

Advance in Railway Vehicle Technology and Future Prospects Mainly in Relation to Bogie

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Abstract

Since the world's first public railway opened in Britain in 1825, high speed and safety have been the most important technical issues for the improvement of rolling stock performance. In particular, the trade-off problem between the curve negotiation and the high-speed running stability is a basic issue for bogie design technology. But today, by the use of simulation techniques, we can design the suitable rolling stock for the various applications. For the higher performance of rolling stocks, the following technical issues have been challenged. The issues for high speed are the prevention of hunting, high speed curve negotiation by the use of tilting control, brake technology to slow down early from the high-speed range, and acceleration of lightweight. The issues for safety are the derailment prevention on the curve, the safety against the natural disasters. In addition, we are working on a ride comfort, an environmental protection such as noise and vibration, and the issues of maintenance.

1. Introduction

Ever since the first public railway of the world began its operation in the U.K. in 1825, the most fundamental requirement for railway technology has been the pursuit for higher speeds and safety.

Soon after the opening of railway services, conical wheel treads, bogies, and other measures essential for negotiating curves safely and smoothly were daily practice as early as around 1830. Bogies were first used in the U.S.A., where the track condition was poor and derailment occurred often, as the leading bogie of steam engines to guide the engine body at curves. Soon after that, bogies began to be also used for passenger cars, and thus the basic configuration of railway vehicles that we see nowadays was established in the early days of railway transport.

Since then, wide varieties of technical measures aiming at higher speeds and safety have been taken. The present paper introduces the latest attempts for higher performance of railway vehicles mainly from the viewpoint of bogie technology, which counts 180 years of history.

Described in the first place are the two most essential and mutually conflicting challenges in the pursuit for faster and safer trains: running stability at high speeds and curve negotiating performance. Then, technical problems related to requirements of higher orders,

namely ride comfort and environmental protection, are dealt with. What is required for maintenance of railway vehicles, an issue of increasing attention, is also considered, and finally, some prospects for the future of railway technology are presented.

2. Bogie Construction and Basic Design Requirements

2.1 Bogie construction and functions

Bogies support the body weight, transfer the traction and braking forces, and in addition to these fundamental functions as the running gear, they also play important roles in realizing various aspects of running performance required for the vehicles, such as stability at high speeds, safe passing through curves, and good ride comfort. Bogies are structurally classified by the use or otherwise of a bolster, a kind of beam to transfer body weight to the bogie frame and allow its turn with respect to the body, into bogies with bolsters (bolster bogies) and those without (bolsterless trucks). A typical bolster bogie for electric cars is given in Fig. 1.

The main components of a bogie are as follows: wheel sets; a bogie frame, the largest structural component of a bogie fabricated by welding steel plates, pipes, castings, forgings, etc., together; primary suspension systems that link wheel sets to the frame and in-

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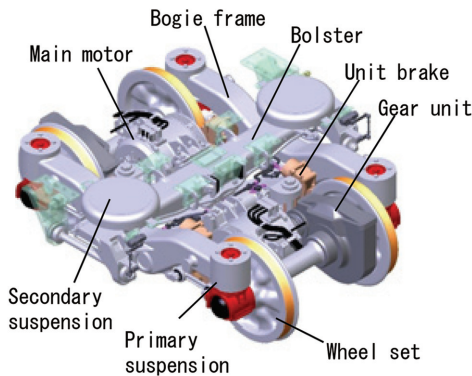


Fig. 1 Bogie components

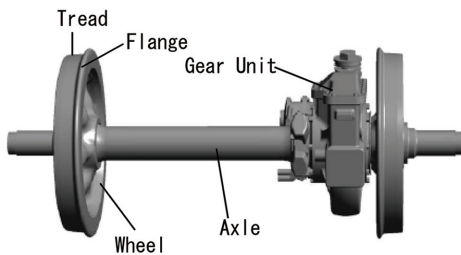


Fig. 2 Construction of wheel set

clude springs of steel coils or rubber; a bolster; a secondary suspension system that links the bogie to the vehicle body, usually using air springs; and running gears consisting of a set or two of the main motor and a gear unit and brake systems.

2.2 Tradeoff between speed increase and curve negotiation

A wheel set assembled by fitting wheels onto an axle is an essential component of a railway vehicle. An example of a driving wheel set is shown in Fig. 2. The surface of a wheel that contacts the rail is called the tread, and as a measure for smooth running at curves and aligning the wheel set to the center line at straight-line tracks, the tread is tapered, the taper being called the tread conicity.

