January 1, 2003

Railway Technology Avalanche

Newsletter on the Latest Technologies Developed by RTRI No. 1

Railway Technical Research Institute
2-8-38 Hikari-cho, Kokubunji-shi
Tokyo 185-8540, JAPAN

Message to You on Founding the Newsletter on Research and Development by RTRI

Tarumi, Hisashi
Director, in charge of R & D Promotion and International Affairs

Honestly, it is really my great pleasure and honor to have our newsletter be at you, which was just founded in January 2003. On seeing the first edition of the newsletter on research and development lately carried through by Railway Technical Research Institute (RTRI), let me send my message to you along with it. So that the information on R & D promoted by RTRI can well be managed, I have tried to make the knowledge obtainable from our work widely shared with workers majoring in research on or management of railway operation all over the world. Therefore, for instance, the *Quarterly Report of RTRI (QR of RTRI)* has been continuously circulated four times a year for over 40 years since started with its initial number in 1960 as a medium by which the results achieved on railway research by RTRI can periodically be available for readers. Unfortunately, however, the publication is not necessarily expeditious even though a lot of people expect the latest information on our act. Frankly speaking, this inconvenience is caused by the manner of the publication not on purpose, in that, *QR of RTRI* is brought out generally by re-editing *RTRI Report* which is published monthly but in Japanese language. Thus, as a matter of fact, there is actually the some lag in time until the publication of *QR of RTRI* after that of *RTRI Report*. To make matters worse, the number of papers circulated through *QR of RTRI* is limited. To overcome this discomfort, I decided to separately edit and then immediately publish a newsletter, which is to follow RTRI Report-editorial work right away. Furthermore, I will put the same articles also in the homepage of RTRI for your convenience so that the information up-to-date on the R & D done by RTRI can quickly be with you, if you frequently run through the homepage. In any case, RTRI will keep you thoroughly informed about our performance, which will absolutely be useful for and helpful to you.

By the by, even after the foundation of the newsletter, *QR of RTRI* will still be periodically published as it is. Let me, therefore, suggest the best manner to know what RTRI currently does to you. First check the newsletter opportunely delivered by RTRI, and then anticipate seeing full papers published in *QR of RTRI* following the newsletter.

Incidentally, as to my action these days, I have earnestly and fully exchanged contemporary sense of enhancing and encouraging railway research with researchers, engineers, to say nothing of workers managing railway operation mainly in Europe, North America, and Asia, through international meetings, namely, ERRI symposium, the 5th WCRR, Surface Transport Technologies for Sustainable Development held in Valencia, Spain, in June 2002, and Eurailspeed 2002. By positively participating in the meetings with papers stressing the importance and significance of what RTRI has been thinking and doing, I surely grasped the atmosphere brought about by ardor and passion in successfully refining railway systems. To be concrete, one sees prompt measures taken by European Union (EU) without hesitation in sturdily efforts in making railway service friendly to the environment and simultaneously acceptable to customers, which I agree with great interest. Truly, what brings Europe increases in the passenger's number and freight traffic, which are shared jointly by all surface transport, that is to say, buses and ferries, is nothing but just endeavor actually made by EU. For the past over ten years, it has strongly led the railway service emitting little substance uncomfortable to the environment, especially, carbon dioxide, which would cause us a serious problem in eligibly controlling its concentration in the air. As well known, this strategy left good results in recovering the role of transportation over there in Europe. RTRI, thus, wishes to follow the measures taken by EU in order for the honor of Japanese Railways to be restored as a transportation means given a top priority by customers. Eventually, what is all-important is the service provided with railway systems reliable, cost-effective, attractive, naturally compatible with the environment, and to realize that is also our goal. RTRI is conducting approximately 260 themes at present with the concept mentioned above, in fact. Through the newsletter, in which a considerable number of papers on the essential work of RTRI will wholly be closely-packed, information on railway work would fully be exchanged with all workers throughout the world, in hope.

In any event, it is a sort of our action in efficiently and certainly progressing with the development of railway systems and proceeding with our task of accomplishing beneficial and fruitful results to let you know the latest technologies established by RTRI. This newsletter what we fondly name "*Railway Technology Avalanche*" will not periodically but a few times a year be conveniently with you at your desk right whenever published. Therefore, you can also be with us through the newsletter full of recent technologies all the time without any difficulty. I wish you to find our service interesting. Your inquiries on articles published in the newsletter are naturally welcome anytime. International Affairs at the e-mail address www-admin@rtri.or.jp is anytime behind you.

At my end, let me hereby briefly walk you through the organization of RTRI by showing the facts and figures of RTRI (see Fig. 1 and Table 1 on the backside). If in need, you can contact International Affairs in the same manner as well all the time. Thank you for listening and hope you enjoy the newsletter always with you!

Tarumi, Hisashi, Dr. Eng.

Table 1. Fact and Figures on Railway Technical Research Institute as of November 2002

Annual Budget for General Account	130 million US dollars
Personnel	519
Awarded	PhD, 85
Intellectual Property	Patents, 1,786; Utility Models, 51; Designs, 25
Premises	Land, 198,000 m^2; Buildings, 66,600 m^2

