High-Speed Track Inspection Car in New Dr. Yellow

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Summary

Multiple inspection trains called 'Dr. Yellow' have contributed greatly to the safety of Shinkansen lines. They inspect track, electrification, signaling, and electric communication every 10 days. The oldest one that Central Japan Railway Company (JR-Central) is now in using needs replacement because of deterioration through 27 years. Therefore, the developments of new inspection devices started in 1996, and the second-generation inspection train based on the newest series 700 Shinkansen rolling stock was delivered in October 2000. A new method for track geometry measurement called 'asymmetrical chord offset' contributes to realize the maximum measuring speed up to 270 km/h. After a series of running tests for checking running safety and for confirming measurement accuracy, the new 'Dr. Yellow' will be in practical use from September 2001.

Keywords

Dr. Yellow, track irregularity, track geometry, track inspection, asymmetrical chord offset

1 Introduction

To enhance the safety and reliability of high-speed transportation, it is one of the most important tasks to examine railway infrastructures frequently and accurately. During 10 years since the inauguration of service on Tokaido Shinkansen in 1964, the electricity inspection train (T1 train set) that was remodeled from the Shinkansen test train and the track inspection car pulled by a diesel locomotive had separately been operated at night between Tokyo and Shin-Osaka.

With the extension of the Shinkansen network to Okayama and to Hakata, the speed-up and efficiency improvement of inspection were required. Therefore, the multiple inspection train (T2 train set) called Dr. Yellow (Figure 1), which could measure both the track and electric infrastructures at 210km/h, was manufactured in 1974. Especially, the development of contact-free optical rail displacement sensor made the high-speed track inspection possible. In 1979, T3 train set, which dependent on the same specification as T2, was added. These two Dr. Yellow have contributed greatly to the safety of Tokaido and Sanyo Shinkansens for long time inspecting tracks, catenaries, signals, and radio equipments every 10 days.

Figure 1: Dr. Yellow (T2 train set)

However, the vehicles and measurement devices of T2 are decrepit after 27 years of use. Moreover, It was afraid that the supply of maintenance parts would become difficult because series 0 trains (base car of T2) had already retired from Tokaido Shinkansen in 1999. In addition, the track inspection car in T2 which has three-bogies restricts the traveling speed less than 210 km/h. Therefore, it's operation of it is restricted in the high-frequency time schedule of Tokaido Shinkansens, and furthermore it is impossible to measure phenomena caused by maximum commercial speed of 270km/h.

For these reasons, the development of a new inspection train was initiated in 1996. After running tests for new equipments, a new Dr. Yellow (T4 train set) based on the newest series 700 Shinkansen train, was rolled out in October 2000 (Figure 2).

Figure 2: New Dr. Yellow (T4 train set)

2 Features of new Dr. Yellow

2.1 Concepts

The new Dr. Yellow (T4) was designed according to following concepts.

- The maximum measuring speed of 270km/h.
- The introduction of latest measuring techniques and the provisions allowing future progress.
- Functional and comfortable measuring environment, which permits long-time measurement.
- Minimization of maintenance cost sharing maintenance parts with commercial trains.

2.2 Exterior and interior design

The T4 train set consists of 7 cars as same as the conventional T2 set. Since multiple inspection trains such as T2 and T3 have been familiar with the nickname of Dr. Yellow, bright yellow was chosen for the base color of the T4. As well as the commercial trains, blue line is also painted. Windows for monitoring camera and for opposite train detector have been installed in the front and the side of lead cars (car No.1, 7). The car No. 4 being the track inspection car is only one trailer, and others are power cars. Car No. 7 has 50 seats and a monitor for visitors. Car No.1, 2, 3, 5 and 6 are mainly used as electric inspection cars (Figure 3). To make measuring rooms to be comfortable environment, the interior design is based on the human engineering not only for operating consoles but also for the colors of carpet, handrail and wall (Figure 4). As a special facility for the measurement, cables wiring space is prepared in the ceiling and in the floor.

