TRACK MAINTENANCE TECHNIQUE FOR 300km/h CLASS SHINKANSEN

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INTRODUCTION

Shinkansen in Japan has been a typical high–speed railway of the world for many years. However, recently, remarkable activities in the development of super–speed railways are witnessed in the world. Also in Japan, the demand for a higher commercial speed of 300 km/h by improving the vehicle and the track is mounting. In this report, we introduce new track maintenance techniques matching 300km/h class shinkansen operation.

1. PRESENT SPEED AND POINTS OF TRACK MAINTENANCE

For 20 years since opening of Tokaido shinkansen in Oct. 1964, the maximum speed has been 210km/h. In Mar. 1985, 240km/h service started on Tohoku Shinkansen. The speed is also raised on other lines. Now, the maximum speed is as follows.

- Tokaido Shinkansen Line 220km/h
- Sanyo Shinkansen Line 230km/h
- Tohoku Shinkansen Line 240km/h
- Joetsu Shinkansen Line 275km/h (only on a short section)

Lately many tests were carried out for speed–up of Shinkansen and the maximum test speeds attained are as follows:

- JR Central 300 series Shinkansen 325km/h
  Mar.1991 on Tokaido Line
- JR East 400 series Shinkansen 345km/h
  Sep.1991 on Joestu Line

JR Central introduces from March 14 Series 300 trainsets between Tokyo and Shin–Osaka, running at 270km/h maximum to cut journey time for 515km trip to 2 hours 30 min. And some other high speed projects with lightweight and high performance trainsets designed for commercial speed from 300 to 350km/h are on schedule.

The relations between train speed–up and track maintenance are as follows. Generally speaking, a vehicle consists of car body, truck and wheelset with suspension between them. When a vehicle runs on track irregularities at certain speed, the vehicle motion is related to its dynamic characteristics. At high speed, long–wave track irregularities give a great influence on vehicle's lateral movement. Otherwise, short–wave track irregularities cause wheelset vibrations and they lead to impact load on track, wheel/rail noise and ground vibrations. As seen in these cases, vehicle's running characteristics are determined not only by train speed and the magnitude of track irregularity but track irregularity wave length. These problems are very important for 300km/h class Shinkansen.

In this report, the following problems are discussed;
- Track geometry and long-wave track irregularity related to riding comfort.
- Short-wave track irregularity related to impact load and wheel/rail noise.
- Newly developed track inspection system.
- Track irregularity data processing system.

2. TRACK MAINTENANCE FOR RIDING COMFORT

2.1. RIDING COMFORT IN CURVES

2.1.1. Evaluation of Riding Comfort

Passenger riding comfort is evaluated by the magnitude and frequency of acceleration which passengers feel on the vehicle. Some methods have been used to evaluate riding comfort in Japan. An example is shown in Fig.1 which was originally recommended by ISO (International Organization for Standard) and modified about low frequency by former JNR (Japanese National Railways, now privatized as JR group). But these standards can not explain the riding discomfort caused by the quasi-static lateral acceleration in curves.

As it is well known, lateral acceleration is main factor of riding comfort and vertical one is only a minor problem.

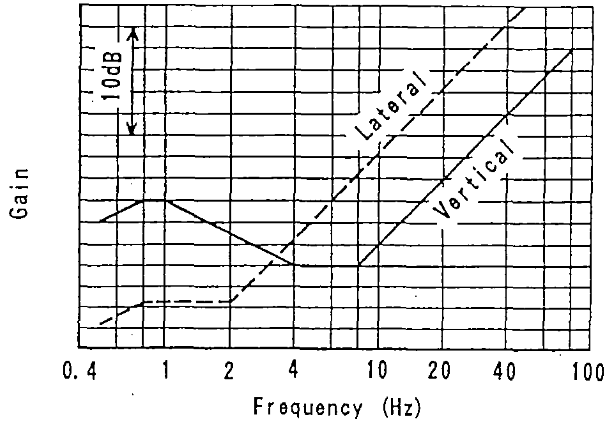


Fig.1 Example of riding comfort standard (originated ISO-2631 modified in Japan)

