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HITACHI
Inspire the Next

Future Railway Technologies for Satisfying Social Needs

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Preface

Highly Reliable Hitachi Railway Systems Supplied Globally

In addition to attracting attention for providing a mode of transportation with a low burden on the environment, railways around the world are expected to play an important role in society, even while the reasons for this may vary from place to place. Examples include the replacement of aging rolling stock in the UK, the birthplace of the railway industry, and mitigation of the increasingly severe traffic congestion that affects emerging economies as they continue their development. Building on its success with its Class 395 trains, Hitachi was awarded a major contract for the Intercity Express Programme (IEP) in the UK. As a total systems integrator capable of supplying both rolling stock and operational systems, Hitachi aims to deploy the technologies it has built up in Japan to the rest of the world, and in doing so to make a global contribution through the supply of highly reliable railway systems.

Hiroshi Nakayama

Vice President and Executive Officer
President & CEO, Rail Systems Company
Hitachi, Ltd.

Success with Class 395 Leads to Major IEP Contract

— In July 2012, Hitachi was awarded a major contract for the Intercity Express Programme (IEP) in the UK. Please tell us about the lead-up to this contract.

Nakayama: The IEP contract involves the production of nearly 600 vehicles and the supply of maintenance services over a period of nearly 30 years. While the UK has been a major focus of the Rail Systems Company, having first entered the market more than 10 years ago, the acknowledged success of the Class 395, which entered full commercial operation in December 2009, was a major factor in our being awarded this new contract. Winning a large overseas order is never easy, and a lot of time went into this one before we finally signed the formal agreement, with the IEP being influenced by factors such as the global financial crisis and the change of government in the UK.

The Class 395 rolling stock that preceded the IEP contract have been operating successfully for three years now, on both conventional line and the High Speed 1 line that runs from London to Ashford. Our involvement went beyond merely supplying the rolling stock and included responsibility for their routine maintenance. The new IEP contract can be seen as a continuation of our work on the Class 395. When I visited the UK Secretary of State for Transport in September 2012, they expressed their high regard for the success of the Class 395 and also left me with an appreciation of the considerable expectations they have for the monozukuri (manufacturing) capabilities that we will be deploying at the UK rolling stock production plant we will be establishing to serve the IEP project.

— What are your future plans for the UK?

Nakayama: As winning the IEP contract means we will be producing rolling stock for two of the UK’s major rail corridors, the East Coast Main Line and Great Western Main Line, as well as supplying maintenance services for 30 years, our plans include establishing a production facility at Newton Aycliffe in County Durham and setting up a maintenance business based at 11 rolling stock maintenance depots located around the country, four of which will be newly constructed. Away from the IEP, we have also won an order for a prototype railway traffic management system for the UK. We also hope to be able to contribute in areas such as traffic management systems and information systems in the future.

Global Activities of Railway Systems Business

— Please tell us about the future activities and objectives of the railway systems business.

Nakayama: While our railway systems business was focused on Japan in the past, it is anticipated that the market in Japan will shrink over time with the drop in population brought about by the aging of society and falling birthrate. Meanwhile, electric power consumption at railway stations has been growing recently for reasons such as the ongoing construction of commercial space inside stations. This has created a growing need to find ways of minimizing power use throughout the railway system, not just that consumed by the rolling stock. We also expect growth in businesses with an environmental connection, such as energy conservation, and we have work ongoing in these areas.

Outside Japan, the UK has further plans for rolling stock upgrades. There are also numerous railway infrastructure projects in emerging economies where Hitachi products and systems could play an active role.

— Outside the UK, in what other countries would you like to see Hitachi having an active involvement in railway transportation?

Nakayama: While our overseas business is mainly in the UK, I also believe that Hitachi products such as signalling systems and electrical components for traction drive systems have a market in China where demand is expected to remain vigorous. We established a joint venture company for electrical components in Xi'an back in 2003 that is engaged in the volume production of electrical parts for Chinese rolling stock manufacturers.

Elsewhere, we are seeking to expand our business into places like Brazil, India, and Southeast Asia. Brazil is faced with the challenge of building urban transportation systems, with monorail projects planned in a number of cities. We have extensive experience with straddle-type monorails,

Hitachi Rail Europe Ltd. (UK)

The conclusion of the UK's Intercity Express Programme contract in July 2012 was the culmination of over five years of work bidding for the largest ever rail contract in the UK. This contract follows a new business model requiring the manufacturer to build and secure finance for almost 600 vehicles, and provide all maintenance and servicing (including cleaning) of the trains for 27.5 years. Hitachi Rail Europe Ltd. developed a private equity consortium, raising finance through a consortium of Japanese and European banks as well as Japan Bank for International Cooperation and the European Investment Bank. This complex transaction took almost 3.5 years to conclude but has resulted in a new model for financing major infrastructure projects in the UK.

The public announcement that the deal was closed was made by the then UK Secretary of State for Transport, Justine Greening, at Newton Aycliffe in the Northeast of England, where Hitachi Rail Europe is planning to manufacture the trains.

The big challenge for Hitachi Rail Europe is now to put everything in place to deliver this contract. This includes building a rail manufacturing plant in the UK and employing around 700 workers, building further maintenance facilities throughout the UK, and ensuring that the delivery of the trains, which is set to start in 2016, runs smoothly. At the same time, the Hitachi Rail Europe team is bidding for its first rail contract in Germany, and for Crossrail, a major infrastructure investment in the London area.

The public announcement of the Intercity Express Programme contract [Justine Greening, UK Secretary of State for Transport (left) and Alistair Dormer, Chairman and CEO, Hitachi Rail Europe Ltd. (right)].

Conceptual drawing of maintenance depot at Newton Aycliffe, Northeast of England.

and I believe that our past success, which includes not only monorails in Japan but also overseas projects in Singapore and Dubai, demonstrates our ability to be involved in these monorail and other projects in Brazil. We are planning to establish a joint venture with IESA, a Brazilian heavy engineering company, and I hope that we will be able to introduce our monozukuri manufacturing practices there in the future.

India is a major nation in the railway field, with numerous projects in the pipeline, including high-speed trains as well as metros, monorails, and other urban railway systems, and also the Indian Railways modernization project. In addition to rolling stock and electromechanical traction drive components, we are also working toward establishing businesses in areas like signalling and traffic management systems. Southeast Asia in turn is experiencing vigorous demand for urban railway construction, including new metros and monorails, and I hope that we can develop businesses there that will utilize our extensive product range and engineering capabilities. We are also taking steps to make our business operations more local, not only to minimize risks such as exchange rate fluctuations but also to ensure that work proceeds more smoothly by establishing local manufacturing facilities.

Other countries where Hitachi products are in use include South Korea and Australia. A monorail is currently under construction at Daegu in South Korea, and we hope to use this project as a showcase that will help us expand our involvement to other cities. We are also supplying electrical components for traction drives to the railway system in Sydney, and we are keeping an eye on other possible projects in Australia, including high-speed railways.

— What specific initiatives are you taking to expand overseas business?

Nakayama: In addition to manufacturing throughout the world, I believe it is important for Hitachi that we establish a range of standard models. Accordingly, we are planning

Hitachi (China) Ltd.

As the railway market in China develops further in the 21st century, Hitachi is looking forward to a period of business growth based on its diverse range of products that includes rolling stock electrical components, monorails, signalling systems, rolling stock air conditioning, ventilation equipment, and the system storing regenerative electric power in wayside storage batteries utilizing regenerative power.

