360 is series of test train sets with the concept of being “a prototype for rolling stock running at 360 km/h”, “an experimental platform to clarify phenomena intrinsic to high speed running” and “a stage to offer comfortable moving space in near future”. It consists of two train sets, the FASTECH360S exclusive for the Shinkansen and the FASTECH360Z for through service on Shinkansen and conventional lines.

Fig. 3 High Speed Test Plan
2.1 FASTECH360S Exclusive for the Shinkansen

The test car set exclusive for the Shinkansen has the series code E954. The 6M2T train set consists of eight cars; trailers with a cab at both ends and six motor cars in between. The trailers have a long nose 16 m in length to control tunnel micro-pressure waves, and the shapes of the noses of the trailers at each end are different to each other to compare the wave control performance. Other visual characteristics include equipment for increasing air resistance, a smooth cover between cars, noise absorbing panels under cars, and cantilever single arm pantographs.

Main circuit consists of three units, one unit per two cars. Those units have different systems from each other for comparison purposes.

To improve ride comfort in curves, the train is equipped with air spring stroke type of car body tilting system with a maximum incline angle of two degrees.

2.2 FASTECH360Z for Through Service on Shinkansen and Conventional Lines

The test car set for through service on Shinkansen and conventional lines has the series code E955. The train set consists of six cars. Both trailers have trailing bogies, but the bogies on the opposite side of the cab of each trailer and all middle bogies are driving bogies, so the MT ratio of the train set is 5M1T. The main equipment for high speed running and environmental measures of the FASTECH360Z is common with that of the FASTECH360S, except for having a smaller car body and equipment for through service on Shinkansen and conventional lines.

In order to achieve fast running performance on Shinkansen lines and curve performance on small-radius curves on conventional lines, bogies of E3 series cars for Shinkansen and conventional lines have a 2,250 mm wheelbase. However, the FASTECH360Z has a 2,500 mm bogie wheelbase, the same as bogies of the test car exclusive for the Shinkansen, emphasizing stability in fast running. Instead, FASTECH360Z achieves a smaller damping force with switchable yaw dampers in running on conventional lines to reduce the lateral force at small-radius curves.

3.1 Higher Running Speed

3.1.1 Current Collection System

Since current collection devices account for a large percentage of wayside noise made in high speed running, we have developed a current collection system with one pantograph per train set (currently two pantographs per train set). Also, we have developed a new low-noise pantograph that has a pantograph head with multi-segment slider. That can flexibly follow vibrating overhead slider by supporting each fractionated part of the slider with springs. This development enables extremely stable current collection even in fast running, along with lighter weight and higher tension of contact wire according to speed range.

3.1.2 Drive System

In order to achieve stable high speed running, we have developed many types of high-output small and light main circuit systems with differing characteristics in their motor system and cooling system. Every type of developed system has shown the required performance in test running so far without major problems. They are now in the evaluation phase from the perspectives of durability, maintainability and cost.

3.1.3 Torque Control and Brake Control of Train Sets

We have built an on-board information network and equipped trains sets with a car information control unit that transmits control commands and controls devices. In order to effectively send drive force and braking force of the wheels to rails by making full use of traction in the high speed range, we use a unit developed to make the optimal torque and brake distribution based on the axle position in the train set in case of wheel slip or slide. That can secure accelerating force and braking force for the whole train set.

3.2 Securing Safety and Reliability

3.2.1 Reliability of Bogies and Bogie Components

In order to meet the increased load on bogies and bogie components with higher running speeds, we have designed a bogie frame and a wheelset based on data of past test cars (performance confirmed up to 425 km/h) and developed new types of a basic brake devices, axle bearings, drive devices, etc. The reliability of those components was verified by a 600,000 km durability test using our bogie testing machine before production of FASTECH360. Also, in order to monitor condition of bogies in fast running, we developed a new bogie monitor that can detect abnormal vibration of bogies and abnormality of axle
bearings and drive devices.

Those bogies and bogie components will be evaluated for durability and maintainability by running 600,000 km on operational lines by the end of FY 2008.