At a curve, a wheel set shifts toward the outer rail, the effective diameters of the outer and inner wheels automatically become different from each other as a result, and the wheel set goes along the curve smoothly just like a paper cup rolls drawing an arc. On the other hand, the tread conicity causes unstable vibration, called bogie hunting, at high speeds. Thus, the larger the tread conicity, the easier it is to negotiate curves, but the more unstable running behavior becomes at high speeds. This dilemma haunts the dynamics of railway vehicles, and the most fundamental problem in the design of bogies is how to deal with the tradeoff. For example, a large tread conicity is preferred for subway cars since there are many tight curves in subway lines and the train speed is not very high, and a small conicity for high-speed bullet trains (such standard-gauge, high-speed trains in Japan being hereinafter called the Shinkansen trains) since the lines have few tight curves and running stability at high speeds is essential.

3. Problems in Speed Increase and Technical Development

3.1 Running stability at high speeds

It is said that the railway vehicle system based on steel wheels

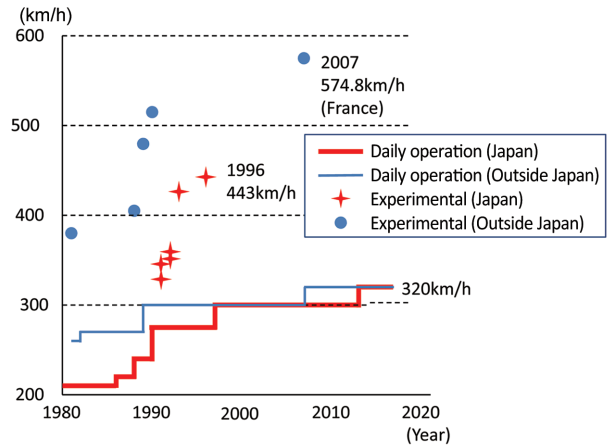


Fig. 3 History of maximum train speed since 1980

on steel rails has to face three barriers in the challenge for high speed: adhesion to transfer the traction force from the wheels to the rails without slipping; high-speed running stability of bogies (prevention of hunting); and power collection with pantographs.

Once it was widely believed that the speed barrier for railway vehicles lied somewhere around 300 km/h, but now, because of improvement in the wheel-rail adhesion, decrease in air drag and other running resistance, and increase in drive power, many trains run stably at 320 km/h on many lines in various countries of the world. The highest train speed record of 574.8 km/h was attained experimentally in France in 2007, and technical developments are under way aiming at commercial operation in the level of 360 km/h. The history of the pursuit for higher train speeds, either experimental or commercial, in and outside Japan since the 1980s is given in Fig. 3.

As stated earlier, the most essential issue in the design of bogies for high-speed operation is stability. Reports say that, in the initial stage of development of the Tokaido Shinkansen Line, bogie hunting of test trains was so violent that the tracks were often deformed. It is widely known that ex-designers of fighter airplanes who changed their jobs after WWII from the aircraft industry to the then Japan National Railways applied the analysis results of the aircraft wing flutter to the examination of the problem, and bogie hunting was put under control.

Today, hunting does not constitute a serious problem any longer because of powerful analysis tools such as computer simulation to define bogies parameters and facilities such as roller-rig bogie test beds.

However, as stated in Sub-section 2.2, realizing both high-speed stability and smooth curve negotiation simultaneously is still a problem. The series E6 trains started operation in the spring of 2013 will run the much straight Tohoku Shinkansen Line of East Japan Railway Company (JR East) from Tokyo to Morioka at high speeds, and from there, go on to Akita via the conventional (non-Shinkansen) route full of curves at lower speeds. To cope with these contradictory conditions, the trains are equipped with a mechanism whereby the force of oil dampers (anti-yawing dampers) to suppress bogie hunting is changed: both anti-yawing dampers shown in Fig. 4 are used in the Shinkansen section, and only one in the conventional-route section.

3.2 Increasing train speed at curves

Besides raising the maximum train speed, what is important for decreasing the travel time from one place to another is to increase

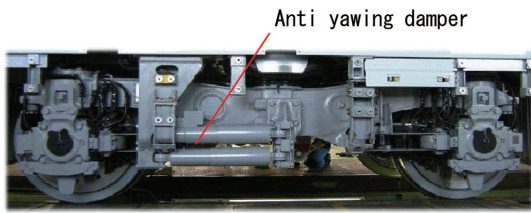


Fig. 4 Bogie for JR East series E6 Shinkansen

train speed at curves. Especially on conventional 1067-mm gauge lines in mountainous regions, raising the maximum train speed does not necessarily lead to shorter travel time because of frequent decelerations at curves. Even on the Shinkansen lines, the importance of train speed at curves has increased with an increase in the maximum cruising speed.

When the train speed at a curve is excessively high, the centrifugal force becomes so large that passengers feel uncomfortable, which has been the most important reason for limiting train speed at curves. Lateral force on passengers is commonly expressed in terms of acceleration; in Japan, a lateral acceleration of 0.8 m/s^2 is generally considered to be the upper limit of comfortable ride.