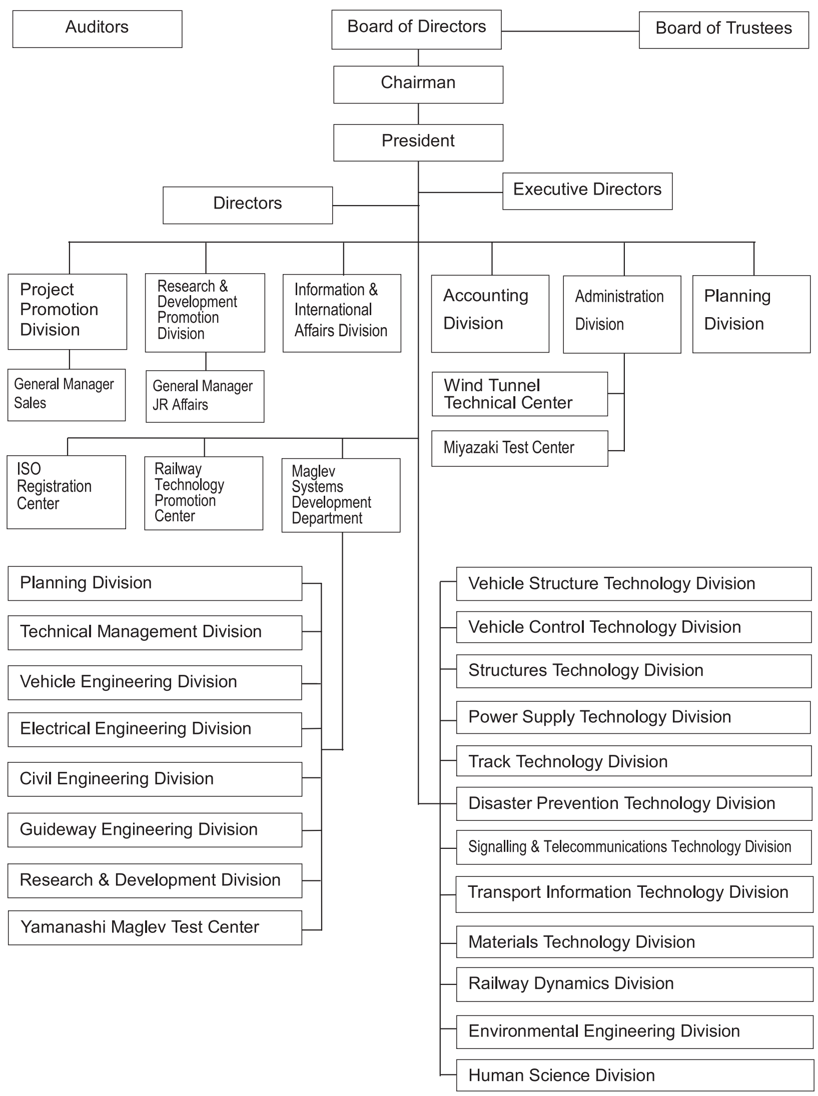

Figure 1. Organization of Railway Technical Research Institute as of July 1st, 2001.

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All your inquiries on the article(s) published in this newsletter to International Affairs at www-admin@rtri.or.jp will absolutely be welcome. If you can kindly electronically give us the information on your name, title as well as regular-mail and e-mail addresses so as to make the handling for air-mailing the rest of the newsletters to you easier for us to properly and correctly perform without any difficulty, we would be highly appreciative.

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Track Inspection Technologies

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Higher speeds of revenue service trains require track inspection cars that run at the same speed. The Railway Technical Research Institute has developed a two-truck inspection technique to use the asymmetric chord offset method and is now bringing out a new track inspection device to apply the inertia measuring method as a means of high-speed inspection at comparatively low costs as outlined below.

TRACK INSPECTION CARS TO PRACTICE THE ASYMMETRIC CHORD OFFSET TECHNOLOGY

Most of the conventional track inspection cars are based on the mid-chord offset method to use three trucks, front, center, and rear, to obtain measurements simultaneously at these three points. However, the center truck cannot run at 210 km h^{-1} for structural reasons. To increase the speed of the inspection car, therefore, we removed the center truck and adopted the asymmetric chord offset method to calculate track irregularities by taking three measurements carried out with the sensors at the ends of the trucks. See Fig. 1. For each of the left and right rails, the sensors are placed at four points, or on the inner and outer sides of each truck. One of the sensors on the inner sides is installed for measurement when the car runs in one direction, and the other in the other direction. The waveforms obtained through the asymmetric chord offset method are digitally converted into those of the mid-chord offset method on the car and recorded for management and maintenance purposes. To use it as a reference line, the car body of conventional inspection cars is extremely rigid and heavy to make a constraint for high-speed operation. If a car body of the normal type is introduced, however, its deflection would be 20 times as large as that of the conventional inspection car to adversely affect measurement precision. So as to set a reference line at a place other than on the car body, we developed a reference device that emits a laser beam from the projector equipped on the end of the car, detects the displacement of the car body with a light sensor or a position sensitive device (PSD), and corrects the measurements of track irregularity. The asymmetric chord offset method cannot accommodate the large and heavy optical rail displacement sensor that monopolizes the center of the car body of conventional inspection cars, since the measuring frame is not so strong to support the sensor. We, therefore, newly developed a rail displacement sensor that has a self-contained light detector of PSD and a projector of a semiconductor laser oscillator. See Fig. 2. Although it uses the conventional principle of measurement, it is far more compact and lightweight than sensors for conventional rail displacement measurement. Based on these new technologies, regular track inspection at 275 km h^{-1} has been realized for Shinkansen in Japan.

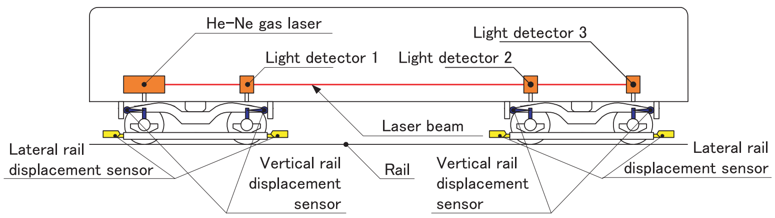

Figure 1. Composition of two-bogie asymmetrical chord offset track inspection car.

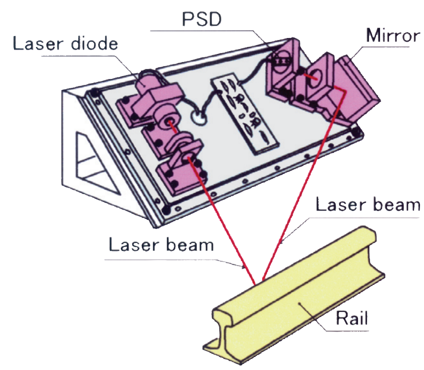

Figure 2. PSD-type lateral rail displacement sensor.

DEVELOPMENT OF NEW INERTIAL MEASUREMENT METHOD

In contrast to the aforementioned mid-chord offset and asymmetric chord offset methods for three-point measurement, the inertia method that integrates acceleration twice enables a one-point measurement of track irregularities. It may also introduce the manufacture of measuring devices at low costs. There were drawbacks in this method, however, in that waveforms were distorted due to the characteristics of electronic circuits to make measurements difficult to process. Thus, we contrived an inertial measuring method to obtain waveforms equivalent to those by the mid-chord offset method, which we call the inertial mid-chord offset measuring method. It features an on-board analog integrator that incorporates the measurement characteristics in the long waveform range of a mid-chord offset method in filter characteristics and calculations for correction with a general-purpose personal computer on the ground. We aim at a compact measuring unit that can be installed directly on a truck. Figure 3 shows an image of system composition, and Fig. 4 the construction of a prototype sensor unit. The newly developed element is the two-axle rail displacement sensor. This sensor tracks the rail with a servo-driven reflector and calculates the lateral and longitudinal rail displacements including those of large scales by the principle of triangulation. Figure 5 shows the irregularities of longitudinal level measured with the prototype device, which are similar to those available by the mid-chord offset method inspection car.

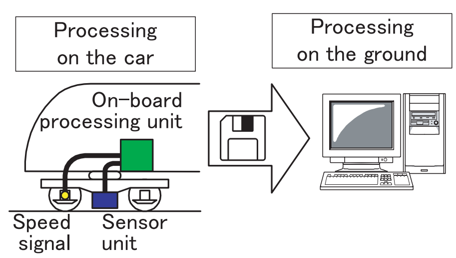

Figure 3. Composition of the inertial mid-chord offset measuring device.

