The track is constantly exposed to vertical and lateral deformation under repeated loading by trains. Periodic measurement of the resulting track displacement (track irregularity) and adequate repair are vital to ensure riding comfort and running safety. To meet this requirement, a track inspection train is effectively utilized.

Inspection of track displacement on the Shinkansen line is carried out by the track inspection car incorporated in the trainset of electric and track inspection train. “Doctor Yellow” having been used so far (Fig. 1) is based on the three-bogie inspection system and the maximum speed has been 210 km per hour according to the running performance.

In the initial phase of introduction, passenger cars also ran at this speed, and there was no problem. Subsequently, the speed of the passenger train has been increased, accompanied by the following issues:

- When the speed of the inspection train alone remains low, train scheduling is inconvenienced.
- In the inspection train, dynamic status of the track, contact wire and others while running are identified correctly, so it is hoped that running performance is as close as possible to the operating conditions of the passenger train.

For these two reasons, the speed of the track inspection car has needed to be increased.

This required commercial use of a two-bogie type inspection car free from running performance problems. To meet this requirement, we started development for commercial use using the train STAR21 and train E3 for KOMACHI, we started to develop a two-bogie type track inspection train that was the same as ordinary cars, and could get inspection performance and running performance on the practical level.

We succeeded in introducing an inspection train capable of running at 275 km per hour, the same speed as “HAYATE” and “KOMACHI” in 2002. This paper introduces the development of a new two-bogie inspection device mounted on the “East-i”.

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2 Two-bogie type track inspection method

The two-bogie type track inspection method and inspection equipment have been proposed in the References 1-2 by the Railway Technical Research Institute.

2.1 Asymmetrical coordinate method

As shown in Figs. 2 and 3, in the three-bogie type track inspection car used so far, rail displacement is detected at intervals of five meters on each car to find out the distance between the mid-position of a 10-meter long reference line and track, i.e. the track displacement of so-called 10-meter chord versine.

Fig 1: Doctor Yellow
By contrast, in the two-bogie inspection car, the car is arranged in the same way as the passenger train, as shown in Fig. 4. Rail displacement is detected at three axis positions. This will show track displacement, as shown in Fig. 5. This is called asymmetrical chord offset method. From the result of measurement according to the asymmetrical chord offset method, the 10-meter chord versine displacement used for practical track maintenance is calculated using the digital filter treatment method.

2.2 Rail displacement detector
The track displacement in the vertical direction (high/low displacement) can be measured by wheel displacement since the wheel is always in contact with the rail top surface. For displacement in the lateral direction (alignment and gauge), the wheel can run keeping a certain allowance between the right and left rails (movable clearance), as shown in Fig. 6. This makes it necessary to measure the rail position. Further, it is specified that the reference should be located 16 mm below the rail top surface. In the Shinkansen line, an optical rail displacement detector has been used in order to ensure safety during high-speed run, because this device is capable of detecting the position without bringing it in contact with the rail side.

Generally, springs and dampers are arranged between the wheel and bogie, and between the bogie and car body to ensure that the track displacement is not conveyed to the car body. If a rail displacement detector is mounted on the bogie or car body, displacement relative to the rail is produced by the deflection of these springs. This makes it necessary to install the detector on the measuring frame fixed on the axle box of the car, as shown in Fig. 7. The measuring frame and detector provides an unsprung mass.

In the three-bogie system, two sets of devices (on the right and left rails) were mounted on the bottom of each bogie, where a halogen lamp was used as a light source, and a pickup tube as a photoreceiver. In the two-bogie system, four sets of devices (front and rear wheels, right and left) must be installed on each bogie. Further, it was necessary to decrease the unsprung mass to ensure running safety for the purpose of providing a higher operation speed than that of the three-bogie system. Thus, the problem was how to reduce the size and mass of the device. The detector of the two-bogie system uses a semiconductor laser as a
light source. In the photoreceiver, a PSD (Position Sensitive Device) is used to detect the displacement. This has been configured as a compact and lightweight device; the size of one set is reduced to about half that of the conventional device, and the mass is decreased to about one eighth. The laser light is reflected 16 mm below the rail top surface and is received by the PSD of the photoreceiver.

Fig. 8 is a photo taken from below the floor. The right and left rail displacement detectors are shown in an upward slanting direction as viewed from the rail. Immediately above the rails on the right and left of the Figure, the photo also indicates magnetic sensors to be used when optical measurement is disturbed by the reflection of light caused by snow.