3.2.2 Running Safety
Running safety indicators (axle load, lateral force, derailment coefficient) in fast running were confirmed to be without problems through running tests using an actual operational train up to the 400 km/h range.

We optimized support stiffness on both sides of the axle boxes and also on both sides of the air springs of the FASTECH360Z and verified necessary wayside improvements to achieve the required curve performance on small-radius curves on conventional lines.

3.2.3 Safety Against Natural Disasters
1) Safety in Running in Case of Earthquake
Since the start of the project, we have recognized safety in case of earthquakes as an important issue for increasing speed. Based on lessons learned from the derailment of the Joetsu Shinkansen in the Mid Niigata Prefecture Earthquake in 2004, we achieved faster sending of emergency braking commands (shorter detection time of power failure of overhead contact lines) and developed a deviation prevention car guide that prevents deviation of cars from the track even in case of derailment. Those developments are already deployed to cars presently in operation.

In order not to cause increased risk in case of an earthquake with greater speeds, we have improved the train set braking force control that makes full use of traction of each car of the train as well as braking control in wheel slip or sliding. And also we have developed an unconventional braking method using equipment for increasing air resistance. We have confirmed that these developments enable 4,000 m emergency braking even when running at 360 km/h; and this distance can be achieved by the basic brakes alone at up to 340 km/h.

2) Countermeasures against Snow Disasters
Falling of snow off Shinkansen cars in fast running can damage wayside equipment and cars. So, to reduce the volume snow adhesion on cars, we are testing a bogie structure that is difficult for snow to adhere to, a snow melting heater and an expanding and retracting boot.

We are also developing a method to melt the snow on cars carried from conventional lines in regions of heavy snowfall using hot water jets from the ground.

3.2.4 Effect of Increased Speeds on Wayside Equipment
As for the effects of increased speed on wayside equipment such as tracks, overhead contact lines and civil engineering structures, we concluded that major modification is not necessary for tracks and civil engineering structures by determining required reinforcement and other modifications. For overhead contact lines, we decided that some modifications such as increase of tension based on the speed and change of the wire type of contact wire are required to secure current collection performance.

3.2.5 Effect of Train Draft
We were concerned that train draft of faster trains could affect passengers on the platform and maintenance staff; but the tests up to now showed that the affect would not be much worse than at present. This is thought to be due to the shape of the train head and the smoother car body.

3.3 Environmental Compatibility

3.3.1 Noise Control
Noise control an important issue for increasing Shinkansen speeds. So, we conducted a range of elemental development before production of the FASTECH360, and also carried out data analysis by acoustic exploration and other examination after starting the running tests, with an aim of improving noise control performance. The main rolling stock improvements are aerodynamic noise control of pantographs by reducing noise at pantograph frames, single arm type low-noise pantographs, pantograph noise insulating panels (FASTECH360Z uses retractable noise insulating panels due to the rolling stock gauge of conventional lines), smooth cover between cars, smoother handles of the cab door, snowplow covers, special high voltage cabling, plug-type doors, aerodynamic noise control for bogie covers, and development of noise absorptive structures for skirts of the underpart of the car body and the underfloor part.

As for spot improvement of wayside equipment, we have conducted technical development of a new noise barrier that has a higher diffracting attenuation effect by improving the upper part of the barrier.

With those noise reduction improvements, the noise level of the coupled FASTECH360S and FASTECH360Z could be significantly lowered compared to the level of the coupled E2 series Shinkansen cars for Hayate and E3 series Shinkansen cars for Komachi; but the running speed did not reach 360 km/h. In particular, it is very difficult to reduce the noise for the FASTECH360Z for through service on Shinkansen and conventional lines due to severe size limits of the car body. In other words, the total noise reduction level depends on the Shinkansen cars for through service. To achieve 360 km/h running, we need further theoretical and empirical approaches such as more effective noise reduction of and around pantographs and noise caused by structures.

Since some noise reduction approaches involve increase of cost and weight, we are evaluating the contribution of each approach along with the technical improvement in noise reduction. Concurrently, we are working on development to improve the reliability, durability and maintainability of the retractable noise insulating panels.
3.3.2 Control of Tunnel Micro-Pressure Waves

Tunnel micro-pressure waves are a phenomenon whereby a fast-running train causes pressure waves at entering a tunnel and the pressure waves are transmitted through the tunnel at the speed of sound, discharging at the end of the tunnel to generate an explosive sound and shake house fittings.