In consideration of this, tracks are inclined toward the inside of a curve (the inclination being called a cant) so as to cancel out the centrifugal force toward the outside with the falling toward the inside by the gravitational pull. The magnitude of a cant is usually expressed in terms of the height difference between the outer and inner rails. The size of a cant is defined, basically, on the basis of the curve radius and train speed, considering factors such as different kinds of trains passing at different speeds, their possible stop at the curve, lateral wind, and its velocity. For this reason, when higher train speeds at curves are envisaged, increase in the cant cannot be an adequate solution. Another solution is to tilt the train body to compensate for insufficient effects of the cant. As a solution, body tilting systems have been developed and commercially applied to cancel out the unpleasant lateral acceleration on passengers and enable speed increase.

In Japan, a body tilting system whereby train bodies supported on rollers tilted at curves under centrifugal force (see Fig. 5) was developed and commercially applied in 1973; this type of train was called the pendulum train. This mechanism allowed the bodies to tilt by up to approximately 5° , and the trains to pass curves at higher speeds. By this mechanism, however, the tilting motion delayed at the entrance and exit of a curve because it showed only when the centrifugal force overcame the rotational resistance of the rollers, which caused motion sickness among many passengers. In consideration of this, an advanced controlled body-tilting system was developed later: on the basis of the curve data stored in the system controller and the travel tracking function, the motion of the tilting bolster was pneumatically assisted before entering a curve.

However, since these body-tilting mechanisms are bulky and complicated, a simpler air-spring tilting system has been developed and commercially applied; by this method, the body is tilted simply by pneumatically differentiating the heights of the air springs on both sides of the bogies (see Fig. 6). Although this method allows a rather limited train speed increase because the maximum tilting angle is set at 2° , its simple structure is a significant advantage.

The simple air-spring tilting system has been used for the Shinkansen trains in appreciation of its light weight as well as for trains of the conventional 1067-mm gauge JR lines and other rail-

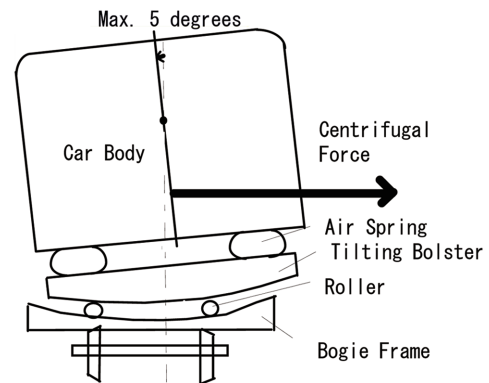


Fig. 5 Structure of pendulum tilting system

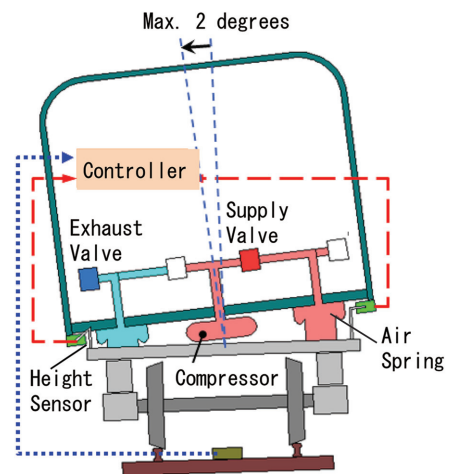


Fig. 6 Structure of air spring tilting system

way companies owing to its low costs of installation and maintenance.

3.3 Braking

The importance of braking technology increases with increasing train speed. When an electric locomotive hauling three passenger cars ran at 331 km/h in France in 1955, setting the world train speed record at that time while causing the overhead power line to fuse and the track to deform, rumors are that the brake system was insufficient to deal with the speed, and that it was necessary to open all windows of the cars to slow down the train. This indicates that it is easier to accelerate a train than to stop it.

Latest electric trains usually decelerate almost to a stop depending only on electric brakes: the drive motors are used as generators, and the braking force is obtained by converting the train's kinetic energy into electric energy and consuming the generated electric energy in the train itself or using it somewhere else. Nevertheless, since braking is of vital importance, railway vehicles must have a mechanical brake system capable of bringing them to a stop by itself.