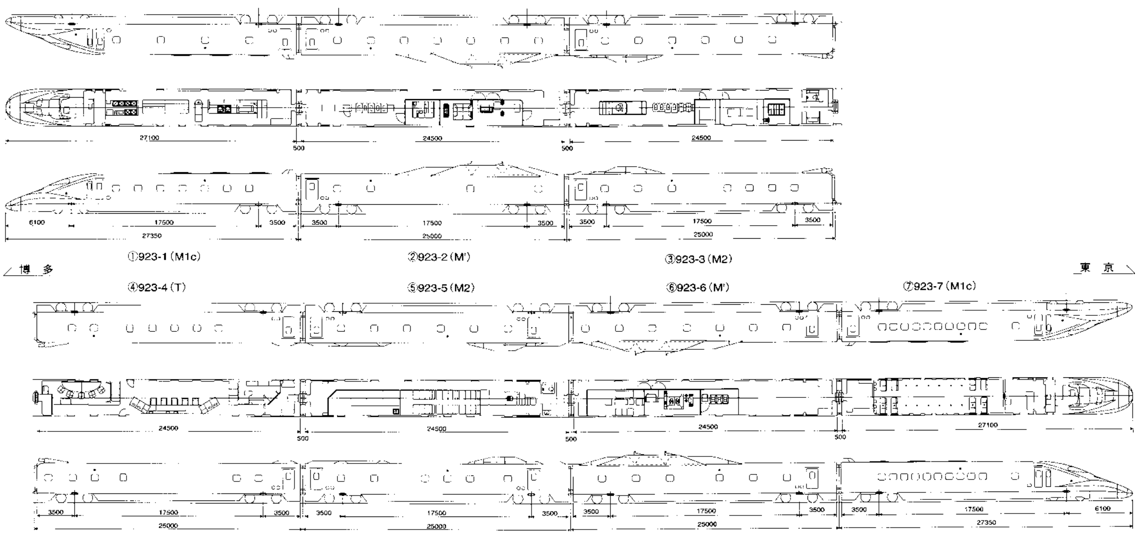

Figure 3: Train set of T4

Figure 4: Measurement room of track inspection car in T4

3 New technologies which enables high-speed track inspection

The track inspection car in T2 has three bogies for 10m-versine measurement. As the stability of the middle bogie in high-speed is not satisfactory, the maximum measuring speed of T2 is restricted under 210km/h. To solve the problem and to achieve the measuring speed up to 270km/h, the new track inspection car bases on ordinary 25m-length car made of aluminum and having 2 bogies. Since this decision made the utilization of mid-chord offset impossible, the developments described in the following section were indispensable.

3.1 Track geometry measurement by using asymmetrical chord offset method

For track irregularity measurement using the track inspection car, the inertia method and the difference method such as 10 m versine are generally used throughout the world. In both of them, the high-speed track inspection cars using ordinary car body and having two bogies have adopted the inertia method. According to the inertia method, the displacement is indirectly calculated by the double integration of acceleration. The difference method depends on the principle that the displacement is directly obtained as the difference between movements at several points.

As a result of examination about merits and demerits of both methods, the asymmetrical chord offset, that is, a sort of difference method, was determined to be adapted to the new Dr. Yellow. The decisive advantage of the difference method is that the track irregularities can be measured even at very low speed. The asymmetrical chord offset method obtains the track irregularities as the difference of rail positions at three points at unequal intervals. The longitudinal level is measured using three axles among four ones. The chord length of 20m is divided into 2.5m (axle spacing) and 17.5m (bogie spacing). The alignment is measured using optical rail displacement sensors placed 0.4m outside of each bogie. Thus, 3.3m and 17.5m asymmetrical chord offset is utilized (Figure 5).