2.1.2. Influence of Quasi-Static Lateral Acceleration

When trains run through curves, lateral acceleration which affects passengers consists of two elements. One is quasi-static element which is determined by curve radius, cant and train speed. The other is dynamic element mainly relating to the track irregularities and train speed. But usually only the former element is supposed to determine train curving speed. In Japan, the admissible standard of quasi-static lateral acceleration is 0.8 m/s^2 which is tolerated by 95% of standing passengers. This standard depends on a result of riding comfort test carried out in Japan in 1960s.

2.1.3. Evaluation Method of Riding Comfort with Combination of Quasi-static and Dynamic Lateral Acceleration

It is said that riding comfort in curves is influenced by not only quasi-static lateral accelerations but also dynamic ones. Fig.2 shows the result of riding comfort test carried out in 1983-84 by BR's Research & Development Division, and this explains the tendency well[1].

In Japan, similar test was carried out which investigated the possibility to change the standard of admissible lateral acceleration in 1989. The result was also similar to that of BR and showed a possibility to allow larger lateral acceleration (Fig.3). Here, vibratory acceleration is expressed as the equivalent vibration level of sum of three-dimensional acceleration. These results show that in case of good track geometry, larger lateral acceleration is admissible.

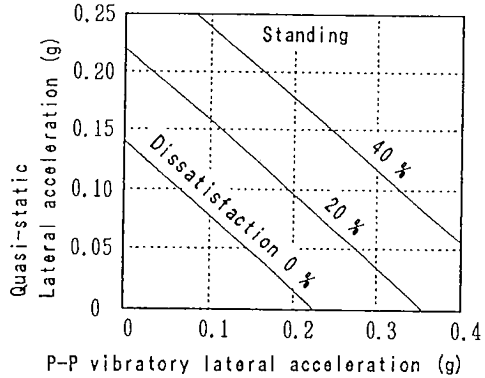


Fig.2 Result of riding comfort test by BR

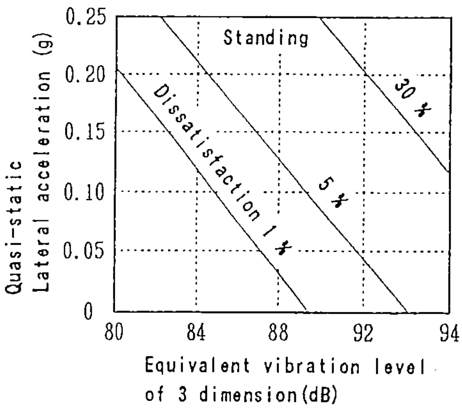


Fig.3 Result of riding comfort test by JR East and RTRI

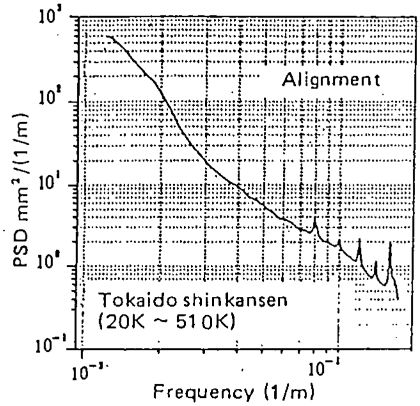
2.2. LONG-WAVE TRACK IRREGULARITY[2]

2.2.1. Track Irregularity Wave Length vs. Vehicle Vibration

Fig.4 shows PSD (Power Spectral Density) of track alignment and vehicle lateral vibration measured on 100 series trainset at 220km/h on Tokaido Shinkansen Line. In case of present shinkansen vehicle, the main lateral vibration frequency is between 1.0 and 1.5 Hz. It means that at 300 km/h the most effective track irregularity wave-length to lateral vibration is 60 to 80 m. So it is important to inspect and correct these irregularities for good riding comfort.