For the urban transportation market, we have supplied rolling stock electrical components to Beijing, Shanghai, Chongqing, and Xi'an. The electrical components supplied to the Beijing Subway made a major contribution to improving the convenience of transportation during the Beijing 2008 Olympic Games, while the monorail supplied to Chongqing has been providing the people of that city with comfortable transportation services since September 2004, when it became the first monorail to commence operation in China.

In the high-speed railway market, we have supplied rolling stock, rolling stock electrical components, rolling stock air conditioning, and ventilation equipment to CSR Corporation Limited, and rolling stock electrical components for use in 380-km/h high-speed trains and 250-km/h intercity express trains to China CNR Corporation Limited.

In signalling systems, we have approximately 70% of the market for onboard signalling equipment for medium-speed trains, and we have earned a strong reputation for the reliability of the signalling system used on the high-speed railway between Guangzhou and Shenzhen that commenced operation in December 2011.

Working with six sales offices located across the country (in Beijing, Shanghai, Guangzhou, Xi'an, Chongqing, and Qingdao), we intend to strive to expand our business in the Chinese transportation market by drawing on the comprehensive capabilities of Hitachi.

Hitachi (China) Ltd. workplace and staff.


Chongqing monorail.

a series of Hitachi commuter trains, suburban trains, high-speed trains, and monorails. The adoption of these common platforms will allow us to supply rolling stock that satisfies customers' requirements quickly and at low cost.

I also believe that our rolling stock maintenance business is essential to expanding our overseas operations. Whereas maintenance is performed by railway companies in Japan, internationally it is becoming increasingly common for this work to be done by the manufacturer. Also important is how we operate our signalling, traffic management, and other systems business. As a vendor, Hitachi can supply all aspects of a railway system other than the actual operation and civil engineering. This includes not only the rolling stock but also maintenance, signalling, traffic management, and substation systems. Finance is another increasingly important factor in large overseas projects and our aim is to establish the capacity to deliver comprehensive solutions that incorporate this and other associated services.

Drawing on Comprehensive Capabilities of Hitachi to Deliver Japanese Railway Technology to the World

— Please tell us about the organizational initiatives you are taking to expand overseas business.

Nakayama: We have already established Hitachi Rail Europe Ltd. (HRE) in the UK, and we will also be setting up a production facility and operation centers as part of the IEP contract. In organizational terms, we will establish companies near these facilities that will have primary responsibility for their management. In addition to its activities in the UK and other parts of Europe, it is also possible that HRE will, in the future, act as a base for business in countries with historical ties to the UK, such as India and Australia. When thinking in terms of a global market, it is becoming increasingly important that we approach business from a perspective other than what comes out of Japan.

Hitachi Korea Ltd.

South Korea's history of urban railways dates back to 1974 when Seoul Metro Line 1 started operation, and the supply of the first 60 metro cars to South Korea for this milestone also marked the birth of Hitachi's railway business in the country.

Now, nearly 40 years later, South Korea boasts world-class railway infrastructure and has large projects in the pipeline. These include a major upgrade of aging rolling stock for medium- to long-distance conventional lines to quasi-high-speed electric multiple units (EMUs) with a distributed traction system in anticipation of the PyeongChang 2018 Winter Olympics, and also the staged construction of urban railways with low cost and a low impact on the environment in the major cities where populations continue to concentrate. As a provider of the precision solutions required for these projects, we are working on the production and delivery of a number of orders, including the Nooriro, South Korea's first quasi-high-speed EMU for conventional lines based on the A-train concept and EMU technology built up over many years, a straddle-type monorail for Line 3 of the Daegu Metropolitan Transit, and systems storing regenerative electric power in wayside storage batteries for various lines in the Seoul Metro subway.

In addition to supplying reliable products to the strong market in South Korea, we also recognize that South Korea's geographical proximity and the similarity of its railway operating practices make it an increasingly attractive option for expanding our business into the railway markets of other Asian countries. Accordingly, we are working to expand our business by strengthening our sales and engineering capabilities at our South Korean operations, and also our relationships with high-quality partners.

Hitachi Korea Ltd. staff involved in project management and system engineering work at Daegu.

Monorail car for Line 3 of the Daegu Metropolitan Transit featuring latest unattended operation and safety equipment.

Three years after first entering service, the Korail Nooriro has become a popular train for conventional lines. It is also used for express access to the Yeosu Expo.

As we expand our business throughout the world, human resources become particularly important. Naturally we need to recruit people from the countries where we operate and also adopt other measures to hire talented people who can take a global perspective. These staff will have an important role in globalizing our business. We also want to play a part in encouraging economic growth in the countries where we operate. We need to take note of these issues as we globalize the company.

— How can you contribute to the world through your railway systems business?

Nakayama: I would like to see not only Hitachi rolling stock but also Japanese railway technology recognized internationally. I hope that the IEP project will lead to more people wanting to ride on trains made by Hitachi and that this will enhance the reputation of Japanese railway technology.

While Hitachi trains are known for their comfortable ride, with low vibration and noise, I believe that minimizing the number of faults is even more important. This keeps the trains running on time. This is more likely to be achieved if maintenance is performed thoroughly and individual components are highly reliable.

While the Class 395 trains entered commercial service in December 2009, they operated a “preview service” for six months prior to that to prepare for the commencement of full operation. Our intention is to continue to emphasize this monozukuri approach to satisfying customer expectations by meeting delivery schedules and supplying reliable products.

Given our broad range of products extending from rolling stock production and maintenance through to traffic management and other information systems, I believe that the railway systems business is one that allows Hitachi to demonstrate its comprehensive capabilities. I want us to contribute globally to the future of railway systems by supplying the world with the highly reliable technology we have developed through our experience in Japan.

Hitachi Australia Pty Ltd.

Hitachi, Ltd. and Hitachi Australia Pty Ltd. (HAUL) have a long history, dating back to the late 1960s, of working with Australian partners to deliver reliable locomotives and passenger trains to each state in Australia, as listed below.

- Sydney — 626 passenger trains “Waratah” (in progress)
- Melbourne — 348 passenger trains
- Cairns — 48 passenger trains (in progress)
- Queensland — 108 locomotives

In 2006, a joint venture between HAUL and one of the biggest rail infrastructure providers in Australia, Downer Rail, was awarded a contract to deliver the main electronic equipment for 626 cars in Sydney. This was one of the largest public private partnership (PPP) projects and single procurement of trains in Australian history, equivalent to about 50% of Sydney’s current suburban fleet. The project is now in the delivery phase and we have already delivered one-fifth of the trains required by the contract. HAUL is seeking to build a strong relationship with Downer, and is working with them to deliver reliable trains, on schedule.

Australia’s population continues to grow, and the states are looking at modernizing or extending their rail infrastructure. Most projects have a local content requirement and require collaboration with a local company. Additionally, most rail manufacturers are shifting their focus to maintenance services rather than manufacturing trains since maintenance contracts have historically been more profitable. This means that equipment maintainability could be a key factor in expanding our business.

Hitachi delivered six cars for Tilt Train, Queensland Rail Limited.

Hitachi Australia Pty Ltd. offices and local Hitachi Australia staff involved in management, sales, and maintenance work.

Test team staff for passenger train “Waratah.”

Development of Cutting-edge Railway Systems that Satisfy Social Needs

Yasushi Yokosuka
Yoshimitsu Nakazawa
Hideo Kitabayashi

HOW TO IMPROVE SAFETY, SECURITY, AND ATTRACTIVENESS OF RAILWAYS

RAILWAY infrastructure suffered significant damage during the Great East Japan Earthquake in March 2011, particularly the railway lines along the nation's east coast. Despite this severe and widespread damage, the disrupted railway network has largely been restored thanks to the efforts by the affected railway companies, except for lines identified as in need of further investigation for reasons such as their role in local recovery plans. There have even been stories of residents along restored railway lines turning out to show their support by welcoming the return of the trains. Not only are we greatly encouraged in our role as staff involved in railway systems development, we can also feel that people have high expectations of us.

