Development of Basic Brake Equipment for High Speed Running

It goes without saying that development of brake equipment that can infallibly stop trains from high speeds is indispensable for increased speed of the Shinkansen. The basic brake equipment is the last resort for safety, and as such must have the definite performance and reliability to infallibly stop the train even when regenerative brakes fail. In this context, one of the requirements for the basic brake equipment is to infallibly bear the increased load that comes with higher running speed.

In current increase in Shinkansen speed, we also aimed to keep the emergency braking distance at the highest running speed under that for cars presently in operation, even after the speed increase. That way, we avoid increased risk in earthquakes that would come with the higher speed. Consequently, we have developed new brake equipment combining center-mounted brake discs, equal pressure brake lining and pneumatic calipers, and confirmed that the new brake equipment meets the required performance by bench tests and tests using an actual FASTECH train. In light of the test results, we have also made improvements to the new brake equipment in the area of noise reduction because the tests identified that the aerodynamic noise caused by the disc cooling fins of the newly deployed center-mounted brake discs accounts for a considerable percentage of the total noise. In this paper, we will give an overview of the development process and the results.

Keywords: Shinkansen, Speed increase, Brake, Noise

1 Introduction

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In current increase in Shinkansen speed, we also aimed to keep the emergency braking distance at the highest running speed under that for cars presently in operation even after the speed increase. That way, we avoid the increased risk in earthquake that would come with higher speed. So, we had to face the difficult task of increasing the initial speed braking while significantly increasing deceleration with emergency braking.

To overcome those issues, we changed the place where the discs are mounted to the wheels from the inner periphery to the center, developed an unprecedented equal pressure brake lining and changed the conventional hydraulic calipers to pneumatic ones.

The results of the bench tests and tests using an actual FASTECH train proved that the equipment developed meets the required performance. We also made improvements in noise reduction for the new brake equipment because tests clarified that the aerodynamic noise caused by the disc cooling fins of the newly deployed center-mounted brake discs accounts for considerable percentage of the total noise.

2 Structure of the Developed Basic Brake Equipment

2.1 Center-Mounted Brake Discs

Conventionally, all Shinkansen side brake discs are mounted to the wheels at the inner periphery as shown in Fig. 2. But such discs deform due to the heat by repeated braking, as shown in Fig. 1.

The heat-deformed discs cannot make even contact to the brake lining, and only the parts that are strongly pressed bear friction. In addition to causing uneven abrasion of the discs that shortens the abrasion life, that also causes localized heating of the discs that leads to brake fade and disc cracking.

To overcome those issues, we changed the position where the discs are mounted to the wheels from the inner periphery to the center (Fig. 2). Mounting at the center can drastically reduce the above-mentioned heat deformation and uneven pressing against the brake lining. As the result, the temperature rise of the discs by braking becomes even and the whole disc can efficiently absorb energy; and accordingly, less brake fade occurs.

On the other hand, center-mounted disc brakes bear risks that the inner periphery-mounted disc brakes do not. One of the risks...
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is that the mounted bolts are easily affected by heat, as the bolts are located near the friction sliding surfaces. Repeated expansion and contraction of mounted bolts by heat might cause too much increase and decrease of the axial force of the bolts due to the difference of the heat expansion coefficients of the bolts and the materials they are mounted to.

Therefore, we inserted sleeves and spring washers that have a specific heat expansion coefficient to the part of mounted of the bolts of center-mounted brake discs to avoid large changes of the axial force of the bolt due to heat. The temperature rise of the mounting bolts of center-mounted brake discs is around 200°C at high-load braking.

The other risk of the center-mounted brake discs is that the mounting bolts located at the center of the sliding surface of the disc might impact the brake lining if those bolts come off from the discs due to breakage or loosening. So, we added bolt stoppers in this development to prevent the mounting bolts from coming out as far as the sliding surface of the disc.

2.2 Equal-Pressure Brake Lining

As described before, uneven pressing of the brake lining to the brake discs has adverse effect on braking performance. Accordingly, we developed an equal-pressure brake lining for high speed Shinkansen that is different from that used for present cars, in addition to developing the above-mentioned center-mounted brake discs. As there is no exact definition of "equal-pressure brake lining", we here mean the brake lining that is improved so that the surface of the lining presses against the sliding surface of the disc as uniformly as possible.

The equal-pressure brake lining that was developed has an equalizer mechanism as shown in Fig. 3. That mechanism can generate uniform pressing force without fail on each small block of the segmented friction material. We developed two types of equal-pressure brake lining for FASTECH as shown in Fig. 4.

