Interpretive article

Technical Development by FASTECH360

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The Research and Development Center of JR East Group launched the Shinkansen High-speed Project in April 2002 for Shinkansen speed increases, building the FASTECH360S type E954 Shinkansen high-speed test train in June 2005 and the FASTECH360Z type E955 in April 2006. Those were used for various running tests up to June 2009 with a technical target of 360 km/h operating speed to further R&D. This article will introduce an overview of the results gained and their application to the series E5 Shinkansen exclusive rolling stock and series E6 rolling stock for through service on Shinkansen and conventional lines that were manufactured as pre-mass production Shinkansen rolling stock.

The article will also introduce issues for the future. Those are broken down into verification for assured 320 km/h operating speed, technical research for further speed increases, technical development to handle the expansion of the Shinkansen network and technical development for changing Shinkansen systems.

1 Introduction

The Shinkansen High-speed Project for increasing the speed of Shinkansen trains started in April 2002. Our challenge began then in the following areas:

- Improvement of service in the expanded Shinkansen network
- Improvement of competitiveness with airlines
- The top level of high-speed technology in the world

We thus developed the FASTECH360S in June 2005 and the FASTECH360Z in April 2006 to carry out technical development for faster Shinkansen trains centering mainly on higher running speed, assurance of safety and reliability, comfort improvement and environmental compatibility. The goal of such development was a top operating speed of 360 km/h.

We built those 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 were conducted from June 2005 to June 2009.

We conducted tests on the Tohoku Shinkansen, using the FASTECH360S in the section between Morioka and Hachinohe and the FASTECH360Z between Sendai and Kitakami. The tests performed were running performance evaluation tests, environmental assessment tests, passing tests, coupling tests and durability assessment tests.

Disassembly studies were also conducted in October 2008 for the FASTECH360Z and August 2009 for the FASTECH360S. The purpose of that was to apply results in future Shinkansen rolling stock design.

We went beyond just rolling stock in development for increasing Shinkansen speed, also confirming the effect on current trackside. A variety of technical development was conducted on overhead contact lines that can be tracked by pantographs passing at high speed and tunnel hoods that reduce micro-pressure waves occurring when entering a tunnel at high speed. It is no exaggeration to say that such development was made possible by the cooperation and technical know-how of many people involved. The results of the tests led to series E5 for which running tests started in June 2009 and the series E6 for which running tests started in July 2010.

2 Main Technical Development Details for Shinkansen Speed Increases

2.1 Improvement of Running Speed

Fig. 1 Overview of the FASTECH360 (Improvement of Running Speed)

2.1.1 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 used 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 contact lines by supporting each part of the slider with springs. This development also enables extremely stable current collection even in fast running by having lighter weight and higher tension of contact wire according to speed range.

For the series E5 and E6, we employed the resulting new low-noise pantograph that has a pantograph head with multi-segment slider, and operation is done as a rule with just one pantograph. In conjunction with that, we are working on renovations for higher tension of contact wire on the Tohoku Shinkansen between Usunomiya and Morioka ahead of 320 km/h operation there at the end of FY 2013.

2.1.2 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. All of the developed systems have shown the required performance in test running so far without major problems.

2.1.3 Torque Control and Brake Control of Train Sets
We have built an on-board information network and equipped train sets with a car information control unit that transmits control commands and controls devices. Using that, we have been able to make full use of adhesion in the high-speed range for a method of controlling optimal torque and brake distribution based on the axle position in the train set in case of wheel slip or slide. We have confirmed the effectiveness of that method that can secure accelerating force and braking force for the whole train set.

The developed results have been applied to the series E5 and E6. And those results have contributed to improved ride comfort.

2.2 Ensuring Safety and Reliability

![Fig. 2 Overview of FASTECH360 (Ensuring Reliability)]

2.2.1 Reliability of Bogies and Bogie Components
In order to meet the increased load at higher running speeds, we have designed and developed new types of basic brake devices, axle bearings, drive devices, etc. based on data for up to 425 km/h gained from the STAR21 test cars built in the past. The reliability of those components was verified by a 600,000 km durability test, a test at the same running distance for bogie inspections, using our bogie testing equipment before production of FASTECH360. We also developed a new monitoring system that can detect abnormality in bogie vibration, axle bearings and drive devices in high-speed running.

We achieved a total running distance of 600,000 km with FASTECH360S on operational lines up to June 2009 and confirmed that there were no problems in terms of durability and maintainability.

We also adjusted the axle boxes and air springs so performance is optimum both when running at high speed in Shinkansen sections and when passing through curves in conventional line sections.

The developed basic brake devices, axle bearings, bogie monitors and other devices were employed on the series E5 and E6 Shinkansen.

2.2.2 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 longitudinal sides of the axle boxes and also on both longitudinal 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.

2.2.3 Safety against Natural Disasters
1) Safety in Running in Earthquakes
Since the start of the Shinkansen high-speed project, we have recognized safety in 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 conducted development for shortening the emergency braking distance (shorter detection time of power failure of overhead contact lines) and L-shaped deviation prevention car guides that prevent cars from deviating from the track even in derailment. Those developments are already deployed to rolling stock presently in operation.