It also reconfirms the importance of developments that make railways more attractive, not only to make railway systems safer and more secure, but also so that more people choose to travel by train.

Hitachi is engaged in continuous development, extending from signalling and control technologies that help achieve safety and security to rolling stock technologies that address the problem of global warming, power supply system technologies, transportation control systems that support reliable transportation services, and information systems that operate in conjunction with these transportation control systems to provide railway users with accurate information.

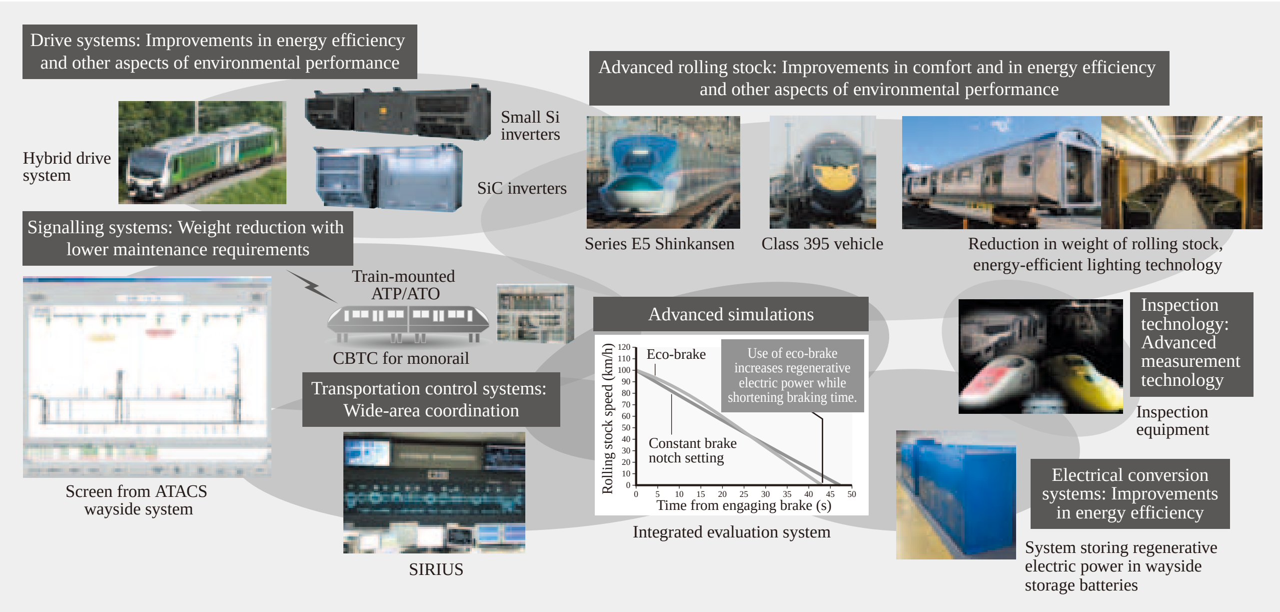
While the forms taken by railway systems tend to be different depending on the areas they serve, there are growing demands for technology to comply with global standards and the extent of this compliance is becoming an important consideration.

OVERVIEW OF TECHNOLOGY DEVELOPMENT AND KEY FIELDS

As a total railway systems integrator, Hitachi is developing cutting-edge technologies that underpin advances in systems needed to satisfy changing social requirements. Hitachi is globally deploying such technologies as reducing the weight of rolling stock so that it will be more energy efficient, making improvements to comfort, and encouraging the reuse of parts and materials to improve environmental performance. Hitachi is also seeking to make electrical components more energy efficient and is working continuously on developments such as technology for smaller size. For signalling systems, it is aiming to make wayside systems lighter and is developing and implementing wireless signalling systems that are less vulnerable to disasters, less work to maintain, and able to cope with high railway traffic density. In the field of electrical conversion systems, Hitachi is commercializing systems that utilize regenerative electric power.

For transportation control systems, Hitachi is making improvements to fault-tolerant technology and developing technology for interoperation between different systems to satisfy the demands of railway operators and make continuous improvements to railway services. Hitachi has also commercialized maintenance technologies for railway systems and made progress on improving the associated inspection techniques. In response to the need that has arisen in recent years to predict various railway system performance characteristics, Hitachi is improving the functions and performance of existing evaluation systems and developing technologies that can perform precise assessments, including of the energy efficiency and headway[(a)] of railway systems (see Fig. 1).

(a) Headway
The headway between consecutive trains on a railway line. While the headway between trains is kept above a minimum time for safety reasons, it is also possible to shorten the interval within this constraint by various means, including varying the train speed. Shortening this minimum headway allows trains to run closer together and increases the volume of passengers or goods carried per unit of time.

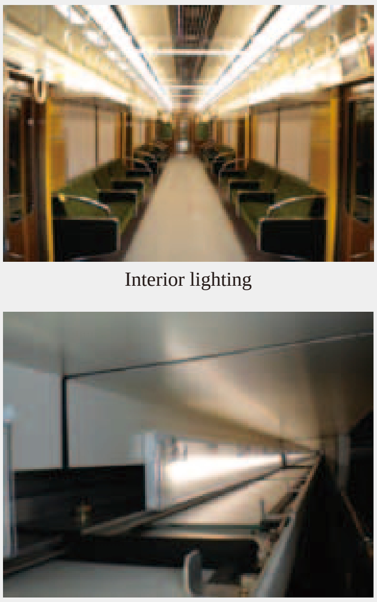


Si: silicon SiC: silicon carbide ATACS: advanced train administration and communications system ATP: automatic train protection
ATO: automatic train operation CBTC: communication-based train control SIRIUS: super intelligent resource and innovated utility for Shinkansen management

Fig. 1—Latest Railway Systems that Satisfy Social Needs.
As a total railway systems integrator, Hitachi is responding to the changing requirements of society by developing and implementing technologies that underpin advances ranging from rolling stock systems to wayside control and information systems.

TECHNOLOGY DEVELOPMENT AND GLOBAL DEPLOYMENT OF ROLLING STOCK SYSTEMS

Hitachi is working continuously on the development of technology for Shinkansen and conventional trains. Hitachi has been devoting considerable effort for some time to developing technology for its A-train[(b)] conventional rolling stock, and uses friction stir welding (FSW)[(c)] in both its conventional and Shinkansen trains to achieve an attractive and smooth carbody finish. Progress is also being made in areas such as modular designs to reduce the weight of rolling stock while also facilitating the reuse of parts and materials. To improve energy efficiency, Hitachi has adopted light-emitting diode (LED) lighting in recent years. This has gone beyond merely replacing the light fittings, and has included the development of technology for delivering the required light levels with consideration of safety,



LED: light-emitting diode

Fig. 2—Indirect LED Lighting in the Series 9000 Trains Supplied to Hankyu Corporation (New Vehicles).
Hitachi was the first supplier to offer full LED interior lighting in December 2010.

(b) A-train
A rolling stock system developed by Hitachi that features a modular production system and use of an aluminum double-skin body structure. “A-train” stands for “advance,” “amenity,” “ability,” and “aluminum.” In addition to dividing rolling stock up into separate modules based on function, adopting the A-train aluminum double-skin body structure, which does not require a frame, results in a rolling stock system that is simple and light while maintaining high quality. It also has excellent recycling characteristics and is achieving increasing success in Japan and elsewhere as a form of rolling stock that places only a light burden on the environment.