2.2.2. Inspection Method for Long Wave Track Irregularity Maintenance

Fig.5 shows an example of track alignment in some expression and vehicle lateral vibration. Here, restored alignment is calculated from the 10m chord irregularity and similar to the absolute value of the irregularity at 6 to 80m wave band. There are several long-wave irregularities, which are not revealed by 10m chord, but made very clear by 40m chord. Vehicle vibrations are caused by the long-wave track irregularities.



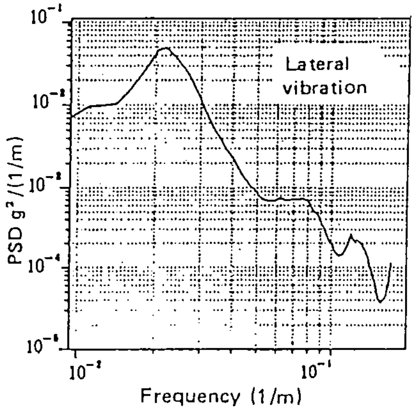


Fig.4 PSD of track irregularity vs. vehicle lateral vibration
on Tokaido Shinkansen Line (100 series at 220km/h)

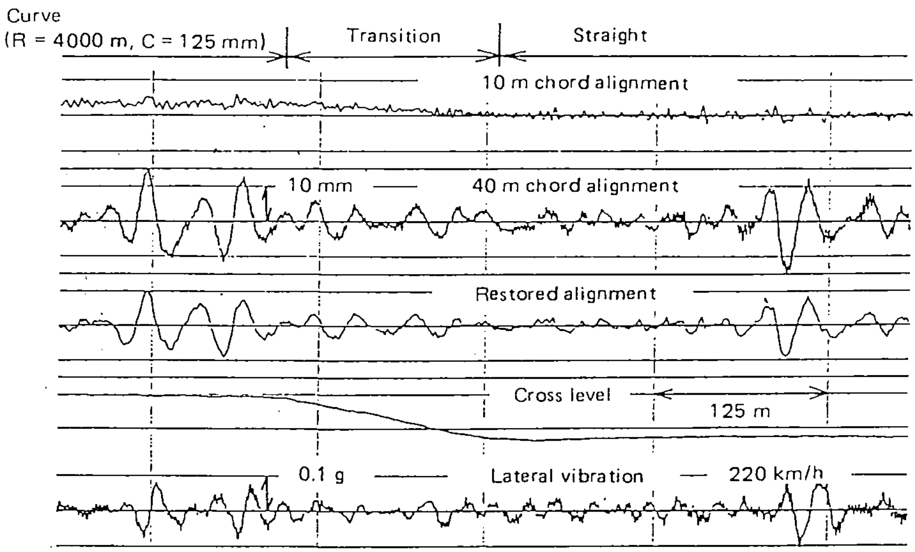


Fig.5 Example of track alignment and lateral vibration

To select track inspection method, many factors besides the relation abovementioned must be considered. Table 1 shows the comparison of some track inspection methods. Weighing these factors, 40m chord is found most suitable.

Fig.6 shows the relation of 40m chord alignment to lateral vibration on Tokaido Shinkansen 100-series train at 220km/h. This figure shows that to keep lateral vibra

Table 1 Comparison of some track inspection method

Criteria	10 m chord	20 m chord	40 m chord	Re-stored	Riding quality
Correlation to vibration	×	△	◎	○	△
Understand-ability	◎	◎	◎	○	×
Ease of handling	◎	◎	◎	×	×
Maintain-ability	◎	○	△	×	×
Extension possibility	×	×	×	○	○
Overall ratings	△	○	◎	○	△

Notes:
◎ Excelent or simple
○ Effective
△ Less-effective
× Non-effective or complex

tions within 0.20g (peak to peak), it is sufficient to control alignment within 10mm by 40m chord method. Actually, JR companies set a little smaller value as the maintenance standard. At first it was very difficult to correct long-wave track irregularities, with enriched experience it is possible to correct almost within 3mm at 40m chord now. These maintenance works have remarkable effect on Shinkansen riding comfort.