Shinkansen trains use disc brakes for the mechanical brake system. Efforts have been bent to enhance the capacity of the disc brake system in view of the increasing braking energy required at higher speeds, and especially to stop the trains as quickly as possible in the event of a big earthquake. Higher train speeds call for higher brak-

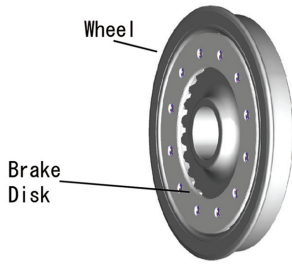


Fig. 7 Center-connection type wheel mounted disc

ing energy, which in turn requires more heat capacity of the discs. To minimize the weight increase and secure stable and powerful braking force, center-connection discs were newly developed and are used for the latest Shinkansen vehicles. While conventional brake discs were fixed to the wheels at bolt holes along its inner circumference, the new type discs have bolt holes along a circle in the center of the friction area. This design allows weight reduction and minimizes thermal deformation during braking. An example of this brake disc fitted to a wheel is shown in Fig. 7.

3.4 Weight reduction

Weigh reduction of the unsprung parts of bogies is important, especially for high-speed vehicles for the Shinkansen lines and the like. This is because an increase in the mass of unsprung parts directly contacting the rails causes the following: increased loads on rails; dynamic change in wheel loads, which may lead to track deformation; and increased noise and vibration adversely affecting the environment along the railway lines.

The measures to decrease the unsprung weight includes things such as use of bolsterless bogies, weight reduction design of bogie based on strength analysis applying the finite element method (FEM), application of aluminum alloys to axle boxes and gear boxes, and use of hollow axles and above-said center-connection brake discs.

4. Running Safety and Technical Development

4.1 Evaluation of safety against derailment

The most important issue about the running safety of trains is the derailment and overturn at curves. When a new railway line is inaugurated or a new vehicle model is introduced, running safety is evaluated in terms of an indicator called the derailment coefficient, usually through test runs using special wheel sets called the PQ wheel sets.

As illustrated in Fig. 8, the derailment coefficient is the ratio (Q/P) of the lateral force Q that a wheel applies to the rail to the vertical force P, or the wheel load. When the value of Q/P is within a prescribed range (0.8 or less, for instance), the curve or the vehicle is considered safe against derailment.

4.2 Running safety at curves

To improve the derailment coefficient Q/P, it is important to suppress the increase in the lateral force Q and prevent the decrease in the wheel load P. A measure to suppress the increase in the lateral force Q is to design the tread shape such that the wheel set can negotiate curves as smoothly as possible, as stated in Sub-section 2.2. Instead of simply changing the gradient of wheel treads, sometimes what is called the arc wheel profile is used to achieve excellent stability at straight-line tracks and good curve negotiation. By this tread design, the tread portion contacting the rail at straight-line tracks has a small-gradient taper for stable running, and that contact-

ing the rail at curves where the wheel set shifts to the outer side has a profile of combined arcs of different radii to obtain the differential diameter effectively. An example of the modified arc wheel profile used mainly for the vehicles for the conventional narrow gauge lines is shown in Fig. 9.

In addition, some bogies are designed to allow displacement of wheel sets according to curves by using soft primary springs between axle boxes and the frame. Note, however, that when the stiffness of the primary springs (or axle box support rigidity) is too low, the running stability at high speeds is adversely affected. Therefore, the track characteristics of the railway line where the vehicles will run, their expected operation conditions, etc., must be taken into account in the bogie design. The consideration of the track conditions and train operation in the design of axle box support rigidity is an important issue in the design of bogies.

More recently, steering bogies capable of steering wheel sets in the direction of curves have been developed and commercially used.