(c) FSW
Abbreviation of “friction stir welding.” A welding technique that works by moving a rotating cylindrical tool along the materials to be joined to generate heat through friction. As the material being welded does not actually melt, FSW results in less strain and distortion in the weld than occurs with melt welding. Other advantages include high weld strength, fewer bubbles, cracks, or other defects, and that the weld surface and rear surface remain flat.

(a) Body structure

(b) Lightweight inner frame bogie

Fig. 3—Key Components of Global A-train.
Hitachi intends to achieve further cost and weight reductions in the global market.

lower power consumption, and ease of maintenance. Key developments have included expanding the spread of light emitted by LED lights from 120° to 170° or more, and the design of lights with a life of 100,000 hours by devising circuit and board designs that are resistant to influence by heat (see Fig. 2).

In the shift to global markets, Class 395 rolling stock based on A-train technology has already been supplied to the UK and these trains have been in commercial operation since 2009. To contribute to advances in railway systems around the world, Hitachi is also working on achieving local certification, lighter weight, better energy efficiency, and easier maintenance. With the aim of maximizing both the flexibility and standardization of rolling stock operating at speeds from 160 km/h to 225 km/h, Hitachi is seeking to reduce costs through local production and is developing lightweight inner frame bogies (see Fig. 3).

Hitachi has also commercialized equipment for track inspection cars. This has included products for measuring rail displacement and wear in overhead wiring, for example. The Doctor Yellow (unofficial name) product for the Shinkansen incorporates inspection equipment able to perform measurements at the operating speed of 270 km/h. To meet the need for continuous monitoring of equipment, Hitachi is working on the commercialization of small measurement instruments able to be fitted in operating trains.

EFFICIENCY IMPROVEMENT FOR TRACTION SYSTEMS

Hitachi has developed traction systems that can make effective use of regenerative electric power both on electrified and non-electrified railway lines, and was the first in the world to commercialize a hybrid drive system for diesel passenger trains. This system uses a series hybrid drive(d) developed in collaboration with the East Japan Railway Company. Hitachi has confirmed this system can achieve energy savings of 15% or more (depending on the nature of the railway line on which the train is traveling) by conducting simulations for a wide range of conditions. Another

(a)

(b)

Fig. 4—Train-mounted Parts of Control System for Expanding High-speed Operating Range of Regenerative Braking.
The train-mounted equipment includes 16 lithium-ion battery modules (a), a chopper [(b)-front], and a main smoothing reactor (MSL) [(b)-rear].

(d) Series hybrid drive
Hybrid drive systems combine two different power sources, such as an engine and electric motor. In series hybrid drive systems, these power sources are mounted in series. The engine drives a generator to produce electric power, which is stored temporarily in a secondary battery. The electric power is then used to turn an electric motor, which drives the train. During braking, the regenerative electric power produced by the drive motor is also used to charge the secondary battery.

Fig. 5—Inverter for Additional Series E233-3000 Units.
Both the external dimensions and mass have been reduced by 20% or more compared to the previous units.

benefit of using series hybrid drive is that it simplifies the mechanical design and reduces the amount of maintenance work required. Since installing the drive system in the Series Kiha E200 trains used on the Koumi Line of the East Japan Railway Company in 2007, it has also been used on the Series HB-E300 resort trains, which entered commercial operation in 2010.

A system that Hitachi has commercialized for electric trains returns regenerative electric power produced during braking to the overhead lines so that it can be used to drive other trains. However, problems such as regenerative braking becoming non-operational can occur if no trains able to use the generated power are nearby. To allow regenerative electric power to be utilized even under low-load conditions, Hitachi has developed a system where secondary batteries are installed on the train to store regenerative electric power for subsequent use. Also, because the extent of regenerative braking is restricted at high speeds due to the motor output characteristics, Hitachi is developing a system that extends the operating range of regenerative braking to higher speeds by installing secondary batteries in the train and increasing the direct current voltage of the inverter. Fig. 4 shows photographs of the batteries and other equipment. Field testing has confirmed that higher voltages result in a higher level of regenerative electric power.

Hitachi is engaged in ongoing development aiming at making the electrical components of drive systems smaller and more efficient. In the case of additional rolling stock for the Series E233-3000 trains supplied to the East Japan Railway Company, both the external dimensions and weight of the new units were more than 20% less than earlier units (see Fig. 5). Meanwhile, the development of highly efficient totally enclosed induction motors that do not require internal cleaning and are 30 dB quieter than previous motors has increased the efficiency of the traction motors to 95%. Hitachi has also developed 3.3-kV silicon carbide (SiC) hybrid modules(e) and built power units with a simple two-level design that are able to operate with 1,500-V overhead lines, reducing inverter losses by 35% (see Fig. 6).

For markets outside Japan, Hitachi has developed a high-output drive system for use in high-speed trains in China in which four 615-kW electric motors are controlled in parallel by combining rolling stock, motors, a main converter, and other components based on European technology. This system is currently undergoing operational trials. Hitachi intends to continue working on improvements in energy consumption and efficiency, taking account of both environmental considerations and the demands of the global market.

ENHANCEMENTS TO WAYSIDE CONTROL SYSTEMS AND ENERGY EFFICIENCY OF ELECTRIC POWER SYSTEMS

The major wayside control systems developed and implemented by Hitachi include transportation control systems, systems for supplying trains with electric power, and signalling systems.

Fig. 6—Inverter Built Using SiC Hybrid Modules.
The losses of the inverter power unit were reduced by 35%.

(e) SiC hybrid module
Power modules for rolling stock inverters that combine 3.3-kV SiC Schottky barrier diodes (SBD) and silicon (Si) insulated-gate bipolar transistors (IGBTs). Interest in SiC as a material has come about because SiC circuit elements have a lower resistance than those made using Si, which means that power modules can be made smaller with simpler cooling systems.

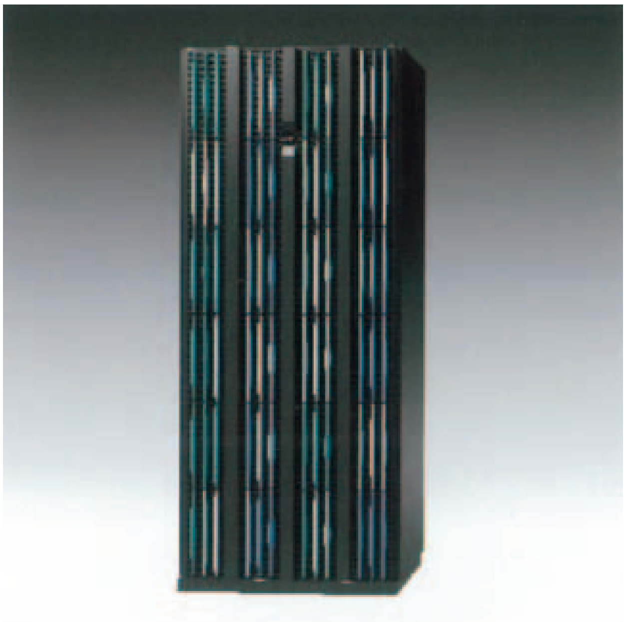


Fig. 7—CF-1000/FT Fault-tolerant Model of Realtime Server.
A loosely coupled architecture with four-fold redundancy is used to achieve high availability and data reliability.

In addition to having developed and installed a wide range of transportation control systems for a variety of different railway lines in Japan, Hitachi also undertook development work aiming at system interoperation between Kyushu Shinkansen and Sanyo Shinkansen services to coincide with the introduction of through trains. The main objective of this development work was to coordinate operation through the exchange of various types of information, including operational functions such as primary and modified timetables and train movement records. The newly developed fault-tolerant models adopted for this work use a loosely coupled[f] architecture with four-fold redundancy. The system is operating successfully, providing high availability and a high level of data reliability (see Fig. 7).