2.2.3. Characteristics of Growth of Long-Wave Track Irregularities

Fig.7 shows track alignment of same section in Jul. 1987 and Jul. 1988 on Tokaido Shinkansen Line. As shown in this example, the growth of long wave track alignment is very slow. So, once we correct the track alignment perfectly, it will be easy to maintain good condition.

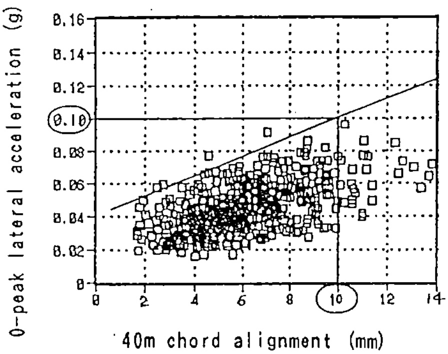


Fig.6 40m chord alignment and lateral vibration

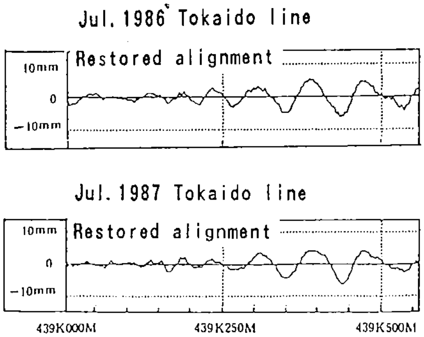


Fig.7 Growth of long-wave track irregularities

2.3.4. Gauge Corner Rail Wear and Vehicle Vibration

It is necessary to pay attention to the fact that gauge corner rail wear affects vehicle vibrations. And research on wheel/rail contact condition is important for future high speed running.

2.3.5. Vehicle Motion Simulation Using Track Irregularity

To establish a really efficient track maintenance, we are going to develop a vehicle motion simulation using actual track irregularities. At first, we input actual track irregularities and get vehicle acceleration as output. Then we correct the track irregularities until the output acceleration comes within planned value. Based on the result, we decide the maintenance work. If this method is developed, we shall be able to estimate track irregularities for the whole range of wave lengths.

2.3.6. Continuous Lateral Vibrations in Tunnels

Some cases are reported about continuous lateral vibration in long tunnels (mostly longer than 2km) on Tokaido & Sanyo Shinkansen. Such vibrations occur in specific tunnels and specific trains. Fig.8 shows an example. Slab tracks are laid in the tunnel and there are very small irregularities including long-wave ones. Nevertheless, lateral vibrations occur strong and continuous.