2.3 Pneumatic Brake Caliper

Present Shinkansen cars use hydraulic calipers that have hydraulic pistons located behind the brake lining. In this development, we introduced pneumatic brake calipers as used on conventional lines and eliminated pneumatic-hydraulic conversion. The purpose is to reduce the number of components by simplifying the structure and to make the total system lighter. This development eliminated the need for conventional use of pressure intensifiers. The weight could be reduced from the 380 kg of the hydraulic caliper system (caliper: 4 X approx. 70 kg, pressure intensifier: 2 X approx. 50 kg) to 340 kg for the pneumatic caliper system (4 X approx. 85 kg). That means an approx. 40 kg weight reduction per bogie.

Fig. 5 shows the two types of pneumatic calipers deployed on FASTECH.
Since conventional calipers have hydraulic cylinders behind the lining, they are easily affected by the heat of braking friction. In contrast, pneumatic calipers have air cylinders on the other side of the lever away from the friction surface; so, they are not affected by heat. That is the other advantage of the pneumatic calipers.

Pneumatic calipers for the Shinkansen were one of the elemental developments completed in FY 2000 and FY 2001. So, basic performance and functions of those, including response to wheel slide re-adhesive control, have been confirmed.

3 Bench Test Results

3.1 Test Conditions

In order to check the performance of the developed basic brake equipment, we carried out bench tests using a brake testing machine in advance of deployment to FASTECH. The test conditions were specified as follows for the main purpose of checking performance at rapid deceleration braking from the targeted FASTECH high speeds.

* Axle load equivalent to 14 t
* Highest speed for initial braking of 400 km/h
* Maximum deceleration of 5.04 km/h/s
* Tests repeated 80 times or more

3.2 Test Results

(1) Friction Coefficient

Fig. 6 shows the friction coefficient measurement results obtained in the bench tests. The results confirmed that the new basic brake equipment keeps a stable friction coefficient up to the 350 km/h range, while the friction coefficient of the present brake equipment fades down to approx. 0.2 in the high-speed range.

(2) Braking Distance

Fig. 7 shows the braking distance from the initial braking speed of 400 km/h in continuous emergency braking tests (bench tests). The test results show that the initial braking distance of the combination of present brake discs and brake lining is nearly 5,000 m and the braking distance becomes longer from the second braking. In contrast, the initial braking distance of the combination of center-mounted discs and equal-pressure brake lining is just over 4,000 m and the subsequent elongation of braking distance is gentle.

The brake lining of the present combination reached its limit of use after repeating the test three times, while the equal-pressure brake lining combined with the center-mounted brake discs remained in a usable condition after 10 times of testing.

(3) Rise of Disc Temperature

Fig. 8 shows the results temperature measurement at the center of the friction surface of the disc in emergency braking from high speed on the brake testing machine.

The test results proved that the present disc and the developed disc are almost equal in average surface temperature rise, but the developed disc shows very small variation in surface temperature rise compared to the present disc. This is probably the result of the combination of center-mounted discs and equal-pressure brake lining bringing about uniform contact between the discs and the lining. The highest acceptable temperature of the discs is 800°C, and the test results confirm that the newly developed brake equipment shows stable values with sufficient margin in relation to the highest acceptable temperature even in emergency braking from 360 km/h.
(4) Disc Deformation Volume
Fig. 9 shows the warping of the discs in the bench tests. As shown in the figure, the deformation at the outer periphery of the present brake disc (inner periphery-mounted) is around 2 mm, while the deformation of the center-mounted disc is a fraction of the deformation of the present disc at around 0.5 – 0.7 mm. That demonstrates the effect of the change of the mounting method.

4.3 Reducing Noise of Brake Disc Cooling Fins
While not an issue related directly to braking performance, we found that brake discs generated considerable noise during high speed running in the early stage environmental suitability tests for the E954 series. Since that noise was of a level that could not be ignored, we investigated the source and determined that the noise was aerodynamic sound caused by the cooling fins on the back of the brake discs when wheels rotate at high speed. Therefore, we changed the shape of the fins to reduce the incoming air.

This improvement lowered the aerodynamic sound from the brake disc cooling fins by around 9 dB at 360 km/h (Fig. 12). We confirmed that this improvement has almost no effect on the cooling performance.

4.1 Conditions in Long-term Use
We installed the developed basic brake equipment to a FASTECH train to test performance on actual cars including that in long-term use. Approx. two and a half years have past since the start of test running. While there has been some troubles such as defects in friction material of brake linings from some manufacturers, those have already been solved. As the FASTECH is a test train, we carried out emergency braking tests many times with its regenerative brakes off, yet the surface of discs remains in good condition.

4.2 Rapid Deceleration Emergency Braking Test
As noted in a different paper in this Technical Review, we measured the braking distance at rapid deceleration emergency braking from high speed—one of the main subjects of the current development —using an actual FASTECH train. The measurement results confirmed that the train could stop at the target 4,000 m after braking at around 340 km/h. To stop at 4,000 m at speeds higher than 340 km/h, the train has to use aerodynamic drag increasing devices too.