In the field of signalling systems, Hitachi was the first company in Japan to implement an automatic train control (ATC) system that works by transmitting digital data along the rails. Hitachi is also engaged in ongoing development of systems that use space-wave radio transmission and has implemented a wayside control system for an advanced train administration and communications system (ATACS) supplied to the East Japan Railway Company. For ATACS, Hitachi was the first to implement a moving block control system (system for preventing collisions between trains) based on positioning data acquired on the trains. This included developing four ground controllers and equipment for controlling field terminals on approximately 18 km of railway line, and also equipment for tracking the locations of trains on the line. The system entered service on October 10, 2011, and continues to operate successfully (see Fig. 8).

Fig. 8—Fail-safe Ground Unit for ATACS.
The ground controller (left) is used for train interval control and the train existence supervision server (right) is used to manage the position of trains on a railway line.

(f) Loosely coupled
In the context of systems that involve the interoperation of multiple processors, application software programs, and other components, “loosely coupled” means that the individual components have a high degree of autonomy. This allows the creation of systems with high availability because the limited degree of mutual interdependence means that problems in particular components do not influence other parts of the system. In contrast, systems in which the components have a high degree of interoperation are called “tightly coupled.”

Fig. 9—System Storing Regenerative Electric Power in Wayside Storage Batteries on Seoul Metro9 Subway.
The system is expected to deliver greater energy savings than initially predicted and has demonstrated its ability to cut peak electric power demand.

In the field of wireless signalling systems for use outside Japan, Hitachi has developed and installed a total communication-based train control (CBTC) system for a monorail in Chongqing, China. The scope extends from wayside equipment to vehicle-mounted equipment and wireless systems. Because the system includes a moving block control system that acquires positioning information from the monorail vehicles, its features include the establishment of predetermined block sections in case wireless communications are interrupted as well as measures for making wireless communications more robust. The system is contributing to public transportation in Chongqing, with a configuration that supports both driverless operation and intervals of as short as 120 seconds between monorail vehicles.

To supply trains with electric power, Hitachi has developed the system storing regenerative electric power in wayside storage batteries. The system was installed at the Itayado substation on the Seishin-Yamate Line of the Kobe City Subway in 2007. The systems supplied to two substations on Seoul Metro9 subway in South Korea also commenced operation in 2011 (see Fig. 9). While total annual energy savings for one of the substations was predicted to be 510 MWh, the actual savings reached 94 MWh in the first month alone, indicating that the system may prove even more effective than initially estimated. The energy savings provided by the system continue to be assessed, and it has also demonstrated its ability to cut peak demand by reducing rush-hour energy consumption.

There is growing demand for the ability to predict factors such as energy consumption and transportation capacity in order to achieve energy efficiency across entire railway systems. Hitachi has developed simulators in the past for estimating power consumption that it has used in engineering, and it has now developed integrated evaluation systems with enhanced functions and performance to meet these needs. In addition to estimating power consumption based on planned timetables, these systems have been enhanced to predict factors such as transportation capacity and power consumption as well as to evaluate optimum run curves for achieving energy efficiency (see Fig. 10). Hitachi has also developed submodules in response to demands such as for operational support functions that assess run curves to achieve more energy-efficient operation. These modules can be combined as required to perform the desired assessments. Hitachi intends to continue enhancing simulation functions so that it can respond accurately to demand for the evaluation of different types of railway systems.

DEVELOPMENT OF TECHNOLOGY TO RESPOND ACCURATELY TO NEEDS

In addition to their use for underground, monorail, and other urban transportation services, railways are also valuable for being a means of medium- to long-distance transportation with an extremely low impact on the environment. For the future, it is also important to satisfy the expectations of society by making further progress and developing technologies for improving railways' attractiveness to users so that they can remain a vital form of urban and intercity transportation, and by achieving an appropriate division of roles with other modes of transportation such as automobiles, buses, aircraft, and shipping.

Countries in the world are engaging in a variety of technology developments with the aim of achieving sustainable societies. Rather than just seeking to improve energy efficiency, this involves considering, from a wide range of perspectives, the question of what sort of future societies people should be aiming for at the level of regions and entire societies.

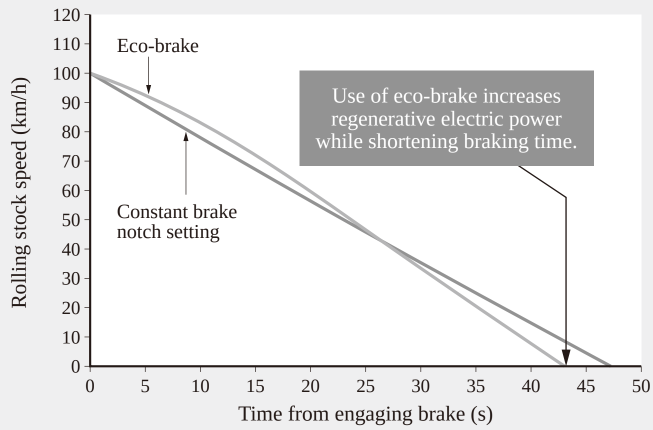


Fig. 10—Example of Brake Notch Optimization during Deceleration.
These results show how use of the brake notch settings can affect braking time and the amount of regenerative electric power.

Hitachi intends to obtain an accurate grasp of these trends in the progress of societies, and to continue engaging vigorously in technology development to respond accurately to the demands placed on railways by combining technologies from throughout Hitachi.

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ABOUT THE AUTHORS

Yasushi Yokosuka

Joined Hitachi, Ltd. in 1984, and now works at the Corporate Development & Strategy Division, Rail Systems Company. He is currently engaged in international standardization and the coordination of railway technology development. Mr. Yokosuka is a member of The Institute of Electrical Engineers of Japan.

Yoshimitsu Nakazawa

Joined Hitachi, Ltd. in 1991, and now works at the Transport Management Systems & Solution Department, Transport Management & Control Systems Division, Rail Systems Company. He is currently engaged in the coordination of railway system engineering.

Hideo Kitabayashi

Joined Hitachi, Ltd. in 1990, and now works at the Rolling Stock Engineering Department, Sales & Marketing Division, Rail Systems Company. He is currently engaged in the system engineering of Shinkansen and conventional rolling stock.

Advanced Train Technology and New Development for Global Markets

Mitsuo Iwasaki
Simon Richards
Kazufumi Yamaji
Katsuyuki Iwasaki
Shingo Hirose
Yasuaki Wakimoto

OVERVIEW: As a manufacturer of rolling stock, Hitachi has developed and produced rolling stock for high-speed and commuter trains in Japan, and has made numerous advances in railway technology to satisfy a wide range of needs. The total number of Hitachi's A-train rolling stock supplied in Japan has already passed 2,000, and development is ongoing in response to new requirements, including energy efficiency measures such as the use of LED lighting. For the UK market, to which Hitachi gained access through the development of the Class 395 trains for that country's High Speed 1 line that commenced commercial services in December 2009, Hitachi has built the AT-100, AT-200, and AT-300 platforms that feature greater compliance with standards, has developed a lightweight carbody for local manufacturing and lightweight inner frame bogies, both of which are key components, and has made progress on optimizing rolling stock information and control systems as well as the traction system.

INTRODUCTION

AS railways have gained increasing attention in recent years for their role as a form of public transportation with excellent energy efficiency, in addition to things like shorter travel times and improved comfort, requirements have also emerged for further reducing the load that rolling stock place on the environment.