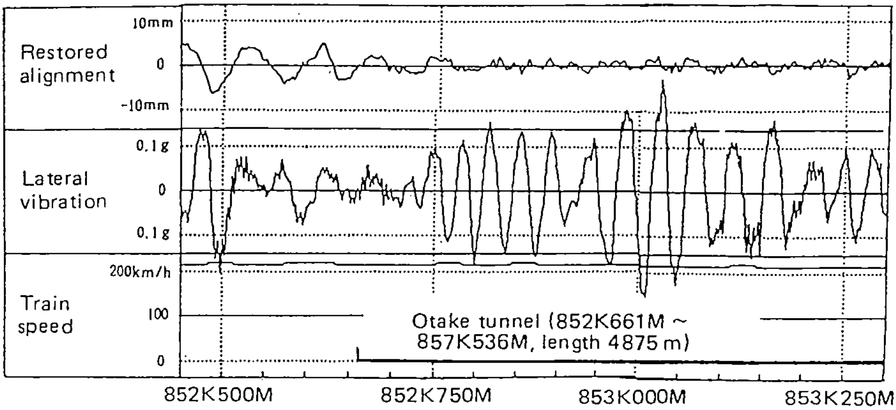


Fig.8 Example of continuous lateral vibration in tunnel

Fig.9 shows PSD of track alignment and lateral vibrations of open and tunnel sections, and their coherence which expresses the strength of the relation. PSD of alignment in open section is a little higher than that in tunnel section. PSD of lateral vibration in open section is somewhat higher than in tunnel section. But there is a remarkable difference in the coherence of alignment and vibration. That is to say, in open section there is high coherence in long wave band, but in tunnel section hardly any coherence in all wave bands. The reason is presumed to be that the continuous lateral vibrations in tunnel do not originate from the track irregularities. This problem is an important research subject for continuous investigation.

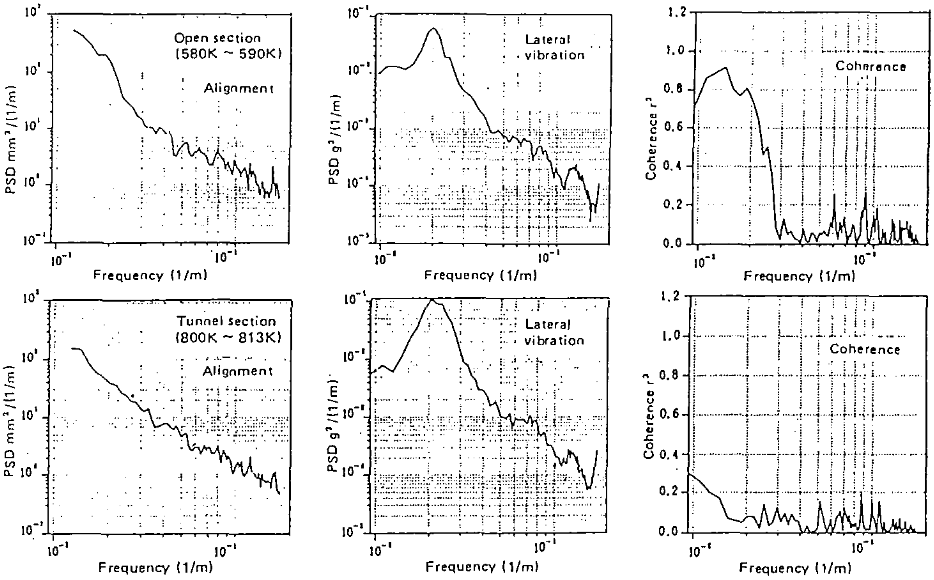


Fig.9 PSD and coherence of track irregularities and lateral vibration in open and tunnel sections

3. SHORT-WAVE IRREGULARITY MAINTENANCE[3]

3.1. ACTUAL CONDITION OF SHORT-WAVE IRREGULARITY

3.1.1. Source of Wheel/Rail Noise on Shinkansen

On Shinkansen it is suggested that not the wheel vibration, but the rail vibration is the main contributor to the wheel/rail noise[4].

Fig.10 shows the rail vibration velocity level of 60 kg rail in vertical and horizontal directions and the wayside noise at 2 m away from the rail in Shinkansen cars operated at 240 km/h. It indicates that the amplitude of vertical vibration is greater than that of lateral vibration, and the frequency range is about 500 to 2000 Hz.

The origin of wheel and rail vibration is the irregularities existing between wheel and rail. And smoothing these surfaces is an efficient countermeasure of wheel/rail noise. At present, wheels are fairly well maintained by wheel tread grinding and other techniques. Then it is very important to maintain rail surface.

3.1.2. Characteristics of Defect at the Welded Section

The most effective element that causes wheel/rail noise and wheel load fluctuation is rail head defect at welded section. It consists of two elements. As shown in Fig.11, one is a several cm long small defect originated from the difference in hardness between welded point and influenced section. The other is rail bending whose wave length is one to several meters. At present, these defects are measured by 1m or 2m straight scales and evaluated by the maximum value. But it was found that the accuracy of scales is not enough and the results have little relation to wheel/rail noise.