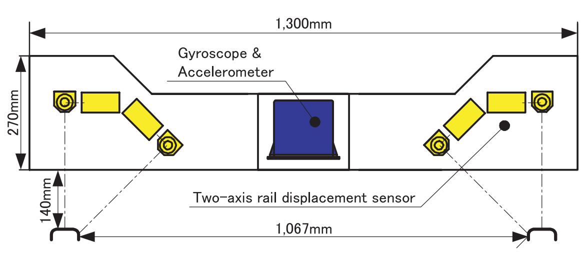

Figure 4. Composition of the sensor unit.

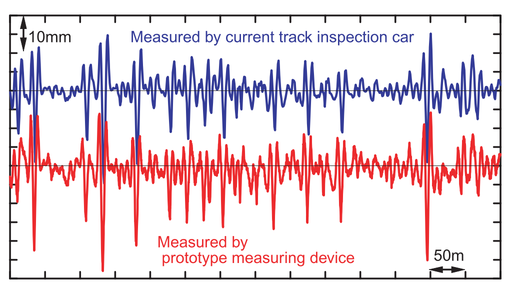

Figure 5. Results of track inspection by inertial mid-chord offset method.

Management of Rail Top Irregularities to Reduce Rolling Noise

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The rolling noise generated from conventional railways is generally defined as the sound emitted from wheel and rail due to the vibration of these two components caused by minor irregularities in between when a wheel rolls on a rail. As an important countermeasure to reduce railway noise, therefore, the rail top and wheel surface shall properly be smoothed to remove irregularities. In this newsletter, we introduce a technique to control rail top irregularities and keep rolling noise at an appropriate level.

It is said that rolling noise is caused by the vibration of rail, which is dominant in the frequency range from 800 to 1,000 Hz. It is required, therefore, that the characteristics of rail top irregularities be correctly assessed which affect this frequency range. We apply power spectrum density analysis to rail-top irregularities by employing the maximum entropy method (MEM) that provides a comparatively stable solution with a small quantity of data. Figure 1 shows power spectra obtained before and after rail grinding. There are no dominant components in rail top irregularities with the amplitude of irregularity spectrum becoming smaller as the waveform becomes shorter. Figure 1 also shows a definite effect of rail grinding to reduce the power spectrum about 10 dB. The equation in the Fig. 1 averages the power spectra in the section where it is assumed that the rail is properly ground and shows the satisfactory condition of rail top irregularities ensured by the present rail grinding technique.

To properly depress rolling noise, however, it is not practical to directly measure rail top irregularities in the order of μm. As a means of indirect management, it is conceivable to monitor rolling noise based on under-floor noise or by using axle box accelerometers.

Figure 2 shows the under-floor noise of a revenue service train that ran in a rail-ground section from which Fig. 1 was given. The average under-floor noise was about 105 dB(A) and 95 dB(A) before and after rail grinding, respectively. The difference in between is almost the same as that in the power spectra pictured in Fig. 1. This means that under-floor noise can be chosen to monitor the condition of rail grinding. An exception in Fig. 2 where the effect of rail grinding is not seen is the place of road crossing.

Figure 3 shows the results of a trial wavelet analysis, which is now in the limelight as a time-frequency analyzing technique, to utilize axle box accelerometers. It has been confirmed that places of abnormal rail top irregularities can correctly be detected by this analysis. We will compose a system to inspect rail top irregularities on the basis of this method.

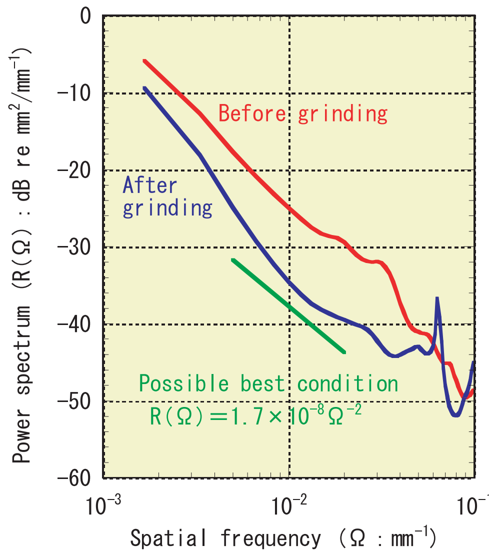

Figure 1. Power spectra of rail top irregularities.

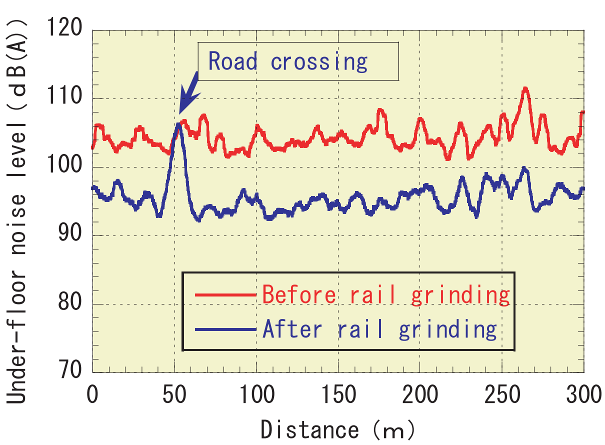

Figure 2. Measurement of under-floor noise (at 110 km h^{-1}).

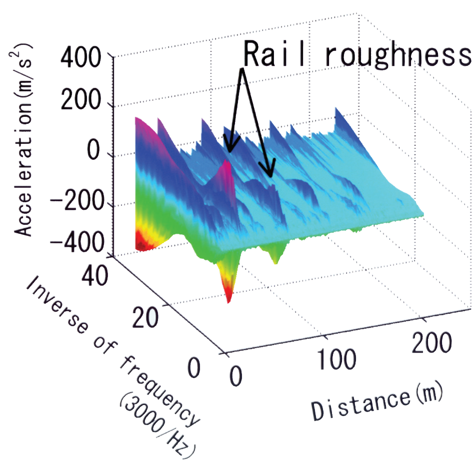

Figure 3. Example of the results of wavelet analysis (at 270 km h^{-1}).

Semi-Active Suspension System

Sasaki, Kimiaki
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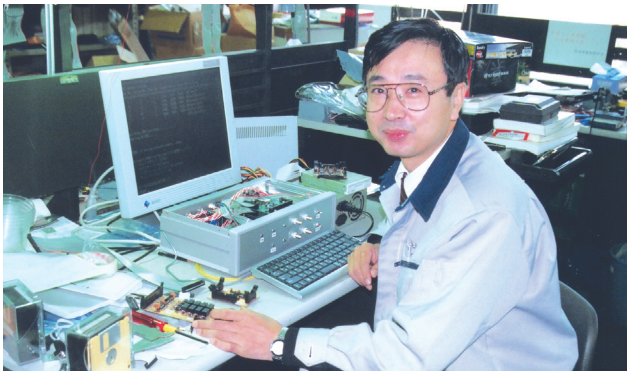

Vibration due to track irregularities and aerodynamic lateral vibration in tunnels worsen the ride comfort on Shinkansen cars and other high-speed rail vehicles. Since the vibration generating model for the vibration transmitted from trucks is different from that for the aerodynamic vibration that directly exerts force on the car body, the optimized damper characteristics become increasingly different for these two categories of vibration when the vehicle speed becomes higher. This means that optimization of passive suspension parameters alone cannot cope with these two cases.