In response, Hitachi has sought to reduce the load on the environment and to cut life cycle costs while also enhancing design and functionality by comprehensively revising the materials, structures, and production techniques it uses based on the next-generation A-train aluminum rolling stock system concept. Features of the A-train include cars built primarily from lightweight and easily worked aluminum alloy and an interior constructed from independent modules. The family of models has been steadily growing since 1999, with the concept being applied to rolling stock ranging from commuter to intercity trains.

Meanwhile, the high-speed Class 395 trains for the UK's High Speed 1 line commenced commercial services in 2009. Based on the A-train concept, this rolling stock took the technologies for light weight and high speed that Hitachi had developed in Japan and applied them to a railway system in the UK. Hitachi is also working on the development of the Global A-train with the aim of expanding its A-train business globally.

This article reports the latest information about the A-train in Japan and describes the development concept and results for the Global A-train.

LATEST A-TRAIN TECHNOLOGY

The total number of A-trains delivered in Japan reached 2,000 in November 2011. Hitachi has been responding to customer requirements in a variety of ways, including providing cars with see-through glass end sections and enlarging the interior space and designed front-end mask. The following section describes the new measures Hitachi is adopting to increase future sales.

In response to the need for energy savings that has arisen in recent years, Hitachi has developed and commercialized light-emitting diode (LED) interior lighting for rolling stock. When used for indirect

Fig. 1—Series 817 Rolling Stock Supplied to Kyushu Railway Company and its Interior LED Lighting.
The interior uses light-emitting diode (LED) lighting in place of the fluorescent lighting used in the past.

lighting, the LED lights provided energy savings of approximately 20% compared to previous rolling stock. The three different types of lighting are indirect, direct, and a mixture of the two. Systems have been supplied for approximately 100 cars to date, including the Series 9000 rolling stock supplied to Hankyu Corporation, the Series 817 rolling stock supplied to Kyushu Railway Company, and the Series 8000 rolling stock supplied to Keio Corporation. Hitachi is also planning to extend use of LEDs to other applications such as headlights for leading cars and, to satisfy customer needs, is currently developing systems that include a backup function in case of light failure as well as overcoming the long-standing problem of needing to make frequent light replacements (see Fig. 1).

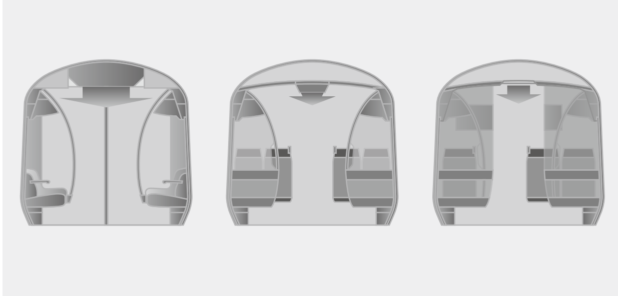

Fig. 2—Platform Combining Flexibility and Standardization. The AT-100, AT-200, and AT-300 (left to right) share the same base structure.

GLOBAL A-TRAIN DEVELOPMENT CONCEPT

To facilitate the global deployment of the A-train, Hitachi has included the following points in the development concept for the Global A-train.

(1) Business considerations
- (a) Local manufacturing
- (b) Lower cost
- (c) Local procurement
- (d) Standardization strategy

(2) Technical considerations
- (a) Acquisition of local certification
- (b) Technologies for lighter weight and energy efficiency that reduce life cycle costs
- (c) System integration to achieve high levels of reliability
- (d) Easier maintenance

One aspect that differs from the approach taken in past rolling stock developments is the inclusion of business considerations in the development concept. With a view to producing the Global A-train outside Japan, this has included designing the rolling stock for easy assembly by workers who may not be highly experienced, and also taking steps to revise and standardize the supply chain.

Technical considerations include taking the development concept of the original A-train as a base and making further technical enhancements, including the obtaining of certifications. Engineers from Hitachi Rail Europe Ltd. have participated from the earliest stages to ensure that development work takes account of the needs of European customers.

GLOBAL A-TRAIN STRATEGY FOR UK AND EUROPE

Global A-train development aims to achieve both maximum compliance with standards and flexibility of car configuration so that customers can enjoy the diverse advantages of selecting Hitachi rolling stock. Hitachi has built the AT-100, AT-200, and AT-300 platforms (where “AT” stands for A-train)

Fig. 3—AT-100 Trains.
These trains feature a crashworthy structure that complies with the European Conventional Rail Technical Specifications for Interoperability (CR-TSI) standards.

for the UK market based on standards-compliant key components[1] (see Fig. 2).

(1) AT-100

Intended for commuter services, the AT-100 has a maximum operating speed of 160 km/h. Although intended primarily for use with longitudinal seating, other configurations are also possible, and a mixture of longitudinal and transverse seating can be used. To maximize the efficiency of passenger entry and exit, each AT-100 carbody can be fitted with up to three doors per side (see Fig. 3 and Fig. 4).

(2) AT-200

The AT-200 is intended for longer suburban services and like the AT-100, has a maximum operating speed of 160 km/h. Features include transverse seating, luggage space, and tables. With two doors per side, the AT-200 only needs a dwell time of 60 to 90 seconds at major stations during commuter rush hours (see Fig. 5).

(3) AT-300

The high-speed AT-300 rolling stock have a maximum operating speed of 225 km/h, with an option to increase this to 250 km/h. A wide range of different interior layouts and door configurations are possible to meet the needs of intercity passengers. The highly regarded Class 395 rolling stock for the High Speed 1 line in the UK are based on the AT-300 (see Fig. 6 and Fig. 7).

KEY COMPONENTS OF GLOBAL A-TRAIN

Hitachi has been developing the key components of the Global A-train so that they can comply with standards. The sections below describe details of this development work.

Lightweight, Locally Manufactured Structure

Using the aluminum structure already proven on A-trains in Japan as a base, Hitachi undertook the following developments (see Fig. 8).

(1) Compliance with European standards

The development of the Global A-train includes compliance with the European Conventional Rail

Fig. 4—AT-100 Interior.
Intended for commuter services, the interior combines both longitudinal and transverse seating.

Fig. 5—AT-200 Interior.
Intended for longer suburban services, the interior uses transverse seating.

Fig. 6—AT-300 Trains.
The AT-300 has the same front-end shape as the Class 395.

Fig. 7—AT-300 Interior.
The layout is designed for intercity services.

Fig. 8—Carbody.
The carbody has a lightweight aluminum structure that complies with CR-TSI.

Fig. 9—Lightweight Inner Frame Bogie.
A lightweight and compact design was achieved in which all components of the bogie are inside the plane of the wheels.

Technical Specifications for Interoperability (CR-TSI). Although this covers a wide range of areas, carbodies must comply with the structural standards related to static strength and the crashworthiness of the structure.

(2) Local manufacturing

The Class 395 uses aluminum extrusions made in Japan for its structural components. With a view to manufacturing these locally in the future, the potential use of aluminum supplied from European producers in particular was allowed for from the very beginning of the new development.

(3) Lighter weight and lower cost

Optimization of the design reduced the number of components in the structure by 30% and its weight by 18% (relative to the Class 395).

Lightweight Inner Frame Bogie

The best way of dealing with the top priority issue of reducing the load on the railway track is to reduce the weight of the bogie and suspension. Accordingly, Hitachi has developed a lightweight inner frame bogie for the Global A-train, in which the bogie frame is entirely contained within the plane of the wheels (see Fig. 9).

(1) Drive system

To achieve both a top speed of 160 km/h and the fast acceleration and deceleration needed by commuter trains, the drive system has a 240-kW traction motor and a gear ratio of 5.13. The drive system is designed for small size, with smaller diameter 830-mm wheels and two-stage gearing as well as a flatter traction motor, allowing it to fit in the restricted space available on the bogie frame, which does not extend outside the plane of the wheels.