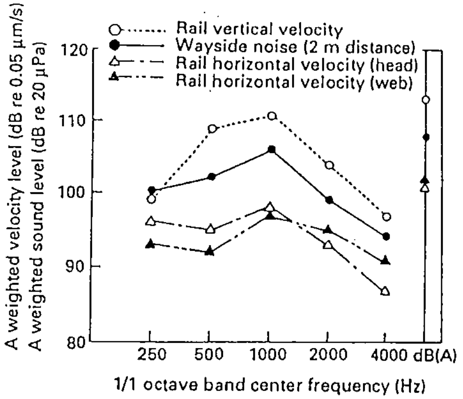


Fig.10 Rail vibration velocity and wayside noise at 240km/h

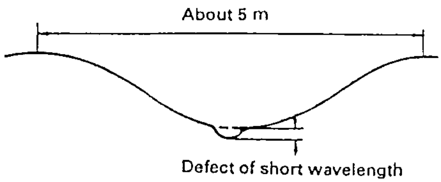
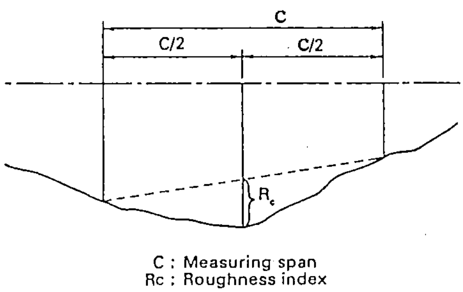


Fig.11 Example of defect at rail welded section

3.1.3. Measuring Method of Rail Roughness

To investigate the rail surface condition, a popular rail roughness measuring device is used in Japan. It has an accuracy of about 0.1 mm; it can not exactly measure the roughness. A rail roughness measuring instrument has been newly developed for Shinkansen. It is an electrical displacement measuring device equipped with a straight edged guide to the rail, i.e., a displacement sensor movable across it automatically with an accuracy of less than 2 micro–m, the measuring length being 600 mm, and the sampling rate 1 mm. The overall error of the instrument is less than 10 micro–m.

To evaluate the rail roughness for maintenance, a new roughness index is introduced. Fig.12 shows the definition of the roughness index, which takes the maximum versine value of 200 mm span out of the 600 mm length. Fig.13 shows the relation between roughness index and track inspection car noise before and after grinding. There is a good correlation, and it seems to be adequate to evaluate rail surface irregularities relating to wheel/rail noise.



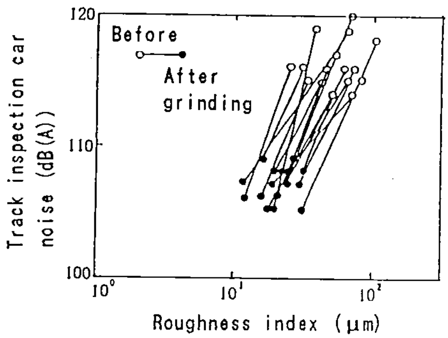


Fig.12 Definition of the roughness index noise before and after grinding

Fig.13 Roughness index

3.1.4. Target Value of Rail Roughness Index

From the results of analysis of actually measured data, it is suggested that to reduce environmental noise value within 70dB(A) at 300km/h, we should keep rail roughness index 20 micro-m or track inspection car noise 102 to 105dB(A).

3.2. EFFECTIVE RAIL GRINDING METHOD

3.2.1. Periodical Rail Grinding by Speno Cars

It is important to make rail head smooth by grinding. Generally, periodical grinding by Speno cars is effective. To control yearly growth of track inspection car noise within 2dB(A), the desirable grinding interval is approximately one year. In this case, a few grinding passes (grinding depth about 0.05mm) are sufficient.