The most fundamental method of steering wheel sets is to tune

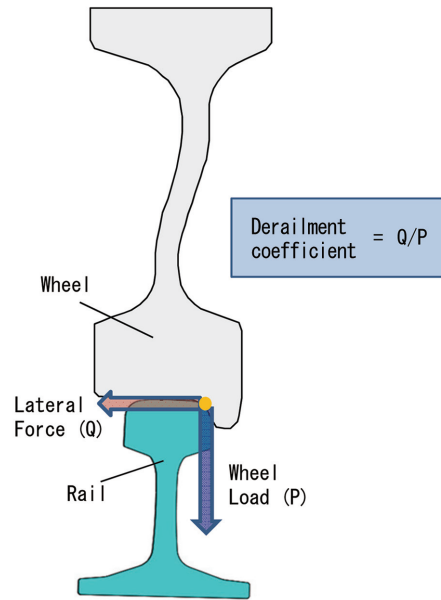


Fig. 8 Derailment coefficient

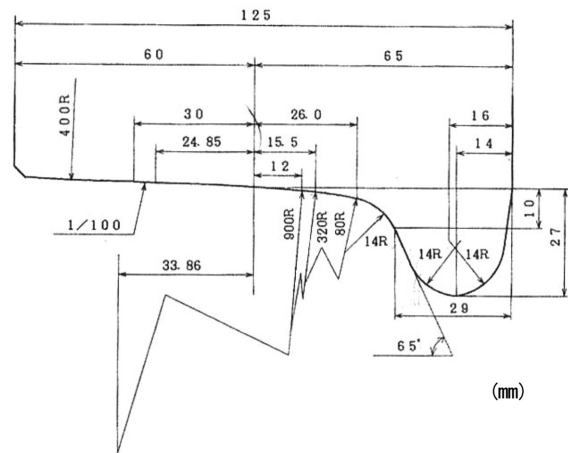


Fig. 9 Modified arc wheel profile for conventional lines

the stiffness of axle box support such that the self-steering functions of wheel sets due to the differential diameter work without restriction. The asymmetric stiffness, self-steering bogie schematically illustrated in Fig. 10 is an example of advanced self-steering bogies developed to realize both high-speed stability and smooth curve negotiation. Its design philosophy is that the axle box support of the wheel set on the body-end side is made less rigid than that of the other; such asymmetric design is rather uncommon to railway vehicles, which are usually designed symmetrically with respect to the direction of travel.

Another type is the semi-forced steering bogie: when the bogie turns with respect to the body at a curve, the turning angle is transferred through linkages to the axle boxes to steer the wheel set in the direction of the curve. This type of bogie, shown in Fig. 11, has been used for the new-model vehicles introduced to the Tokyo Metro's Ginza Line in 2012.¹⁾ For more details on this new steering bogie, see a separate article in the present issue.

Steering bogies are greatly effective at enhancing running safety at curves by decreasing the lateral force, as well as reducing noise and wear of rails and wheels due to their friction and creeping.

The decrease in wheel loads, on the other hand, constitutes a serious problem, especially at the gradual cant-decreasing zone at both ends of a curve, where the track is twisted to match the cant. As countermeasures, some bogies have vertically elastic primary suspensions so that the wheel sets easily follow the twisting track, and others are structured such that the bogie frame twists. Furthermore, a new method has been brought to commercial use, wherein the pressures and heights of four air springs supporting a vehicle body are controlled in accordance with the twisting track.

Before taking these measures, standards and regulations require that vehicles are designed such that the weight of the body is distributed equally to all the wheels, and the difference in wheel loads of each wheel set is controlled within a prescribed range at periodical vehicle inspections, and accordingly, bogies have mechanisms and accessories for easy adjustment of wheel load distribution.

In addition, it has been known that the derailment coefficient is closely related to the coefficient of friction between a wheel and the

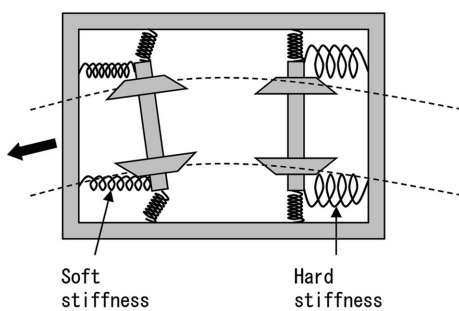


Fig. 10 Structure of asymmetric-stiffness, self-steering bogie

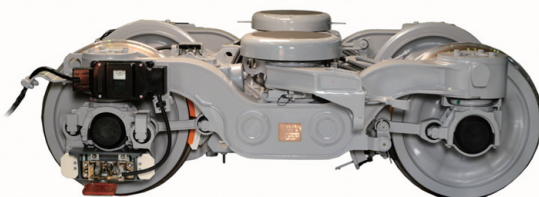


Fig. 11 Steering bogie for Tokyo Metro Ginza Line



Fig. 12 L-shaped guide to prevent deviation from rails

rail, and the degree of friction fluctuates depending on factors such as weather, atmospheric conditions (temperature, humidity, etc.), and the frequency of traffic. Although decreasing the friction coefficient is effective at enhancing the safety against derailment, it may cause other problems such as slipping and skidding. In consideration of these trade off factors, various measures have been tested and applied; an example is the development of friction control agents to keep the friction coefficient within a desired range.²⁾

4.3 Safety against natural disasters

A train was caught by a large earthquake in Niigata Prefecture in 2004 when running on the Joetsu Shinkansen Line, and derailed. Warned by the incident, methods for quickly bringing trains to a stop at an earthquake, and guides to prevent trains from significantly deviating from the tracks even if they are derailed, have been developed and actually applied. An example is shown in Fig. 12: an L-shape guide is bolted under each axle box of all Shinkansen vehicles of JR East to prevent deviation in an event of derailment.

Strong lateral wind is capable of overturning trains, and such possibilities are also taken into consideration in the bogie design.

5. Factors of Ride Comfort and Technical Development

5.1 Ride comfort

Ride comfort depends on many factors; an important point in the design of bogies is to make the vehicle body as free from unpleasant vibration as possible to offer smooth ride to passengers.

Generally, suspensions are designed to insulate the body from disturbances from the track, and the characteristics of the spring systems are defined on the basis of vibration calculations.