(2) Mechanical brake

Use of wheel tread brakes on the motor cars was made possible by optimizing the motor car:trailer car ratio for the trainset configuration. The trailer cars use wheel tread brakes and two disk brakes per axle.

(3) Bogie frame

In addition to structural optimization and lighter weight, the bogie frame design with side beams made of welded steel plate and cross beams made of pipe has the strength to comply with British Standards and other European standards.

(4) Bogie weight

Excluding the traction motor, each bogie weighs 5.2 t. This is approximately 2.5 t lighter than normal outer frame bogies that comply with European standards.

Traction System

As part of development, Hitachi undertook to optimize the entire system, including the bogie, drive, traction converter, and traction motor, to ensure the best possible traction circuit and system for the trainset configuration. In addition to using a two-stage, side-by-side cardan reduction gear and developing a new traction motor with a smaller external dimensions to fit in the lightweight inner frame bogies described above, the traction converter also uses a newly developed inverter that features small size and high efficiency.

Rolling Stock Information and Control System

Hitachi has developed a flexible, high-quality, next-generation autonomous train integration (ATI) system for rolling stock information and control that incorporates general-purpose technologies, including using Ethernet as the main network technology. For the Global A-train, Hitachi intends to equip this next-generation ATI system with functions, such as maintenance, that are specific to overseas markets.

CONCLUSIONS

This article has reported on the latest information about the A-train in Japan and described the development concept and results for the Global A-train. By incorporating the latest technologies, Hitachi intends to make further enhancements to the A-train to deliver rolling stock that match the needs of the time.

In addition to developing the product for the UK market described in this article, Hitachi is also undertaking more work aimed at creating platforms for the Global A-train that take account of potential projects in continental Europe and emerging nations.

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ABOUT THE AUTHORS

Mitsuo Iwasaki
Joined Hitachi, Ltd. in 1991, and now works at the Rolling Stock Systems Design Department, Kasado Works, Rail Systems Company. He is currently engaged in coordinating the design of rolling stock.

Simon Richards
Joined Hitachi Rail Europe Ltd. in 2008, and now works as an Engineering Manager. He is currently engaged in work on rolling stock for the UK and Europe.

Kazufumi Yamaji
Joined Hitachi, Ltd. in 1991, and now works at the Rolling Stock Systems Design Department, Kasado Works, Rail Systems Company. He is currently engaged in coordinating the design of electric rolling stock for public and private railway companies and conventional railway lines.

Katsuyuki Iwasaki
Joined Hitachi, Ltd. in 1994, and now works at the Rolling Stock Systems Design Department, Kasado Works, Rail Systems Company. He is currently engaged in bogie design.

Shingo Hirose
Joined Hitachi, Ltd. in 1991, and now works at the Product Design Department, Design Division, Research & Development Group. He is currently engaged in coordinating the design of rolling stock and monorails.

Yasuaki Wakimoto
Joined Hitachi, Ltd. in 2000, and now works at the Rolling Stock Systems Design Department, Kasado Works, Rail Systems Company. He is currently engaged in rolling stock projects for overseas customers.

LED Lighting System for Rolling Stock

Isao Ishii
Fumio Shimada
Mitsuru Asahara
Shigenori Iwamura

OVERVIEW: With energy efficiency becoming increasingly important in recent years, demand is growing for the adoption of LED lighting as a replacement for fluorescent interior lighting in passenger trains. Rather than simply replace fluorescents with LED lighting, Hitachi has drawn on its experience and past activities as a manufacturer of rolling stock to achieve power savings of 40 to 60% while also taking account of interior design considerations and the color of the light. Hitachi has also succeeded in approximately halving life cycle costs compared to existing general-purpose LED lighting through measures that include adopting a dedicated power supply and designing long-life circuits. In the future, Hitachi intends to continue development with the aim of adopting LEDs for train headlights and other lighting with systems that further enhance the functions of LED lighting for passenger train interiors.

INTRODUCTION

SINCE 1997, Hitachi has been developing and marketing its A-train rolling stock based on its own proprietary concepts. Recently, more than a decade later, in addition to specifications, design, safety, recycling, and maintenance, there is also a strengthening demand for the adoption of eco-technologies that are kind to people and conscious of the environment. Given the growing need for a shift from fluorescents to light-emitting diode (LED) lighting in passenger train interiors, rather than simply adopting general-purpose LED lighting, Hitachi has drawn on its experience and past activities as a manufacturer of rolling stock to develop LED lighting specifically for use in trains that complies with railway-specific standards, including for testing.

With new technology and product development in recent years, there have been numerous instances where problems that have inhibited commercialization have arisen from differences in philosophy and understanding between the people who operate these products and technologies and the people who produce them. Taking account of this, Hitachi went back to the basic principles of manufacturing in the development of this lighting system and embarked on a product development that involved combining technologies learnt from past mistakes with the latest new technologies, undertaking this through the development of the LED lighting system for rolling stock.

This article describes the purpose and features of LED lighting, LED interior lighting for rolling stock, and LED lighting systems.

PURPOSE AND FEATURES OF LED LIGHTING

Features of LED Lighting

The features of LED lighting systems are listed below.

(1) Lower power consumption

LED lighting typically provides a simple replacement for previous types of lighting; is said to roughly halve energy costs and carbon dioxide (CO_2) emissions; and represents a simple, effective, and significant measure for implementing laws such as the Act on the Rational Use of Energy (law relating to the rationalization of energy use) and the Law Concerning the Promotion of Measures to Cope with Global Warming (law encouraging measures for preventing global warming).

(2) Elimination of flickering

LED lighting is ideal for use in trains because it is powered by direct-current (DC) electric power and does not produce the flickering that occurs with fluorescent lighting. This should reduce eye strain.

(3) No emission of ultraviolet rays

As the spectrum of light produced by an LED depends on the semiconductor and phosphor material, unlike most other light sources such as fluorescent and incandescent lighting, it does not include any of the ultraviolet or infrared rays that do not provide any illumination. Similarly, it is also less prone to attracting insects because it produces very little ultraviolet light in the part of the spectrum visible to insects. In outdoor as well as indoor lighting applications, not having to worry about insects means that a feature of LED light fittings is that they are less prone to becoming dirty.

(4) Reduction in life cycle costs

As the life of an LED element is approximately 40,000 hours, it significantly reduces the work associated with the frequent replacement, lighting on/off control, stock control, and waste disposal tasks that are an issue for halogen, fluorescent, and other forms of conventional lighting. The lifetime of an LED lighting system is defined as the point at which the brightness falls to 70% of its initial level. As the principle of operation of LED lighting systems means that they are not subject to the phenomenon of burn out that occurs on halogen and fluorescent light bulbs, they do not need to be replaced before reaching their design life. Similarly, it is not necessary to keep spares on hand in case of light bulbs burning out.

Installation Requirements for LED Lighting System for Rolling Stock

The requirements for use of LED lighting systems in rolling stock are: (1) Functionality (safety), (2) Reduction in power consumption, (3) Design, (4) Maintenance, (5) Consciousness of the environment. Only once these five requirements have been satisfied can the lighting system be adopted, and it is also necessary to have an adequate understanding of each railway company’s equipment and the conditions in the trains where the lighting system will be installed, particularly regarding safety considerations.