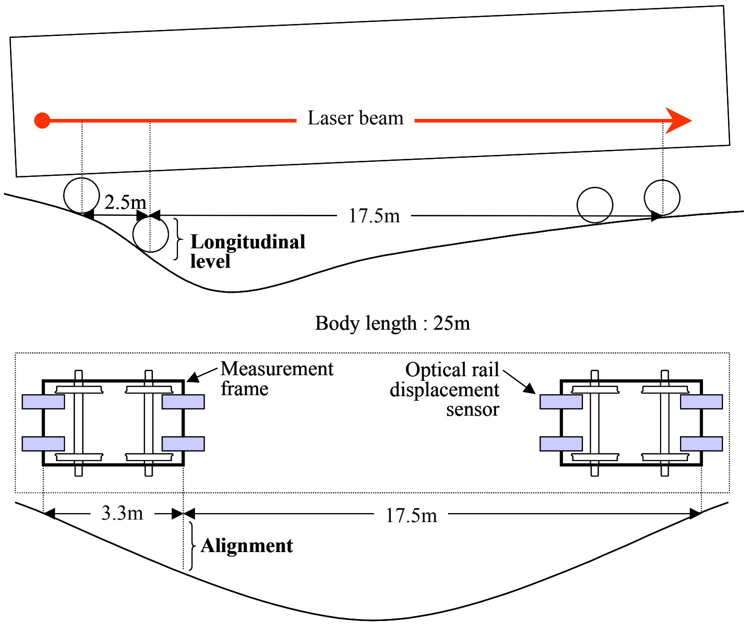

Figure 5: Asymmetric chord offset

The frequency response functions of the 2.5m-17.5m asymmetrical chord offset measuring are shown in Figure 6 with that of the 10m-versine measurement. As is evident from the figure, the gain of the 2.5m-17.5m asymmetrical chord in the measurement for long wavelength, which is important for riding comfort, is considerably higher than the 10m-versine. Furthermore, the 2.5m-17.5m chord can measure irregularity of the 5m wavelengths that cannot be detected in 10m versine. In return for those advantages, the output irregularity has an unavoidable wave distortion because the asymmetrical chord offset cannot to get linear phase property. Moreover, the measured waveforms of two reverse directions don't coincide with each other.

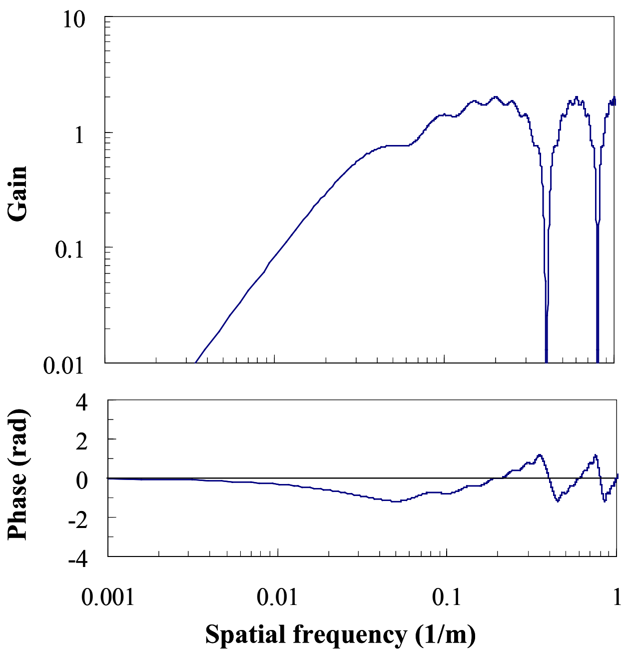

Figure 6: Frequency response functions of 2.5, 17.5m

3.2 Conversion to the mid-chord offset and original track profile

Running safety has been checked by the value of the 10m-versine, and the quality of the riding comfort has been judged using the 40m-versine for the Shinkansen track. Since the aimed values for track maintenance and speed reduction standards are regulated by using versines, asymmetrical chord offset records must be transferred to 10m-chord and 40m-chord versines. Further, original track waveforms on ground are necessary for controlling tamping machines. These transfers are realized by using the digital signal processing technique. These conversion filters are expressed as follows:

$$H_1 = \frac{H_{10}}{H_a}, \qquad H_2 = \frac{H_{40}}{H_a}, \qquad H_3 = \frac{1}{H_a} \cdot H_{bpf}$$

Where;

H_{10} : FRF of the 10m-chord measurement,

H_{40} : FRF of the 40m-chord measurement,

H_a : FRF of the asymmetrical chord offset measurement

H_{bpf} : FRF of the band-pass filter (from 6m to 100m)

H_1 : FRF of the conversion filter from asymmetrical chord to 10m-chord,

H_2 : FRF of the conversion filter from asymmetrical chord to 40m-chord,

H_3 : FRF of the conversion filter from asymmetrical chord to original track waveform on the ground.

Frequency response functions of these filters are shown in Figure 7-9. Unfortunately, the complete restoration of the actual track geometry is impossible because the gain of the filter closes to infinity as the spatial frequency lowers. To avoid this, a restricted restoration in the extent of wavelength from 6m to 100m is generally performed.