The semi-active suspension system for Shinkansen cars was developed as a means to solve this problem with its effect to decrease vibration confirmed in running tests, and has been adopted for series 700 and 500 Shinkansen cars.

We developed the semi-active suspension system, the first one of its kind in the world to be used for revenue service trains, with safety and reliability as absolute prerequisite conditions, and have mounted on seven cars in a train-set including the cars equipped with a pantograph, first-class cars with special accommodations, and head/tail cars that are subject to large vibration.

To perform what is called the "sky hook control," the semi-suspension system determines the speed of car body vibration from the output of the lateral acceleration sensor mounted on the car body at a position directly above the truck and produces a force in proportion to the vibration speed with a changeable lateral damper on the truck. The damping force of the damper is controlled by changing the combination of throttle holes that pass the working fluid with quick electromagnetic valves. The controller has damping force corresponding to the piston speed for each combination of throttle holes to look for damping force nearest the value required for sky hook control. Since this demands the measurement of piston speed, each damper has a built-in displacement sensor. See Fig. 1 for an outline of the semi-active suspension system.

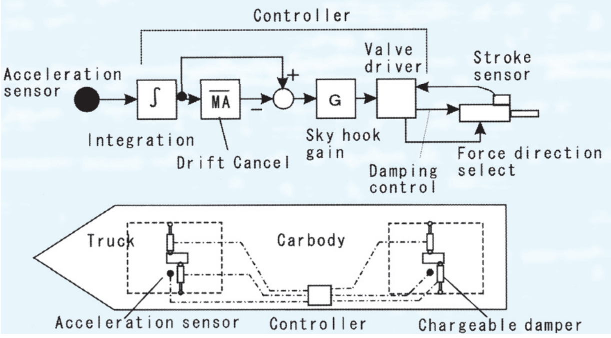

Figure 1. Semi-active suspension system of Shinkansen train.

This system also has an electromagnetic valve to release the force in the direction opposite to the damping force that is commanded by the sky hook control to realize Karnopps' method as the performance of hydraulic circuit. Attention is paid to ensure the fail-safe feature so that failure of a part does not lead to a dangerous state. When the power switch is turned off, the damper functions as a normal damper.

Figure 2 shows the ride comfort improved by the semi-active suspension system when a train ran at 300 km h^{-1} in a tunnel. In this test, the semi-active suspension was adopted for cars Nos. 5, 8 to 10, and 13. The car at the tail of the train was installed with one that produces the control force by pneumatic pressure. When trains with and without the semi-active suspension system are compared, the ride comfort was virtually the same on the cars without vibration control, but significantly enhanced on those with vibration control. The damping performance of the semi-active suspension system was close to that of the active suspension system.

It is the case that new types of Shinkansen cars are normally installed with dampers and the semi-active suspension system. Therefore, a new system is still being developed to use changeable dampers of the proportional relief valve type. A semi-active suspension system of this type is used for the series E2 Shinkansen cars that have made their debut recently. According to running test results, the new system has damping performance equal to or over that of the conventional system. The manufacturing cost of the new system is estimated to be 40% lower. An endurance test has also proved that there are no problems in the new system. It is expected that the semi-active suspension system of the proportional relief valve type will be employed in wide ranges.

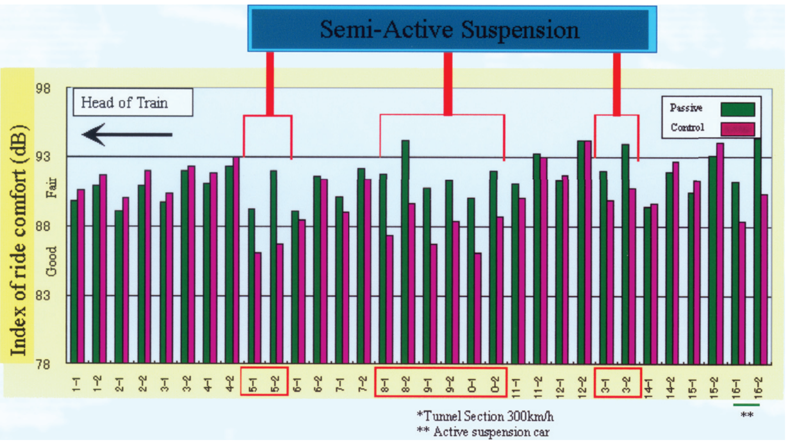

Figure 2. Effect of semi-active suspension.

Application of Permanent Magnet Synchronous Motor to Driving Railway Vehicles

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The development of power electronics technology in recent years has realized the inverter control of large-size induction motors. This technology is now applied to driving railway vehicles. Another noteworthy motor is the permanent magnet synchronous motor (PMSM) that has the performance required for traction motors and is more compact, lightweight, and efficient than induction motors. This report explains the construction and features of the PMSM, introduces the research and development at the Railway Technical Research Institute on its use as a direct drive traction motor and a totally-enclosed motor, and clarifies its potential in the future.

CONSTRUCTION AND FEATURES OF PMSM

Construction of PMSM. Figures 1 (a), (b), and (c) show the cross sections of typical PMSMs when the rotor is cut at a right angle to the motor shaft. Those illustrated in Figs. 1 (a) and (b) are called the surface magnet type motor since permanent magnets are fixed at the rotor surface. The motor in Fig. 1 (a), which has no saliency in the core profile, gives magnet torque but not reluctance torque in principle. Owing to the salient structure of the core, reluctance torque can be prepared by the motor given in Fig. 1 (b). The motor with magnets buried in the core in Fig. 1 (c) is called the buried magnet type motor, whose core normally has magnetic saliency to produce reluctance torque. Since the buried magnet type motor has no fragile magnets on the surface, it is simple and robust, and can be manufactured at low costs. Traction motors for railway vehicles must be durable and sturdy. To protect the main power circuit, it is desirable to use motors of the buried magnet type, in order to effectively utilize reluctance torque, and minimize the interlinkage magnetic flux generated with permanent magnets and the voltage induced at high-speed coasting.

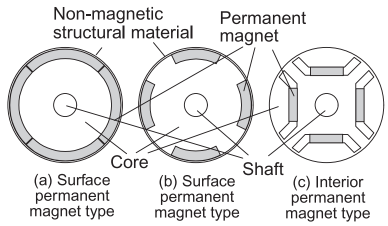

Figure 1. Cross section of the rotor of PMSM.