3.2.2. Effectiveness of Local Rail Grinding at the Welded Section

About deep defects beyond Speno car's grinding ability, local grinding is necessary. Fig.14 is an example of track inspection car noise and rail head defect measured before and after grinding at welded section. Large noise of about 120dB(A) at welded section was reduced to the same level as on other sections. As shown in this example, removing a short wave length (10 to 20cm) irregularity is important.

3.3. PRACTICAL USE OF AXLE ACCELERATION

3.3.1. Application of Axle Box Acceleration for Wheel/Rail Noise Control

Track inspection car noise is useful to maintain wheel/rail noise, but it has weakpoints as follows:

- influence of environment like noise protection wall
- impossibility to estimate right and left rails individually
- influence of welded section reaching the mid-part depending on time constants.
- aero-dynamic noise at high speed

For these reasons, a new method of using axle box acceleration was proposed instead of using track inspection car noise. It is found that the axle box acceleration is highly related to rail surface roughness.

3.3.2. Application of Axle Box Acceleration for Wheel Load Variation

Reducing wheel load variation is an important problem for high speed railways. Wheel loads are measured by a special wheel installed for the purpose. As measured wheel loads are discrete with 70cm distance, the dynamic impact load occurring at welded section can not be measured perfectly. Then we try to use axle box acceleration which can be measured continuously. Fig.15 shows the relation between axle box acceleration and axle load. At present, dynamic wheel load is expressed by static wheel load and wheel load variation caused by unsprung mass. In this figure, effective mass of unsprung mass is 70% which is a little smaller than expected.

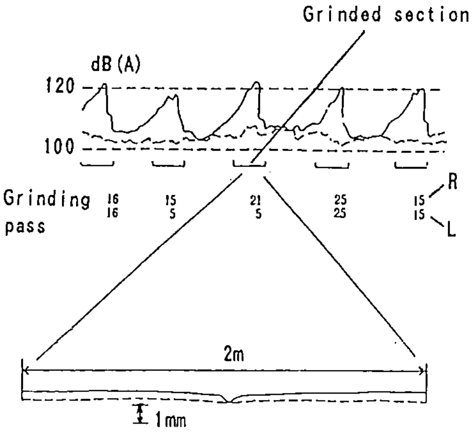


Fig.14 TIC noise at welded sections before and after spot grinding

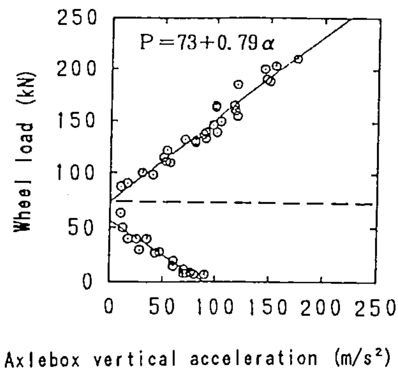


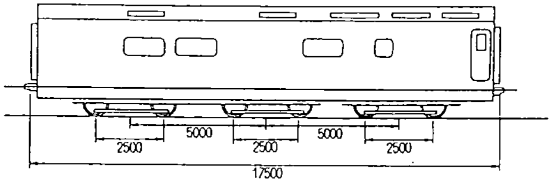
Fig.15 Relation between acce-leration and axleload

4.TRACK MEASURING SYSTEM[5]