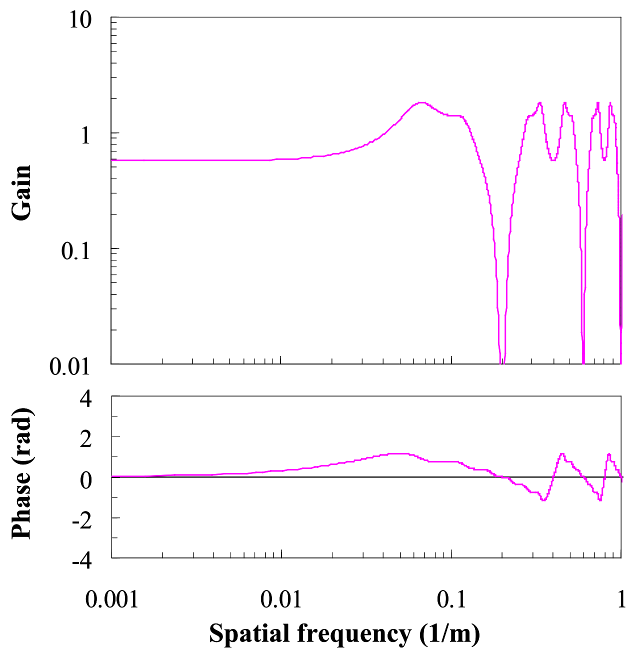

Figure 7: Conversion filter for 10m-chord versine

As the phase of these filters has an opposite sign of the phase of asymmetrical chord measuring, above-mentioned wave distortion is rectified completely and calculated waveforms of two reverse running directions coincide with each other.

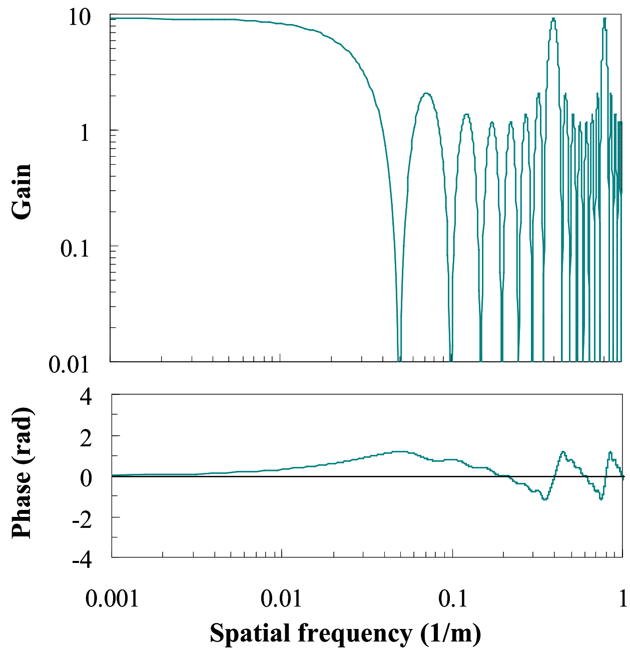

Figure 8: Conversion filter for 40m-chord versine

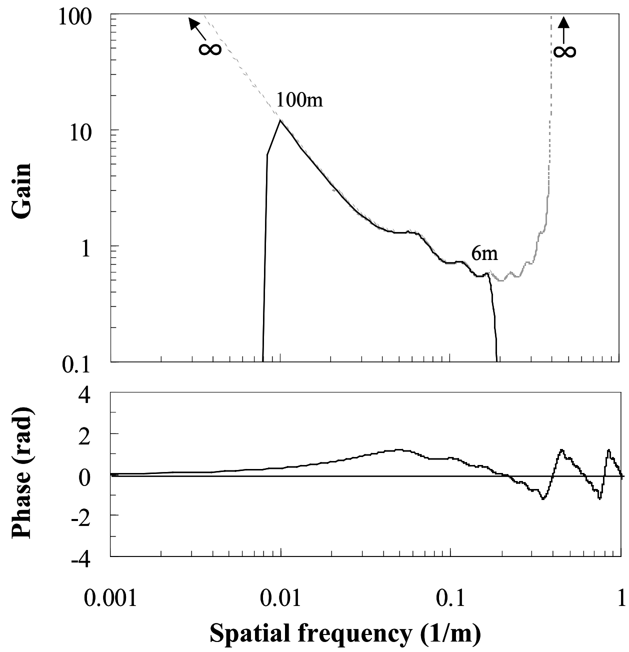

Figure 9: Inverse filter for original track waveform

3.3 Compensation of the car body displacement

Track geometry measurement by difference method needs the base line (chord) of the measurement. So far, the base line has been a stiff and short (17.5m) car body itself in T2. T4 having the car body of 25m long is made of aluminum alloy and is not equipped with the middle bogie. It is impossible to use car body itself of T4 as the base line of measurement because the body deflection caused by the vibration and the air pressure alteration in tunnel is too large.