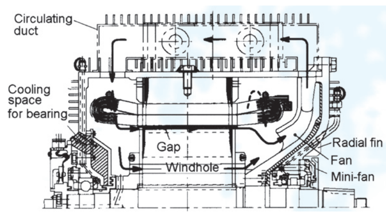

Figure 2. Cross section of the prototype totally-enclosed traction motor.

Features of PMSM. The most important feature of the PMSM is its high efficiency given with the ratio of input power after deduction of the loss to the input power. There is no field current or rotor current in the PMSM unlike in induction motors. The rotor is not subject, therefore, to loss in principle. Copper loss or generation of Joule heat due to a current flow, which is the largest loss in motors, is about half that of the induction motor. This significantly improves efficiency and subsequently reduces power consumption or power cost to make railways a more effective means of transport. Since the smaller the loss of the motor is, the smaller its constitution becomes, the PMSM features higher output than the induction motor of the same physical dimensions, or more compact and lightweight even when the output is the same.

APPLICATION OF PMSMS TO DRIVING RAILWAY VEHICLES

Use as a Direct Drive Traction Motor. To make traction motors smaller, gear units are normally employed. In a railway vehicle, the torque given by traction motors is transmitted to the wheel axle to drive the vehicle. There are a number of problems in the gear unit, however, such as transmission loss, emission of noise, and difficulty in maintenance work. Adoption of the direct drive system will solve these problems, but will make traction motors larger, increase the unsprung mass, and subject traction motors to larger shock. For these reasons, it was tough in the past to adopt the direct drive system for trucks whose size and weight are limited. Since PMSMs are more compact and lightweight than induction motors, we felt the feasibility of a direct drive system to use PMSMs and developed a traction motor of the direct drive type. See Table 1 for its features. A field test proved that noise was reduced 14 dB when prototype traction motors of the direct drive type were installed on narrow-gauge commuter EMUs. For its simple structure, the direct drive type traction motor may also be introduced for gauge-changeable EMUs and low-floor streetcars. The motor of this type should be developed further.

Use as a Totally-Enclosed Traction Motor. A ventilation cooling system is normally employed for compact and high-output traction motors for railway vehicles. However, the dust contained in the cooling air soils the inside of the traction motor, which requires regular disassembling and cleaning. The traction motors for narrow-gauge vehicles emit high noise at high-speed rotation, since a ventilating fan is connected directly to the rotor, say, self-ventilation cooling. If the traction motor is totally enclosed, little dust rushes into the inside. This will eliminate the necessity of disassembling and cleaning, and cut noise to make them quieter. However, the cooling performance of totally-enclosed motors is inferior to that of ventilation-cooling-type motors. To ensure the same performance for a totally-enclosed motor that has the same physical dimensions as those of a conventional motor, therefore, it is required that a new cooling system be introduced to reduce heat generation down to the allowable limit. To suppress temperature rises, we adopted a high-efficiency and low heat generation PMSM. In the case of a totally-enclosed motor, the whole motor structure is subject to temperature rises. This requires prevention of excessive rises in temperature at bearings. We tested a prototype PMSM equipped with a newly developed bearing cooling system and checked the effects of cooling and low noise emission (Fig. 2). The test proved that it was possible to manufacture totally-enclosed traction motors with the same output as that of conventional self-cooling motors with equivalent physical dimensions, reduce their noise 10 dB even at high-speed rotation, and attain high-efficiency and compactness of the structure.

Table 1. Features of the direct drive type motor

Advantage
-Does not require the maintenance of gear unit
-Does not require the space for installation of gear unit
-No power transmission loss (high efficiency)
-Low noise
Disadvantage
-Large shock on traction motors
-Tends to be heavy and slow in rotation
-Larger unsprung mass

POSTFACE

The traction motors for railway vehicles must be robust, compact, and lightweight. PMSMs, which inherently feature high efficiency, compactness, and lightweight, are ideal for railway vehicles and essential for the times when energy saving and environmental preservation are all-important social problems. We hope that the research results on PMSMs will help promote their dissemination and application to railway vehicles.

Power Storage at Substations

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Application of a power storage system to electric railways will cut the contact demands, power consumption and electric charges at substations, effectively utilize power regenerated to save energy, and relieve the voltage drop of overhead lines. This study aims at establishing specifications for the power storage system for electric railways.

OUTLINE OF POWER STORAGE SYSTEM

We had an eye to electric double layer capacitors (EDLCs) as a medium to store power for electric railways for the reason that it features a long life without requiring frequent maintenance and has quick charge/discharge characteristics better than those of secondary batteries. These features suit electric railways under large fluctuations in workloads. A high-efficiency step-up and -down chopper is promising as a power converter to control the charging/discharging operation without relying on the EDLC voltage. Based on the above discussions, we had a mini-model of a DC 400 V power storage system manufactured by using an EDLC and a step-up and -down chopper. Table 1 indicates the specifications for EDLCs. Since the voltage per cell of an EDLC is 2 V, we increased the voltage and capacity of the model by connecting cells in series and parallel, respectively. The energy capacity of the model was about 80 kW available for five seconds. The voltage on the EDLC side was increased or dropped by the chopper to transfer energy to and from a DC 400 V feeding system. Figure 1 shows the major components of the mini-model, which has a rectifier, a power source and resistance/inductance to simulate a substation, a railway vehicle and the impedance of overhead lines, respectively, in addition to a power storage system. Figure 2 gives the test results of the mini-model. When the powering current is large, the voltage of the railway vehicle drops. Since the EDLC discharges, however, the current supplied by the substation is suppressed. This in turn suppresses the voltage drop that would occur when an EDLC is not used. As the EDLC absorbs the power regenerated during regenerating operation, the voltage of the railway vehicle does not increase. As a result, we were able to confirm that the EDLC would contribute to the stability of the power supply system for electric railways. As a revised version of the mini-model, we are now discussing a power storage system that combines an EDLC and a high-capacity lead storage battery. We are also performing an accelerated degradation test of a DC 100 V power storage system to verify the life of the EDLC.

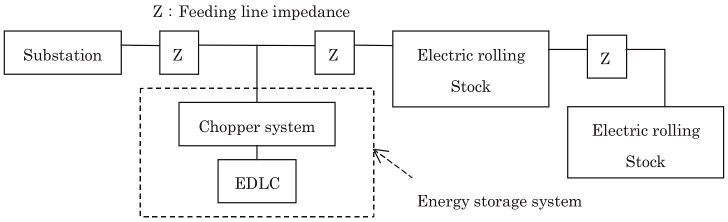


Figure 1. Main circuit of mini-model.

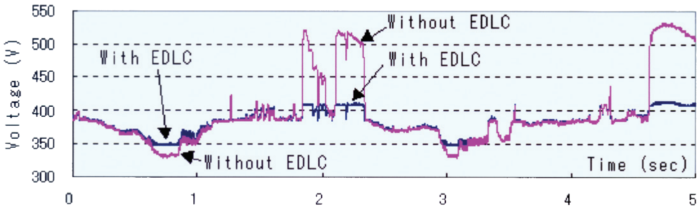


Figure 2. Test results.