2.3 Laser reference equipment

In the three-bogie track inspection car, the length of the car body was as short as 17.5 meters, and track displacement was calculated by increasing the rigidity of the car body and using the car body as a reference. The two-bogie inspection car uses a normal car body with bending flexibility, so the deflection of the car body would cause an inspection error. Laser light is passed through the floor, and this is used as a reference for measurement.

The device comprises the phototransmitter of a He-Ne gas laser beam expander, multiple photoreceivers using a PSD, and a light blocking duct to be connected.

3 Development of East-i track inspection car

3.1 Overview

During the period from fiscal 1992 to 1995, we used the STAR21 to develop a commercial two-bogie inspection car. It was found that, in order to improve the rail displacement detection accuracy, measures had to be taken against electric and optical noise. Then improvements were repeated. When the Nagano Shinkansen line was opened for commercial operation in 1997, it became necessary to develop a lightweight inspection car based on the two-bogie system because of the smaller design load adopted there. Then a passenger train was modified and was built into Doctor Yellow.

Further, with the introduction of the new inspection train East-i (Fig. 9) based on Series E3 (cars for KOMACHI connecting Tokyo and Akita), which car run on conventional lines as well as Shinkansen sections capable of measurement at the maximum speed of 275 km per hour, we developed a new technology to ensure running safety and measuring accuracy while running at the maximum speed.

As discussed above, the measuring frame with a rail displacement detector is fixed on the axle boxes of the car. However, since the elastic deformation of the measuring frame causes vibration, the rail displacement detectors are displaced in the vertical direction relative to the rail. In this case, the detected position of the rail changes slightly, with the result of an inspection error. To avoid this problem, we took the following action:

<1> The measuring frame overhung from the wheel, and we reduced the amount of overhang. Accordingly, the following modifications were made based on the Series E3 cars:
- Reduction of the disk brake spacing (from 700 to 360 mm)
- Reduction of wheel diameter (from 890 mm to 820 mm)

<2> The cross sectional rigidity of the measuring frame was increased. Section modulus was increased to about three times that used for the STAR21 running test.

Figs. 10 and 11 illustrate the new inspection bogie.
3.2 Running test

During the period from November to December 1999, a prototype car was mounted on the Series E3 cars and a running test was carried out on the Shinkansen section and the section of through operation of Shinkansen trains on conventional lines (conventional line section connected with the Shinkansen, having a gauge of 1,435 mm converted from 1,067 mm).

In the Shinkansen section, we measured the maximum value on the positive and negative sides of the vertical displacement of the rail displacement detector at intervals of 0.25 msec. at a speed of 174 to 272 km per hour in the section between Sendai and Kitagami having an extension of 26 kilometers. As shown in Fig. 12, m + 3 \( \mu \) was below the target value of the vertical displacement of ± 2 mm. The inspection at a speed of 275 km per hour is considered to exhibit an accuracy of ± 0.5 mm, judging from the relationship between the vertical displacement of the detector and inspection error.

There was no problem with the wheel load and lateral force. The relationship among the average wheel load, average lateral force and speed is shown in Figs. 13 and 14. The wheel load was slightly greater than that of Series E3 cars. This is considered to be caused by the increase in the unsprung mass (0.6 t for each axle). It was greater than the mass, and dynamic influence can be considered. Lateral force was analyzed at the most conspicuous curve of R4000m in the Shinkansen high-speed section. No difference from the normal car was observed.

In the section of through operation of Shinkansen trains on conventional lines, measurement was made in the same manner as above in the section having an extension of 9 km at the speed of 80 to 130 km per hour out of the area from Akita to Ohmagari. The vertical displacement met the reference value of 4 mm in the section of mixed operation of Shinkansen trains and conventional lines. Further, wheel load and lateral force were greater than those of the ordinary car, depending on the track conditions, but there was no problem. The relationship between the average wheel load and average lateral force is given in Figs. 15 and 16.
3.3 Conclusion

A recently developed track inspection car has been built onto the next-generation inspection train East-i based on Series E3 to check final performance, and track inspection has begun.

Our next goal is to create an excellent maintenance framework worthy of the name of world’s best Shinkansen, based on the data measured at a speed of 275 km per hour.

References:

1) TAKESHITA Kunio: Development of Track Inspection Car for Protection of Future High-speed Railway, RRR, September 1987, pp. 7-12.