As one of the countermeasures to the problem, three laser beams are longitudinally irradiated inside the floor are used as chords for measurement. The laser beam equipment measures car body displacements at each axle. Output signals are used to calibrate irregularity calculations for alignments and longitudinal levels (Figure 10).

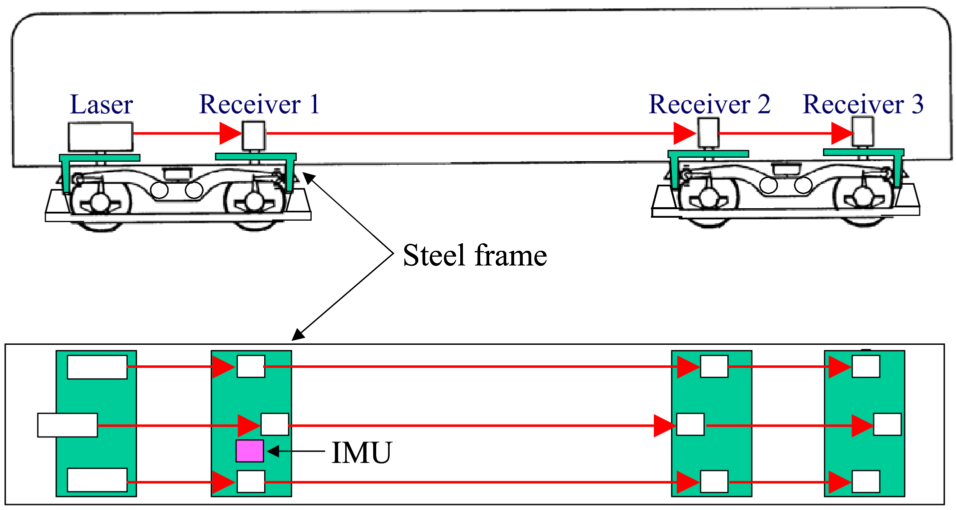

Figure 10: Laser equipment and steel frame

Furthermore, another countermeasure is taken for the deflection in lateral direction. Stiff steel frames are installed inside the floor as seen in Figure 10, and sensors such as displace transducers, laser beam equipments and IMU (Inertial Measuring Unit) are put on these frames. As they are isolated from the car body, measured track irregularities don't accept the influence of the car body deflection.

3.4 New optical rail displacement sensor

In Japan, the 'light section method' has been used as a principle of contact-free optical rail displacement sensor. The principle enables measurement of gauge and alignment at fixed position of the rail, 14 mm below the running surface, regardless of the lateral movement of the bogie.

The asymmetrical chord offset method requires four sensors per each bogie as seen in the Figure 5. As the former sensor used in T2 weighs 80kg apiece, the reduction of the weight and size was necessary because the high-speed running for measurement requires the reduction in unsprung mass. By the use of semiconductor laser and PSD (Position Sensitive Device), the new rail displacement sensor lightened to about 1/8 was successfully developed (Figure 12). An optical fiber cable transmission system is also utilized in order to reduce noise between sensors and signal conditioners.

Figure 11: New optical rail displacement sensor

3.5 Measurement frame and bogie

As shown in figure 5, the optical rail displacement sensors have to be placed outside the bogie for asymmetrical chord measurement. These sensors are attached to the special measurement frame, which is set on axle boxes. The measuring position of optical sensors for the gauge and alignment is 14 mm under the rail surface. If the measurement frame moves vertically, the detection point changes, and the measurement accuracy deteriorates. Therefore, high rigidity is required to the frame. On the other hand, from the viewpoint of the running stability, the measurement frame must be as light as possible because it all increases the unsprung mass. Furthermore, it requires smooth running on transition curves. Thus, the measurement frame must provide the contradictory properties such as high rigidity, lightweight, and smoothness. The measurement frame is shown in Figure 12. It developed through computer analysis and running tests using three kinds of prototypes. It is partly comprised of aluminum alloy, which lowers weight and reduces deflection simultaneously. In addition, the use of diagonal links, which support a beam for the optical rail displacement sensor, enhances rigidity so as to realize a resonance-resistant structure.