Table 1. Specifications for EDLCs

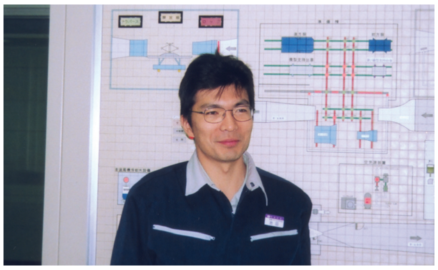
Item	Unit	Block	Module
Constitution	46-Cell series	8-Unit parallel	3-Block series
Voltage	93 V	93 V	280 V
Current	50 A	400 A	400 A
Capacity	12 F	97 F	32 F
Resistance	0.44 Ω	0.05 Ω	0.16 Ω
Dimension	D, 340 mm	D, 431 mm	D, 1000 mm
	W, 340 mm	W, 465 mm	W, 900 mm
	H, 50 mm	H, 537 mm	H, 2300 mm
Weight	7.2 kg	74.5 kg	715 kg

FUTURE SCHEDULE

We will simulate a power storage system to establish specifications optimized for optional electric railway sections, and promote researches to test a power storage system that will be applied to actual service lines.

Precise Contact Force Measuring Method for Current Collection System

Ikeda, Mitsuru
Senior Researcher, Current Collection, Railway Dynamics Division



The current collection system is subject to vibration due to the interaction between catenary and pantograph through the contact force in between. This requires precise measurement of the contact force, which is an essential factor in evaluating the performance of current collection. At the Railway Technical Research Institute, we have promoted researches on the method to measure the contact force and succeeded in substantially expanding the range of measurable frequencies as explained below.

METHOD TO MEASURE THE CONTACT FORCE

We first set a control volume on the pan as shown in Fig. 1 and considered the equilibrium between the forces acting thereon. The contact force is then expressed as the sum of the force F_a on the cross section A, the force F_b on the cross section B, and the inertia force acting on the part sandwiched between these sections. F_a and F_b are measured with load sensors fixed at the pan. Types and positions of the load sensors are determined in consideration of the profile and supporting method of the pan. We can easily obtain F_a and F_b by measuring the shearing force with strain gauges pasted on its side when the pan is not so rigid, or measure the pan springing load when the pan is supported at the center or highly rigid to make it difficult to detect strain. The inertia force F_{ine} can be measured with an accelerometer placed on the pan. In actuality, however, it is difficult to measure F_{ine} at high frequencies, since elastic vibration becomes dominant to make it impossible to regard the pan as a rigid body. In the conventional method, therefore, the components at these frequencies are cut with a low pass filter. The cut-off frequency is set at 20 Hz in the European Standard of EN 5031, for example. To solve this problem, we have developed a method to measure the inertial force by calculating the weighted average of the measurements obtained from a plurality of accelerometers installed on the pan. To correctly determine the inertia force when there are n dominant vibration modes in the frequency range to measure the contact force, we measure the values of acceleration at discrete points xj (j = 1 to n), and multiply each value by an appropriate weighted factor. This enables us to measure the inertia force at high precision even in the high frequency range where elastic vibration is dominant.

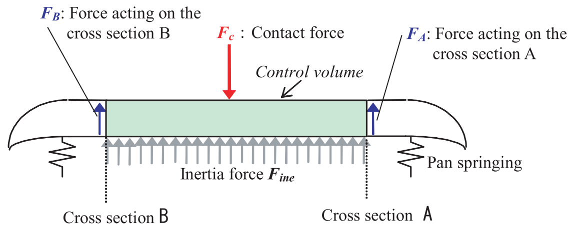


Figure 1. Force equilibrium on a panhead.

PRECISION OF THE CONTACT FORCE MEASUREMENT

Figure 2 shows the precision of the contact force measurement when this technique was applied to the Shinkansen pantograph PS202. The inertia force was measured with three accelerometers attached to the pan bottom. Since the first elastic mode of the pan is at about 80 Hz, the conventional method to use an accelerometer can measure the contact force only up to about 40 Hz. In contrast, this technique enables measurement in the frequency range up to 100 Hz at high precision.

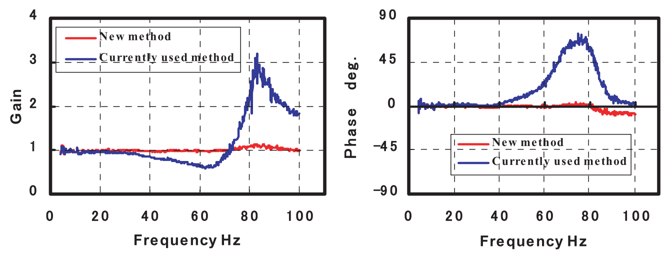


Figure 2. Measurement precision.

APPLICATION TO THE DIAGNOSIS OF CONTACT LINE FACILITIES

The standard deviation of contact force measurements has been used to evaluate the performance of current collection. As a case study of the diagnosis of contact line facilities, however, we will estimate below the wave propagation velocity in trolley wires, which is one of the parameters that determine the performance of current collection. The fluctuation of contact wire is strongly affected by the spatial periodicity of contact line facilities, such as the spans between support poles and between hangers. Since the spatial periodicity depends on train speed, however, it is effective to observe frequency information and time-related information simultaneously, in order to extract the features of contact line facilities. The chart in the middle of Fig. 3 shows the fluctuation of contact force measured in a simple catenary section. The chart at the top displays the contact force processed through short-time Fourier analysis, with the frequency normalized with respect to train speed and converted into the number of waves, or the power spectrum density normalized by a logarithmic scale. The red part indicates the place of high power spectrum density. This chart shows that dominant components exist at the specific numbers of waves, in particular, at the number of 0.2 that corresponds to the hanger interval of 5 m. We can confirm by this chart that the fluctuation of contact force depends on the spatial periodicity of contact line structure. The contact force also fluctuates when the pantograph receives the waves that are excited by the fluctuation of contact force over hanger intervals and reflected at hanger points, as expected by theoretical analysis. The chart also indicates that this phenomenon has occurred in the present case. The number of waves of the contact force fluctuation for the above reason depends on train speed and wave propagation velocity in the trolley wire. Based on this fact, we can also estimate the wave propagation velocity. By comparing the estimated and measured values, we have proved that the wave propagation velocity can be expected at the precision of about 10% (Fig. 4).

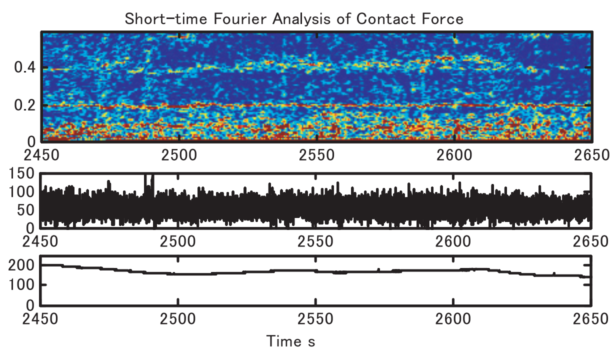


Figure 3. Measurement results of contact force on a line test.