Recently, programs of multi-body dynamic analysis have been often used for vibration analysis, instead of directly using equations of motion. Multi-body dynamic analysis is a method for automatically formulating models simply by feeding a computer with the information of the components of the system in question and the elements that connect them together. Off late, software packages including analysis tools for wheel/rail contact are available in the market for application to railway vehicles. For further details, see another article in this issue.

Suspensions for railway vehicles are composed of mechanical elements such as springs and dampers. Ride quality of vehicles has been greatly enhanced because of the introduction of oil dampers, air springs, rubber bushes, and other new mechanisms and improvements in simulation technologies.

However, through the efforts for better ride comfort over many years, it has been made clear that there is a certain limitation in the improvement of ride comfort simply by tuning the parameters of the mechanical suspension components. In addition, as the speed of the Shinkansen trains increased, a phenomenon wherein vehicle bodies

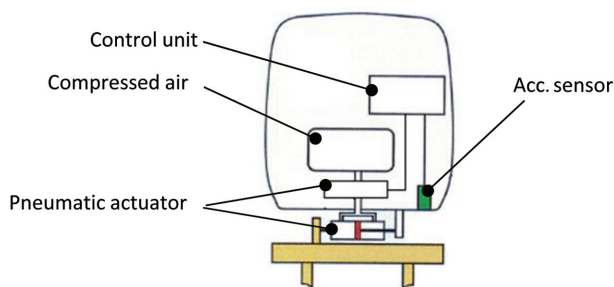


Fig. 13 Structure of active suspension system

were laterally excited by the air flow around them in tunnels began to attract attention. It became known, however, that the conventional mechanical solutions were insufficient for solving such problems. Then, as a new and radical countermeasure against such problems, the concept of active suspension to suppress vibration by computer control has been developed.

As the world's first example of active suspension, a pneumatic actuation suspension system was introduced to the series E2 Shinkansen trains of JR East in 2001;³⁾ its configuration is schematically illustrated in Fig. 13. Thereafter, similar systems were introduced in Japan to many other trains for superior services on conventional lines of various companies, too.

An active suspension system using electromechanical actuation of higher performance has been developed and introduced to all the vehicles of the series E5 Shinkansen trains of JR East commissioned in 2011, which raised the operating speed to 320 km/h in March 2013. For more details on the active suspension by electromechanical actuation, see a separate article on the present issue.

Besides the above, semi-active suspension to suppress vibration by changing the damping capacity of oil dampers has been commercially applied. Although semi-active suspension is theoretically inferior to active suspension in terms of vibration attenuation capacity because it uses the damping capacity of oil dampers, since it does not require supply of substantial energy such as compressed air or electricity from outside the system, it is used for various vehicles including the Shinkansen trains for purposes where its characteristics are suitable.

These varieties of active suspension systems are used mainly for suppressing lateral vibration. While vertical vibration has been put under control by the use of air springs, as the ride comfort level of railway vehicles has been enhanced over the years, further improvement is required regarding the high-frequency vibration caused by the bending of vehicle bodies.

5.2 Barrier-free measures

Leveling the heights of station platforms and train floors is one of the main barrier-free issues that have been tackled from the bogie approach. It was necessary to climb some steps to get on a conventional streetcar at a stop, which was a substantial barrier, especially for elderly and handicapped passengers. In consideration of this, low-floor light rail vehicles (LRVs)—such as the one shown in Fig. 14, having little height difference from the platform surfaces—have been developed. The body of this type is divided into three sections, and with the bogie provided under each of the two end sections, the floor of the center section is made very low. Another type of streetcars has been designed, wherein the drive motors, usually mounted inside bogies, are mounted directly under the body floor and the wheels are driven using propeller shafts; this arrangement allows the



Fig. 14 Low-floor light rail vehicle

floor to be nearly as low as the axle level.

6. Environment-related Problems and Technical Development

6.1 Noise and vibration

Noise and vibration are the principal environmental problems of railway vehicles closely related to bogies. There were cases in the past where groups of residents near train lines filed suits claiming compensation for noise damage to their daily life, which were partially granted. Since those cases, train noises have been drawing increasing public attention.

In addition, stringent environmental standards have been applied to the noise of the Shinkansen trains, and whenever higher train speeds are envisaged, noise problems inevitably arise and have to be solved.

Train noises are classified according to the source into the following: wheel rolling noises, power collection noises, aerodynamic noises, structural noises, and equipment noises.

Wheel rolling noises are caused by minute surface roughness of wheels and rails when the former turn on the latter, the impact of wheels at rail joints, turning of wheels partially flattened owing to slippage during braking, collugated rails, etc.