In order not to cause increased risk in an earthquake with greater speeds, we have improved the train set braking force control that makes full use of adhesion of each car of the train as well as braking control in wheel slip or slide. We have also developed an unconventional braking method using equipment for increasing air resistance. We have confirmed that those developments enable 4,000 m emergency braking even when running at 360 km/h, and
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 of snow accretion on cars, we tested a bogie structure that is difficult for snow to adhere to, a snow melting heater and an expanding and retracting boot. We have confirmed the effectiveness of the snow melting heater as a result of the tests. To confirm durability ahead of practical implementation, we are verifying using series E3 rolling stock of Komachi trains for through service between Shinkansen and conventional lines.

We have also confirmed a certain level of effectiveness with a method to melt the snow on cars carried from conventional lines in regions of heavy snowfall. That method uses hot water jets from the ground.

2.2.4 Effect of Increased Speeds on Wayside Equipment
As for the effect 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 according to speed range and in some cases lightening of the contact wire are required to secure current collection performance.

The top operation speed of series E5 and E6 rolling stock is 320 km/h, so the only modification we made was increase of tension.

2.2.5 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 effect would not be much worse than at present. This is thought to be due to the shape of the nose and the smoother car body.

2.3 Consideration for the Environment

2.3.1 Noise Control
Noise control is an important issue for increasing Shinkansen speeds because it is particularly important in Japan to keep down noise along railway lines. So, we conducted a range of elemental development before production of the FASTECH360. We 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 low-noise pantographs ("e" shaped arm and single arm types), pantograph noise insulating panels (retractable noise insulating panels with FASTECH360Z due to the rolling stock gauge of conventional lines), smooth cover between cars, smoother handles of the cab door, snowplow covers, relocation of special high voltage cabling under the roof, plug-type doors and development of noise absorptive structures for skirts of the underpart of the car body and the underfloor part. As for 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 FASTECH3605 and FASTECH3606Z at the planned 320 km/h operating speed for the series E5 and E6 could be significantly lowered compared to the level of the coupled series E2 rolling stock for Hayate trains exclusively for Shinkansen and series E3 rolling stock for Komachi trains for through service between the Shinkansen and conventional line at the current operating speed of 275 km/h. But noise could not be kept at current levels at 360 km/h. In particular, it is very difficult to reduce noise for the FASTECH360Z due to severe size limits of the car body. In other words, the total noise reduction level depends on the 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.

For the series E5 and E6, we adopted smooth full covers between cars, smoother handles of the cab door, special high voltage cabling relocated under the roof, plug-type doors and noise absorptive structures for skirts of the underpart of the car body. We are currently making final checks on the effects of those with the series E5 and E6.

2.3.2 Control of Tunnel Micro-pressure Waves
Tunnel micro-pressure waves are generated when a fast-running train enters a tunnel. Those pressure waves are transmitted through the tunnel at the speed of sound and discharged at the end of the tunnel to generate an explosive sound and cause vibrations in building 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 conducted development 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. And we conducted comparison tests with arrow-line long noses 13 m and 16 m in length for the FASTECH360Z. We found that the arrow-line type long nose has higher micro-pressure wave control performance and that the shapes of the 16 m-long nose and the 13 m-long nose of FASTECH360S have equal micro-pressure wave control performance. We also confirmed that tunnel entrance hood measures according to speed range are 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, applying that to improvements for 320 km/h operation.

2.4 Improvement of Passenger 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 the active suspension system 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 even while running at 360 km/h than that of the present series E2 rolling stock for Hayate trains running at 275 km/h.

For better ride comfort in curves, we introduced an air spring stroke type car body tilting system. 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, and thus it remains as an issue to tackle for the future.

The active suspension system and body tilting system were both applied to the series E5 and E6 Shinkansen. Those contributed to improved ride comfort.

2.4.2 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, and floor) and reduced noise from areas such as air conditioning devices and underfloor devices on FASTECH360 high-speed test cars. Those improvements achieved a noise level in the passenger cabin at 360 km/h equal to or less than that of the series E2 rolling stock for Hayate trains at 275 km/h, which is sufficiently quiet in practical terms. The series E5 and E6 Shinkansen were built taking that structure into consideration.

At the end of 2007, we announced that we would gradually increase speeds of trains using series E5 and E6 rolling stock on the Tohoku Shinkansen, going from 300 km/h in FY 2010 to 320 km/h by 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, the series E5 and E6 are designed and manufactured with car performance of 320 km/h running, the fastest in Japan. Series E5 (10-car train sets) pre-mass production rolling stock (Fig. 5) was completed in June 2009, and series E6 (7-car train sets) pre-mass production rolling stock (Fig. 6) was completed in July 2010.

Characteristics of the pre-mass production rolling stock are as follows.