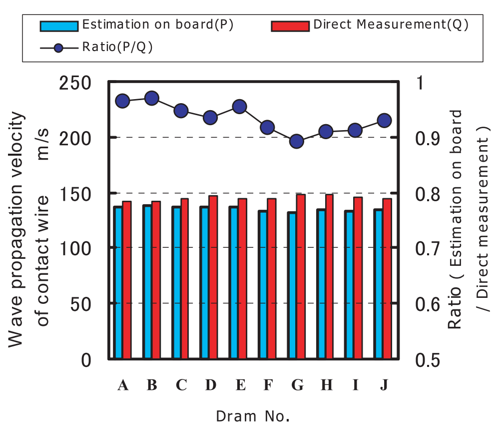


Figure 4. Estimation of wave propagation velocity of contact wires by contact force measurements.

POSTFACE

The method to measure the contact force introduced above can be applied to pantographs of other types. We have already measured the contact force of different pantographs used for Shinkansen and narrow-gauge lines. As a technique to measure the contact force in a wider frequency range than that coped with by the above method, we have also developed a method to estimate the contact force based on the dynamic response of pantograph through the analysis of pantograph vibration, by using sensors more than the number of dominant vibration modes installed on the pantograph and the transmission function from each sensor to the contact force. This method features a high degree of freedom for sensor arrangement. As an expanded version of this method, we have also developed a method to simultaneously measure the contact force not only in the vertical direction but also in the longitudinal direction. We will promote researches focusing on the method to utilize the contact force measurements for the diagnosis of contact lines.

Development of a New Early Earthquake Detection and Alarm System

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The Railway Technical Research Institute (RTRI) has developed an urgent earthquake detection and alarm system (UREDAS) and put it into practical use mainly for Shinkansen. Valuable knowledge is being accumulated to issue an urgent alarm for earthquakes due to the development of the real-time seismology in recent years. The Japan Meteorological Agency (JMA) and other governmental organizations are improving the nationwide earthquake observation network and planning to distribute prompt earthquake information (now-cast earthquake information). Under the circumstances, RTRI is studying new methods to predict seismic source parameters based on the P-wave and urgently estimate earthquake damage, and promoting the development of a new early earthquake detection and alarm system to utilize the prompt earthquake information provided by governmental organizations jointly with JMA.

NEW EARLY EARTHQUAKE DETECTION AND ALARM SYSTEM

A New Method to Predict Seismic Source Parameters. The conventional system roughly estimates the magnitude and the epicenter by observing the period and the maximum amplitude of the initial P-wave measured at a observation point, and issues an alarm before the arrival of the main shock. RTRI has discussed a method to predict seismic source parameters based on the P-wave by utilizing the latest knowledge in seismology and other scientific fields, and developed a new method to estimate the magnitude and the distance to the epicenter from the maximum amplitude and the amplitude increasing rates of the initial P-wave (Fig. 1). The relationship between the rate of increase in the envelope of the initial P-wave and the distance to the epicenter from observation points is illustrated in Fig. 2. When compared with the conventional method, the new method estimates the magnitude at higher precision (Fig. 3) while less affected by the noise of ground motion.

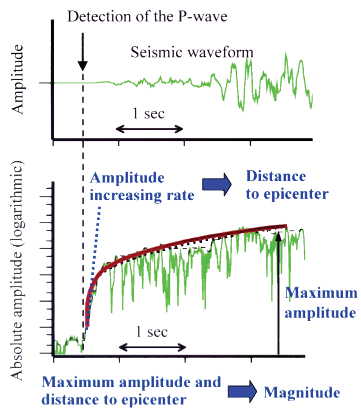

Figure 1. New method to predict seismic source parameters.

Seismograph for the New System. RTRI has developed a seismograph for the new system by applying the new method to detect seismic source parameters (Fig. 4), and by assuming the application to observation points of railway operators. Since it applies the latest information technology, it has several merits when compared with the conventional system, in addition to the aforementioned improved precision in the detection of source parameters. A built-in PC, for example, makes the seismograph compact and lightweight and enables parallel processing and remote operation with a real-time OS. Circuits are designed to incorporate countermeasures against electromagnetic noise. This makes it possible to use the seismograph at observation points in wayside substations.

Now-Cast Earthquake Information. JMA has a plan to measure the seismic waves near the epicenter at 180 observation points across the country and prepare the information on the epicenter, magnitude, main shock arrival time and predicted seismic intensity, which is called the now-cast earthquake information, before the main shock arrives. The now-cast information will be distributed when the P-wave has arrived at the observation point nearest the epicenter and repeatedly thereafter at certain time intervals. The information which is created first (the 0^{th} information) is on the seismic source parameters estimated from the data of the P-wave which is caught at an observation point in a few seconds. The new method mentioned above will be used to process this information. After that, more precise information (the 1^{st} information, the 2^{nd} information and so on) will be distributed, as the seismic motion is observed at other observation points. The new system uses the now-cast information (mainly the 0^{th} information) provided by JMA in addition to the information obtained by railways. It is thought, therefore, that the function of the UREDAS for Shinkansen will significantly be improved. It will also be possible to apply it to narrow-gauge lines at low costs.

FUTURE PLAN OF RTRI

RTRI has constructed a prototype compound system to combine the new early earthquake detection and alarm system and the post-earthquake operation restart support system on its premises in 2002 autumn for operation tests, based on which it will propose the specifications for a practical compound system at the end of fiscal 2002. In 2003 autumn, it will start a test of the normal operation of the compound system based on the now-cast information and two-dimensional information on the seismic intensity estimated by JMA.

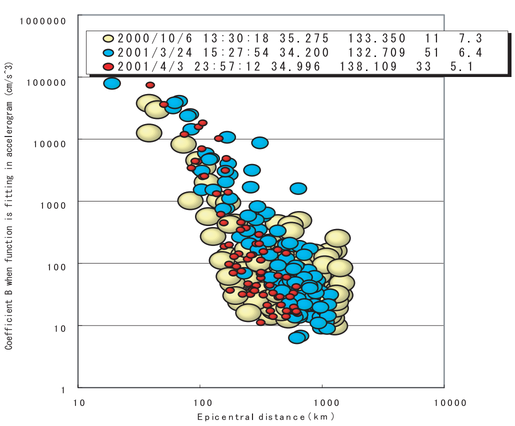

Figure 2. Relationship between the rate of increase in the envelope of the initial P-wave and the distance to the e picenter.