The noises from wheels and rails also include the flange noise arising from the contact of wheel flanges with the outer rails at curves, and the squeaky noise due to vibration of wheel discs resulting from stick slip, or the relative lateral vibration of wheels and the inner rail at curves.

The countermeasures against wheel rolling noises include lubrication of wheels and rails, noise-damping wheels, and steering bogies; Fig. 15 shows two types of noise-damping wheels.

Equipment noises are those arising from the equipment under the body floor; gear noise from drive gears is a typical equipment noise related to bogies. A separate article in the present issue deals with noise reduction through improvement of gear shapes.

Aerodynamic noises result from the air turbulence caused by the running of trains: the principal sources of the turbulence are the front end of a train, the gaps between coupled cars, the unevenness of body surfaces, the pantographs, and the insulators supporting them. Thanks to various noise suppression efforts, the body-related aerodynamic noises of the latest high-speed trains have been reduced to such a level that wheel rolling noises and aerodynamic noises of bogies have started attracting increasing attention.

6.2 Energy saving

Energy saving technology, especially that for saving electricity, has been commanding attention after the East Japan Earthquake in March 2011 and the shutdowns of nuclear power plants in the wake.

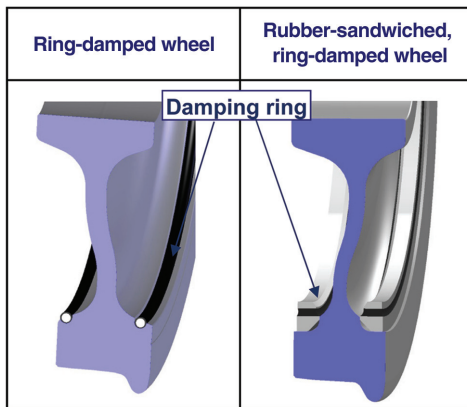


Fig. 15 Noise-damping wheel

The common measures for energy saving in bogie design include weight reduction and decrease in mechanical loss. The latest development in steering bogies to reduce the running resistance at curves and body tilting to decrease the need for deceleration before curves and acceleration after them are also effective at reducing energy consumption.

7. Vehicle Maintenance and Technical Development

7.1 Maintenance of railway vehicles

Railway vehicles are kept in good working order, as per the philosophy of preventive maintenance; vehicles undergo periodical inspection at intervals defined by travelling distance or time period. The latest trend is that the conditions of vehicle equipment are remotely monitored using cables running through a train. This has proved to be an effective tool for maintenance activities, and is being introduced increasingly widely.

Such monitoring systems also serve as inspection tools to check the functioning of various equipment units at periodical inspection. For instance, an active suspension system is equipped with a self-diagnosis function whereby functioning of its component equipment is confirmed by applying acceleration to the vehicle body while in a stationary state. Besides detecting an equipment failure when one occurs, the monitoring systems usually have an additional function to store information on the functioning of the device in question before and after the trouble for later investigation into the cause.

7.2 Condition monitoring

Studies are under way on changing the maintenance philosophy for railway vehicles from preventive maintenance to monitored maintenance. Systems based on similar philosophies have already been used; for example, a bearing temperature monitoring system is applied to the bogies for the Shinkansen trains. A failure is considered imminent when the temperature of a bearing exceeds the prescribed value.

According to the philosophy of monitored maintenance, the monitoring systems' functions are further advanced such that the functioning of all components of an entire vehicle is constantly monitored, and inspection and repair are conducted when a symptom of a failure is detected, instead of doing so after one has taken place. Various systems have been developed for application to bogies to monitor bearing temperature, vibration, etc.

Besides the above, systems to constantly monitor tracks using commercially operated vehicles have also been developed. As an example, Fig. 16 shows a track condition monitoring bogie called

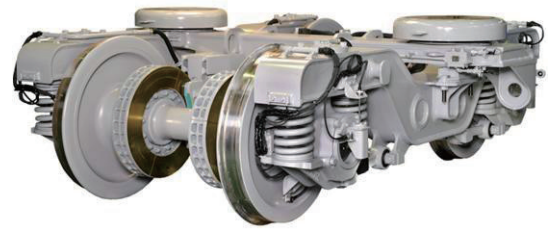


Fig. 16 Track condition monitoring bogie

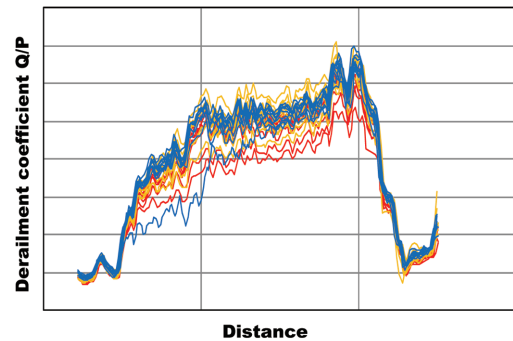


Fig. 17 Derailment coefficient measured using track condition monitoring bogie (1 week)

the track condition monitoring bogie,⁴⁾ whose usage is being Tokyo Metro is expanding to an increasing number of lines.