To realize high-speed inspection, the lightening and the running stability improvement were done in the bogie for track inspection car. In order to reduce weight and to avoid the interference with optical rail displacement sensor, this bogie is not equipped with the ECB (Eddy Current Brake) equipment. The brake force shortage of the track inspection car is supplemented by raising the force of other cars. As a countermeasure to the increase of the unsprung mass and in order to keep reliability of stability, yaw damper of the measurement bogie was increased from 2 to 4 (per bogie). The running stability of the bogie attached with the measurement frame was confirmed actually through bench tests in Railway Technology Research Institute, where the rolling tests up to 450km/h were executed. Further, wheel load and lateral force measured at running tests showed that the stability of the measuring bogie was acceptable.

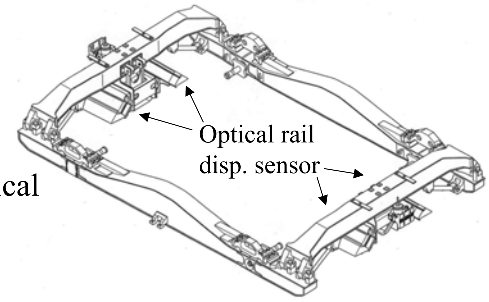

Figure 12:
Measurement frame for optical rail displacement sensors

4 Data processing

4.1 On-line

During the running of measurement, output signals from every transducer are adjusted by the signal conditioners. Then, these signals passed through spatial anti-alias filter, and they are sampled at spatial intervals (0.25m) by 16-bit ADC (Analogue to Digital Converter) synchronized with the wheel pulses. 69 kinds of data shown in table 1 are calculated from 76 kinds of sensor signals by the modern DSP (Digital Signal Processor). Finally, 10m, 40m-versine and original track waveforms are calculated by using above-mentioned digital filters.

Table 1: Items for track measurement

No.	Measurement items		
1	Longitudinal level	Asynmetrical chord offset	R
2			L
3		Asynmetrical chord offset	R
4			L
5		10m versine (axle No. 1,2,4)	R
6			L
7		10m versine (axle No. 1,3,4)	R
8			L
9		40m versine (axle No. 1,2,4)	R
10			L
11		40m versine (axle No. 1,3,4)	R
12			L
13		Original track waveform	R
14			L
15		Original track waveform	R
16			L
17		Long wave	R
18			L
19	Alignment	Asynmetrical chord offset	R
20			L
21		Asynmetrical chord offset	R
22			L
23		10m versine (axle No. 1,2,4)	R
24			L
25		10m versine (axle No. 1,3,4)	R
26			L
27		40m versine (axle No. 1,2,4)	R
28			L
29		40m versine (axle No. 1,3,4)	R
30			L
31		Original track waveform	R
32			L
33		Original track waveform	R
34			L
35	Cross-level		

No.	Measurement items			
36	Gauge	Axle No.1		
37		Axle No.2		
38		Axle No.3		
39		Axle No.4		
40	Twist			
41	Car body acceleration	Car No.1	X	
42			Y	
43			Z	
44		Car No.7	X	
45			Y	
46			Z	
47	Bogie acceleration	Car No.1	Y	
48			Z	
49		Car No.7	Y	
50			Z	
51	Axle box acceleration	Car No.1	Y	R
52				L
53			Z	R
54				L
55		Car No.7	Y	R
56				L
57			Z	R
58				L
59	Under floor sound level	Front		
60		Rear		
61	Oppositing train	Car No.1		R
62				L
63		Car No.7		R
64				L
65	Velocity			
66	Reference point signal	1km		
67		10km		
68		ATC		
69	Electric pole			

If the track irregularities exceed predetermined standard values, the value and location of the irregularity are displayed on a monitor with additional information such as velocity. Waveforms of all data are continuously displayed on three monitors, and the waveform chart can be printed at any time.

4.2 Off-line

A computer system called RINDA (Relational and INtegrated DAtabase system for Shinkansen) processes measured data recorded in the MO (Magneto-Optical) disk. After the precise processing, all the data for track irregularities are distributed to the 20 track maintenance depots through WAN (Wide Aria Network). The RINDA terminal in each depot checks track irregularities for the aimed values for maintenance work, and it gives the positions where maintenance works are necessary. In addition, the waveforms before and after the work at maintained section are compared in order to judge the payment to the contractor.