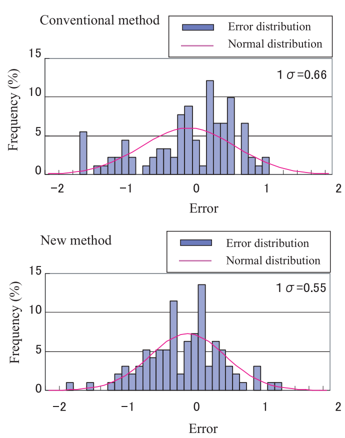

Figure 3. Comparison of the precision of the estimation of magnitude.

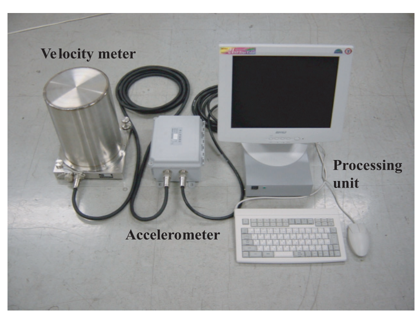

Figure 4. Seismograph for the new system (prototype).

A Method to Estimate the Efficiency of Ground Vibration Reduction Wall

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Among the various countermeasures for rolling stock, tracks and structures that have been discussed to prevent the ground vibration along railway lines, burying a wall in the ground is expected to be a comparatively effective solution to cut off vibration. Since the effect of vibration isolation work depends on the ground conditions and the materials, size and other conditions of wall-in-ground, however, there are no quantitative designing methods established to isolate vibration. Therefore, we reviewed the results of model experiments and field tests in the past from a new viewpoint and developed a method to quantitatively evaluate the effect of vibration isolation work as described below.

OUTLINE OF THE EVALUATION METHOD

In planning and designing vibration isolation work, it is desirable to have a simple and convenient method to evaluate its effect. Thus, we composed a moderately simple theoretical model to evaluate the effect of vibration isolation work in quantitative terms. This model features the following (Fig. 1):

(1) Assumes that a surface wave (Rayleigh wave) is generated from the ground vibration and that the vibration energy behind the wall-in-ground is the sum of the energy of the transmitted wave through the wall and the energy of the diffracted wave originated from its side and bottom.

(2) Applies Kirchhoff's diffraction theory, which is introduced in the fields of optics and acoustics, to the evaluation of the diffracted wave.

(3) Applies the one-dimensional wave transmission theory that is normally used and the beam deformation theory by regarding the wall-in-ground as a beam to calculate the transmission rate of the wave transmitted through it. Since it is far simpler than the numerical analysis by the finite element method (FEM), the newly developed evaluation method will be useful for planning and designing vibration isolation work along railway lines.

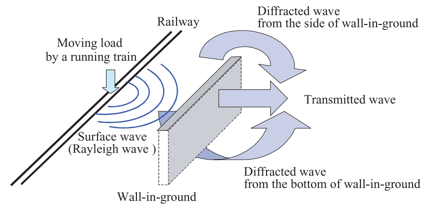

Figure 1. Schematic illustration of transmitted and diffracted waves by the wall-in-ground.

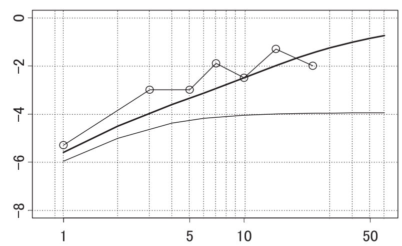

Figure 2. Estimation of vibration reduction by wall-in-ground. The wall is a concrete wall and has a depth of 3 m, a thickness of 1.2 m and an extension of 80 m. Estimated reduction (1) is obtained by using the diffracted wave from the bottom of wall-in-ground and the transmitted wave. Estimated equation (2) is the estimated equation (1) corrected for the diffracted wave from the side of wall-in-ground.

VERIFICATION WITH MEASUREMENT DATA

To verify its validity, we applied the evaluation method to 13 model experiments of vibration isolation work in the past and seven field-execution tests in Shinkansen viaduct sections. As a result, the actual effect to isolate vibration was reproduced through calculations in consideration of the diffraction wave that comes from the bottom of the vibration isolation structure and the wave transmitted through it in the vicinity from the structure to a place 5-m distant therefrom, and can quantitatively be evaluated by correcting the calculations for the diffraction and transmitted waves with respect to the effect of the diffraction wave from the side of the structure beyond the said point (Fig. 2).

TRIAL DESIGNING OF VIBRATION ISOLATION STRUCTURE

We applied this evaluation method to the construction of a concrete wall-in-ground under the actual ground conditions indicated in Fig. 3 (normal ground at the site A and soft ground at the site B) and found that:

(1) The effect of vibration isolation structure of the same size is different for different ground conditions (Fig. 4).

(2) Deeper structures are more effective up to a ceiling point, beyond which the effect is not proportional to the depth.

(3) Longer structures are more effective (Fig. 5).

Since the effect of vibration isolation work is significantly different for different ground conditions as mentioned above, it is important to design an effective vibration isolation structure most appropriate to the object site.

POSTFACE

According to the researches and studies hitherto carried through on the countermeasures against the vibration along railway lines, it is possible to quantitatively evaluate the effect of lightweight vehicles, tracks with a low spring constant, and vibration isolation structures. In addition, there are various categories of vibration isolation work that are still at the stages of basic discussions, experiments, and numerical analyses. We will promote research and development on such categories of vibration isolation work and establish a manual for countermeasures against vibration to be consulted for selecting the vibration isolation work that best suits the actual conditions of ground vibration.

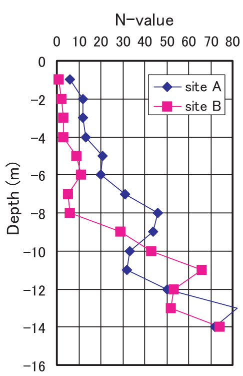

Figure 3. N-value profiles at the sites A and B.

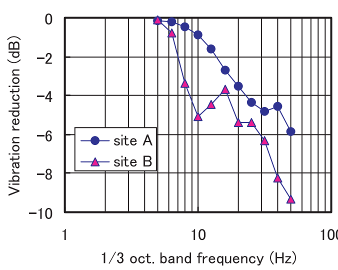

Figure 4. Estimated frequency spectra in the 1/3 octave scale of vibration reduction by the wall-in-ground at a point 1-m distant from the wall-in-ground. The wall-in-ground has a depth of 3 m and a thickness of 0.8 m.

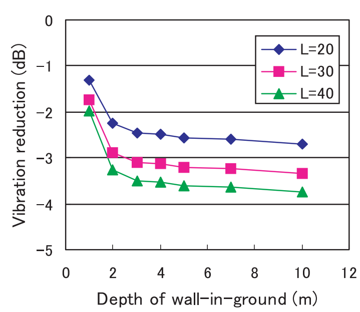

Figure 5. Estimated vibration reduction by the wall-in-ground at a point 12.5-m distant from the track. L means the length of wall-in-ground (unit: m).