1) Environmental performance
   - Long nose shape
   - Noise absorptive structures for skirts of the underpart of the car body, smooth full covers between cars, low-noise pantographs (“<” shaped arm and single arm types)
2) Improved running performance and securing reliability
   - Main circuit devices, pantographs, brake devices
3) Improvement of comfort
4.1 Verification for Assured 230 km/h Operation
Operation at 320 km/h will be performed on the Tohoku Shinkansen at the end of FY 2013 using series E5 and E6 rolling stock. To assure such 320 km/h operation, we have run cars approx. 600,000 km (the bogie inspection cycle) and confirmed durability and conducted disassembly studies of items developed and equipped to the FASTECH360S. By doing so, we verified data required for future maintenance and applied the results to design of partially modified pre-mass production rolling stock.

We are also carrying out performance tests and durability tests over a period of two years from FY 2009. Those are done using series E5 pre-mass production rolling stock designed and built for 320 km/h rolling stock performance.

4.2 Technical Development for Further Speed Increases
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 by running cars approx. 600,000 km (the bogie inspection cycle of Shinkansen rolling stock). Specific items we will have to take on are as follows.

1) Improvement of running speed
For power collection, change to lightened contact wires is needed at speeds in excess of 320 km/h.

2) Securing safety
The following development is being conducted to assure safety.
   - Modification of characteristics of lateral dampers that improve performance in resistance to derailment as a countermeasure against earthquakes
   - Improvement of snow plowing ability by increasing strength of auxiliary life guards, etc.
   - Identification of correlation of track displacement and running safety at high speeds

3) Consideration for the Environment
Compatibility with the environment, especially countermeasures against noise, is an important issue for further speed increases. Proper systematic organization from the basic study phase such as analysis of noise sources and degree of contribution to overall noises generated is needed as specific content of development.
   - Analysis of degree of contribution by the noise sources and elemental development of countermeasures
   - Clarification of mechanisms of generating structural sound, ground vibration and low frequency sound and development of countermeasures for those
   - Improvement of reliability of movable pantograph noise insulating panels devices
   - Development for reducing cost of tunnel hoods

4) Improvement of passenger comfort
We conducted many tests with the FASTECH360 for improving...
rolling stock comfort. The following development will be conducted for improving comfort in high-speed running.

- Development of countermeasures for body rattling vibration
- Development for improving body tilting systems to improve ride comfort in curves
- Development for aerodynamic improvement of lead cars and improvement of vibration control devices to improve ride comfort in tunnels in coupled operation of Shinkansen and conventional line rolling stock

The hurdles for remaining issues are very high, and we cannot deal with those overnight. We are going to address further basic research to clarify phenomena related to measures to reduce noise along lines, measures against tunnel micro-pressure waves and measures to improve ride comfort in curves. And we will take new approaches including attempts from new perspectives and research cost reduction of wayside countermeasures based on experiences with FASTECH360.

4.3 Technical Development to Handle the Expansion of the Shinkansen Network

The Tohoku Shinkansen was extended to Shin-Aomori in 2010, and it will also extend to Hakodate later. The Hokuriku Shinkansen is also to extend to Kanazawa. We are thus taking on R&D for that Shinkansen network expansion. Specifically, we plan to conduct development on the following items.

- Development of equipment and components that can handle anticipated low temperatures and snow and the high humidity and salinity in the Seikan Tunnel as measures for expansion of the Shinkansen to Hokkaido
- Effective noise countermeasures in flat land and excavated sections

Fig 8 Expansion of the Shinkansen Network

4.4 Technical Development for Changing Shinkansen Systems

It was in June of 1982 that the Tohoku Shinkansen opened between Omiya and Morioka. Since then, we have seen changes such as the opening of the Joetsu Shinkansen and its expansion to Tokyo, opening of the Nagano Shinkansen and expansion of the Tohoku Shinkansen to Hachinohe. The systems running the Shinkansen are very reliable, but we are still working on new technical development for those. Goals in such development cover topics such as further improvement of safety, security, reliability and comfort, reduction of the burden on the environment and changes to rolling stock and wayside equipment systems.

5 Conclusion

The top operating speed at the opening of the Tohoku Shinkansen was 210 km/h. That was later increased to 240 km/h then 275 km/h, and we will achieve the top operating speed in Japan to be 320 km/h at the end of FY 2012.

As one can perceive from the name, FASTECH360 high-speed test trains were developed with a goal at first of running at 360 km/h. Unfortunately, we have not yet reached the goal of 360 km/h operation. One may think that 360 km/h is “just” 40 km/h faster than the 320 km/h top operating speed that will be used from the end of FY 2012. But the excess centrifugal acceleration in curves that becomes greater proportionally to the square of the speed when increasing the speed must be controlled, effect on wheels and tracks minimized and ride comfort maintained. Also, many hurdles must be overcome in going forward with noise countermeasures such as how to keep down aerodynamic noise for which the sound source level increases to the sixth power of speed.

Railways can be expected to have a future in a post-carbon society and for conserving energy, and they produce great economic effects by shortening time distance. Moreover, the JR East 2020 Vision long-term management plan has a goal of “Expanding the Shinkansen network and increasing earnings from railway operations”. Increasing Shinkansen speed thus plays an important role in supporting JR East business.

We would like to take this opportunity to thank all who have assisted us in our efforts up to now. And we in the research and development sections further continue efforts in achieving 360 km/h Shinkansen operation.