The derailment coefficient (Q/P) mentioned in Sub-section 4.1 is measured using a test train equipped with special wheel sets made for the purpose. It is known that tracks are constantly dislocated gradually as trains pass, and their conditions change depending on temperature, humidity, rail/wheel lubrication, and the condition of rail surfaces. In view of the fact, a method of track maintenance is being studied, whereby track condition is constantly monitored, and on the basis of the analysis of track deformation information obtained, repair work is conducted before a problem actually takes place.

The graph in Fig. 17 shows the data on the deformation of the rails at a curve obtained over a week using the track condition monitoring bogie. It is clear from the graph that the value of Q/P fluctuates from place to place and changes every day.

Contrariwise, monitoring systems in the opposite direction have been actually used: strain gauges attached to rails collect the Q/P data on every train that passes the track portion, and the data thus accumulated are used for predicting possible vehicle failures. It has to be noted, however, that since monitored maintenance requires accumulation of a vast amount of information every day, the biggest problem about it is how to analyze the data efficiently.

7.3 Wear and degradation by aging

Replacing worn or degraded parts with new ones is an important but troublesome part of maintenance practice. To minimize such trouble, many sliding parts have been eliminated from bogie structure and replaced by those made of rubber, which led to the development of bolsterless bogies. This, however, caused another problem of replacing degraded rubber parts with new ones.

To decrease the wear of wheels and rails, lubrication technology and steering bogies have been introduced, and furthermore, simulation to predict the progress of wear is being developed. More attention will have to be paid to these problems in the boundary region

between wheels and rails.

8. Future Prospects

It has been nearly 190 years since the first public railway began to operate, roughly 180 years since bogies were invented, exactly 140 years since the first railway in Japan was inaugurated, and it will soon be 50 years since the Tokaido Shinkansen Line was opened as the world's first railway line exclusive for high-speed trains. While the basic construction of railway vehicles has changed little over the years, train speed has increased to surpass 300 km/h, and R&D efforts are being bent to raise it to 360 km/h or beyond. The society's demand for higher additional values of railway services will grow stronger, to which railway engineers will continue to respond.

Computer control was first applied to bogies when active suspension was developed; this was already 10 years ago. In the meantime, the reliability of computer control has been proven, its being effective at improving vehicle performance has been confirmed, and now it is considered indispensable for offering high riding quality to the passengers. As the reliability of computers becomes higher and their prices lower, computer control is expected to cover an increasing number of functions of railway vehicles to realize "intelligent cars."

The demand for safety is growing stronger while maintenance of railway vehicles faces various problems, typically including securing sufficient human resources, transfer of technology and skill from generation to generation, and reduction of vehicles' lifecycle costs. In this situation, studies are under way to switch from conventional preventive maintenance based on periodical inspection to monitored maintenance based on wide application of condition monitoring systems. While the application of monitoring systems to constantly watch and record the condition of commercially operating trains is

expanding, how to deal with the large data accumulated day by day is a problem. Innovation in maintenance work making use of information and communication technology (ICT) such as condition monitoring systems is urgently awaited.

To develop and apply such new technologies, enhancement in test and evaluation facilities is indispensable. In the final development stages of new railway technologies, the safety, reliability, durability, etc., of developed vehicles or systems have to be verified in real size. In this sense, however, Japan, where all these are done on commercially operated lines, is much behind Europe and China, because European vehicle builders own long test lines of their own, and some Chinese universities have substantial test equipment and lines. This seems to be one of the reasons for the difficulties that Japanese railway technologies are facing in the global market. The recently announced construction project of a 3.2-km-long test line that allows a maximum speed of 100 km/h, focusing on urban rail transport, is very significant for improving the situation.

The need for engineering innovation for railway vehicles will continue to grow. Further technical development is required for realizing safer and more comfortable and environment-friendly railway vehicles.

References

- 1) Togami, Y. et al.: Proc. 19th Jointed Railway Technology Symposium. Tokyo, 2012-12, Japan Society of Mechanical Engineers, p. 73
- 2) Aircraft and Railway Accidents Investigation Commission (ARAIC): Investigation Report on Derailment at Naka-Meguro Station of Teito Rapid Transit Authority (Now Tokyo Metro)'s Hibiya Line. 2000, p. 85
- 3) Koizumi, S.: The International Symposium on Speed-up, Safety and Service Technology for Railway and Maglev Systems. Seoul, 2012-9
- 4) Shimizu, M. et al.: Rolling Stock and Technology. No. 167, 15 (2010)



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