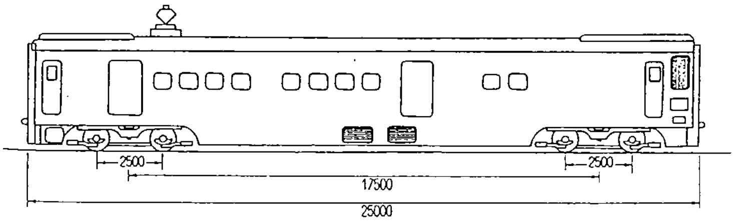
Present track inspection car for Shinkansen has three bogies to measure irregularities by midchord offset method. The running speed is restricted to 210km/h for reason of the running stability of the center bogie. So, we are developing a two-bogie type track inspection car for high speed over 210km/h track inspection. Fig.16 shows the outside appearances of track inspection cars. But the two-bogie type is not fit for the same method. Then an asymmetrical chord offset method was proposed. Fig.17 shows the comparison of inspection characteristics. Research on asymmetrical chord offset method has revealed different outputs being produced depending on the direction of track inspection car progress. Therefore , it is decided to transform the asymmetrical offset into a midchord offset by the digital technique.

The newly developed track inspection car incorporates many newly developed technologies. These are as follows:

- Application of laser as basis of straight line because of the car body bent.
- Lightweight optical sensor with use of semiconductor because it reduces. unsprung mass
- High accuracy gyro with use of ring laser.
- High speed digital data processor to calculate ordinary 10m chord track irregularity from asymmetry offset ones.

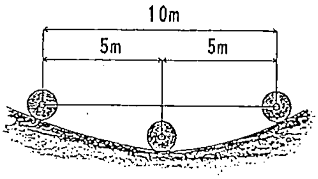


Three-bogie track inspection car (in use)

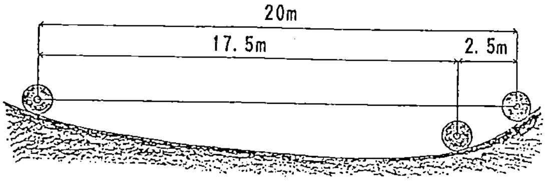


Two-bogie track inspection car (being developed)

Fig.16 Present three-bogie track inspection car and newly developed two-bogie one



Three-bogie track inspection car (in use)



Two-bogie track inspection car (being developed)

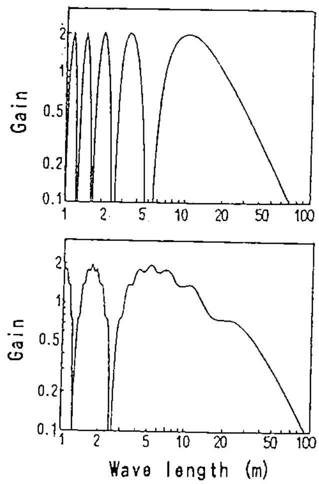


Fig.17 Characteristics of three-bogie track inspection car

5. TRACK DATA PROCESSING SYSTEM

To analyze track irregularities, use of computer is very helpful. We developed a general–purpose data processing system called "Micro LABOCS". This can be used with NEC PC–9801 Series micro computers which are one of the most popular micro computers in Japan. Micro LABOCS system performs many useful functions in analyzing track irregularity data. For example;

- data sampling on distance basis
- data conversion
  from 10m chord to 20m chord, 40m chord or restored alignment.
- filtering
- statistical index
  minimum value, maximum value, mean value, standard deviation, etc.
- spectral analysis
- database
  geometry, structure, irregularity

6. CONCLUSIONS

Thus, in the near future, commercial service at 300 km/h of Shinkansen with good riding comfort will be feasible enough as a result of the above–mentioned track maintenance techniques and newly developed tools. It may be concluded as follows:

(1) Riding comfort in curves should be evaluated by the combination of quasi–static and dynamic lateral acceleration.
(2) For high speed track maintenance, long wave irregularity maintenance is very important and 40m chord method is most suitable for inspection and maintenance works.
(3) Rail roughness index is effective to evaluate rail defect at rail welded section.
(4) Rail grinding is effective to reduce wheel/rail noise.
(5) Axle box acceleration is useful to locate the sections which need grinding works.
(6) New three–bogie type track inspection car for high–speed running has been developed.
(7) Micro Computer system called "Micro LABOCS" has been developed for analysis of track irregularity data.

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