5 Accuracy of new track inspection car

In spite of the speed-up of 60km/h, the precision of the new track inspection car is high enough. Figure 13 shows the comparison of track irregularity records of T2 (thick) and T4 (thin). There is a good correspondence between them. Differences are within 0.3mm in the standard deviation. It has been confirmed that the repeatability is 0.2mm or less, even if the measuring speed is changed.

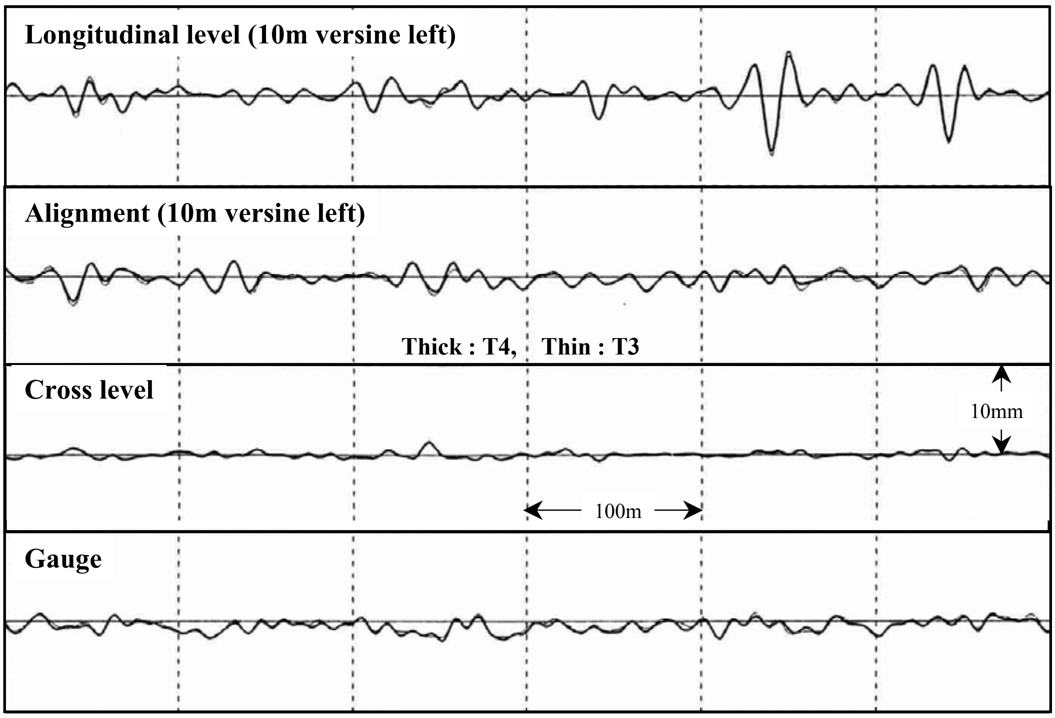

Figure 13: Waveform comparison of T4 and T3

6 Conclusions

The conclusions are summarized as follows:

- A new method called asymmetrical chord offset is utilized in order to realize the track geometry measurement using the ordinary structure of car body, and it enables high-speed inspection at 270km/h.
- The asymmetrical chord offset measuring has two major advantages compared with the 10m-versine. One is that it is able to measure the irregularity of 5m wavelengths. Another is the higher gain at the long wavelength. In return for these advantages, output waveforms has an unavoidable wave distortion.
- Asymmetrical chord offset irregularity data are completely converted to the 10m and 40m versines by using specially designed digital filters. It is also possible to calculate the original track waveform on ground. These filters are able to rectify the wave distortion of the asymmetrical chord offset irregularities.
- The laser beam equipment, the steel base frame in the floor, the measurement frame for optical rail transducers, and the specially designed measurement bogie realizes the adoption of asymmetrical chord offset method for high-speed track inspection.
- In spite of the high-speed inspection at 270km/h, the measurement accuracy of the new Dr. Yellow is highly precise.

The new Dr. Yellow is expected that the round measuring trip from Tokyo to Hakata, which is necessary for 3 days at present, is shorten for 2 days. It is possible to measure various phenomena arising in 270km/h running. The new Dr. Yellow will make the inspection of ground facilities efficient and precise. At present, the running tests are being carried out. It will be in practical use from September 2001.

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