The tunnel micro-pressure waves that increase as the running speed of Shinkansen increases need to be kept under the current level, but it is impossible to achieve that at the speed range of 360 km/h only by the improvement of cars. Accordingly, we have developed under a policy of making improvements to cars as much as possible and supplementing that by improvement of wayside equipment.

We compared two types of long noses (arrow-line and streamline) 16 m in length for the FASTECH360S along with two types of long noses 13 m and 16 m in length for the FASTECH360Z. The comparison clarified that the arrow-line type long nose has higher micro-pressure wave control performance; that the shapes of the 16 m-long nose of FASTECH360S and the 13 m-long nose of FASTECH360Z have equal micro-pressure wave control performance; and that tunnel entrance hoods according to speed range initially predicted is required. For wayside improvements, we are working on technical development for a tunnel entrance hood with ducts and a light-panel tunnel entrance hood to reduce cost.

3.4 Improvement of Comfort

3.4.1 Ride Comfort

In order to bring about drastic reduction of horizontal and vertical vibration in high speed running, we made a complete review of the specifications and features of Shinkansen bogies and made many adjustments through running tests. Furthermore, we changed actuators of car body vibration protectors from air type to electromagnetic direct driven type and roller spring type to improve the response and control characteristics, improving on horizontal vibration that comes with increased speed. Those resulted in better ride comfort with the FASTECH360S than that of the present E2 series Shinkansen running at 275 km/h.

For better ride comfort in curves, we introduced an air spring stroke type of car body tilting system that has a simple structure. This enabled faster speed in curves (330 km/h or more at R = 4,000 m, 360 km/h or more at R = 6,000 m), while controlling excess centrifugal acceleration. To prevent rolling in curves, we adjusted the rolling stiffness and air spring incline. And as a way to prevent car body vibration in tunnels caused by aerodynamic excitation in coupled operation, the anti-vibration device control method was improved on for better ride comfort.

Those improvements brought about higher comfort level than that of present Shinkansen cars running at 320 km/h. But the level at 360 km/h is still not satisfactory, thus remaining as an issue to tackle for the future.

3.4.2 Improvement of Quietness

Maintaining quietness even in high-speed running is important for passenger comfort. With an aim at achieving a level of quietness where passengers can talk as usual on the train even at 360 km/h, we improved sound insulation of the car body (side windows, side panels, ceiling, floor) and reduced noise from air conditioning devices and underfloor devices. Those improvements achieved a noise level in the passenger room at 360 km/h equal to or less than that of the E2 series at 275 km/h, which is sufficiently quiet in practical terms.

4 Future Technical Development

On November 6 2007, we announced that we would gradually increase speeds from FY 2010 to operate all Hayate and Komachi type Shinkansen at 320 km/h at the end of FY 2013. This is because we determined that speed up to 320 km/h would be reasonable in terms of environmental measures and cost performance for the time being, based on the test results for FASTECH360. In this context, we are planning to design and manufacture advance mass-production Shinkansen rolling stock with car performance for 320 km/h running, with an eye at the start of operation of Shin-Amori station on the Tohoku Shinkansen. Performance tests and durability tests will be performed for two years from FY 2009. We plan to settle on specifications for rolling stock for through service on Shinkansen and conventional lines based on the evaluation results of the FASTECH360Z running tests.

In the future, first we will make in-depth adjustments and durability verification to ensure commercial operation at 320 km/h.

We have postponed 360 km/h running for now; but we will still keep working at technical development for further speed increases. Issues to tackle in the efforts to reach 360 km/h levels have been identified through research and development for the FASTECH360; but at the same time, it is clear that the hurdles for remaining issues are very high. We can not deal with those overnight; but for the next leap, we are going to address further basic studies to clarify many phenomena, research new approaches including attempts from new perspectives and research cost reduction of wayside countermeasures based on experiences with FASTECH360.

And also we will address technical development for changing the Shinkansen network system.