Philosophy behind Lighting Level Standards

A mandatory requirement is to satisfy the criteria in JIS E4016 (“Illuminance for Railway Rolling Stock—Recommended Levels and Measuring Methods”), the Japanese Industrial Standards (JIS) for lighting levels in rolling stock in Japan. For passenger train interiors, the standard stipulates 200 lx or more at a height of 850 mm above the floor. The wavelength of LED light (roughly 450 to 500 nm) is shorter than that of fluorescent light (roughly 550 nm), and this gives it a characteristic bluish tint. Because the light is whiter than fluorescent lighting with an emission intensity about 1.3 times stronger, text and similar on illuminated objects have a crisper appearance than when fluorescent lighting is used.

Interdependence of Illumination Intensity and Angle of Spread

Because it is produced in a discharge tube, fluorescent lighting has a spread of 360°. In contrast, the angle of light spread for typical LED lighting is approximately 120°, only about one-third that of fluorescent lighting. This means that, compared to fluorescent lighting, there is little illumination intensity to be gained by using a reflector with an LED light.

The indirect LED lighting developed and adopted initially was designed to have a spread of 140°, which is 20° more than normal LED lighting, and the newly developed direct lighting has increased this to about 173°.

INTERIOR LED LIGHTING FOR ROLLING STOCK

Improving Energy Efficiency of Interior LED Light Fittings

Although LED lighting is already more energy efficient than fluorescent lighting, Hitachi has proceeded with development aimed at reducing power consumption further. As the intensity of LED light is roughly proportional to the electric current, Hitachi has established circuit designs and devices that keep the current low without loss of light intensity. Also, the sheet selected for light diffusion is one that has a high level of transparency while still retaining its ability to diffuse light. The result, from data on use in actual rolling stock, is an approximate 40 to 60% reduction in power consumption compared to fluorescent lighting.

Lengthening Life of Interior LED Light Fittings

As has already been noted, general-purpose LEDs typically have a life of 40,000 hours. The newly developed LED features circuit and board configurations that are resistant to the effects of heat and designed for long life, giving it a life of 100,000 hours (16 years). Both the 100-V DC emergency lighting power supply and the 200/254-V alternating current (AC) power supply have shapes that are compatible with fluorescent light fittings. The entire light fitting was developed to have a long life, with the power supplies being designed especially to use long-life components to give them the same 100,000-hour (16-year) life as the LED devices.

LED Lighting with Strong Yellow Component

A feature of its technology for being gentle on the eye is that the newly developed LED lighting system for rolling stock incorporates a technique for synthesizing and amplifying light that uses the inherent properties of light without using an LED diffuser lens. Hitachi has also developed leading-edge

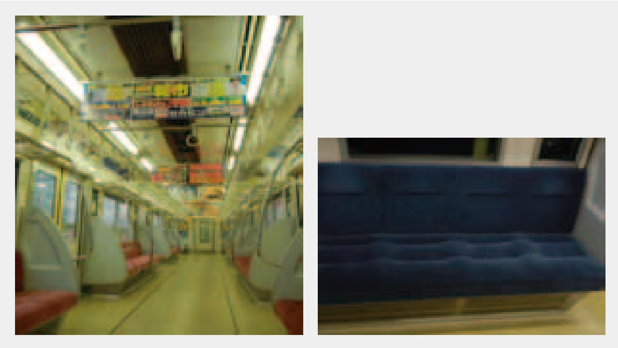

Fig. 1—Train Interior Using Conventional Fluorescent Lighting and Blue Seat.
This shows the train interior with fluorescent lighting prior to refurbishment, and priority seating for the elderly and people with disabilities.

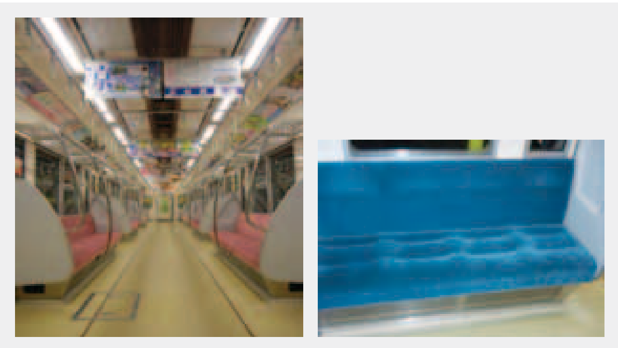

Fig. 2—Train Interior Using LED Lighting with Strong Yellow Component and Blue Seat.
This shows the train interior after refurbishment with light-emitting diode (LED) lights with a strong yellow component, and priority seating for the elderly and people with disabilities. The vivid blue coloring is highlighted.

technology for producing white light with a high level of color rendering properties that mixes blue, yellow, red, and green from the three primary colors (red, green, and blue). This technology has been deployed in LED lighting on trains (see Fig. 1 and Fig. 2).

Structure of Interior LED Light Fitting

The most recently developed LED light fitting has a design that allows it to be used in any train and which requires the minimum amount of work for retrofitting into refurbished trains. The design also features an aluminum base for the LED circuit board, and the ability to change the light cover to suit the specific design of the train.

Maintenance has also been improved by the use of a replaceable LED circuit board to allow for future LED upgrades. The design allows the entire circuit board to be unplugged from the connectors and replaced as a single unit (see Fig. 3).

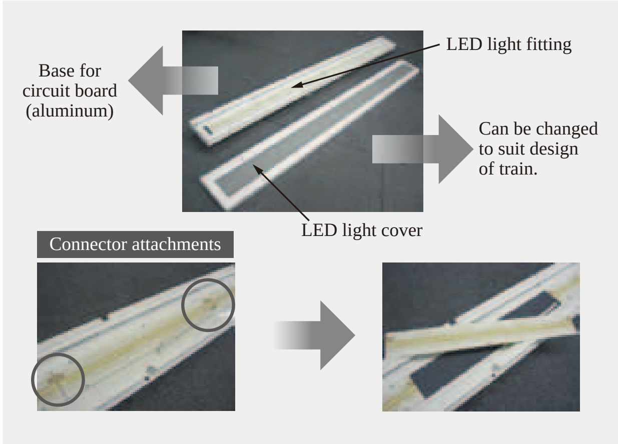

Fig. 3—LED Light Design and LED Circuit Board.
The light fitting in which the circuit board is installed is made of aluminum and the cover is made of toughened glass over which is spread a highly transparent diffuser sheet. The LED circuit board is designed for easy replacement of individual blocks.

Example Installation of Interior LED Light Fitting

The following sections describe the use of the above LED technology both in the refurbishment of existing trains and subsequently in new trains, beginning with its use in indirect lighting. The first LED lighting system for rolling stock was introduced on Hankyu Corporation's Series 9000 trains. This installation used quasi-indirect lighting and the initial type of LED (see Fig. 4).

Next, direct lighting using LEDs with a strong yellow component was installed in refurbished Series 8000 trains of Keio Corporation. These lights have been positioned so as to emit light from the side of the compartment to illuminate the advertising along each side of the ceiling (see Fig. 5).

A direct lighting system has been installed in new Series 817 trains for the Kyushu Railway Company. The system is an LED version of a form of lighting that attaches to air conditioning vents and allows

Fig. 4—Indirect LED Lighting for New Series 9000 Trains Supplied to Hankyu Corporation.
These initial types of LEDs first installed by Hitachi in rolling stock were positioned perpendicular to the floor. The color temperature was selected to produce light of the same color as the previous fluorescent lighting.

Fig. 5—Direct LED Lighting Installed in Refurbished Series 8000 Trains Supplied to Keio Corporation.
Direct LED lighting was installed as a replacement for the previous fluorescent lighting. Being flatter than the fluorescent lights they replace, the LED light fittings create a more open ceiling space.

Fig. 6—Direct LED Lighting Installed in New Series 817 Trains Supplied to Kyushu Railway Company.
These interior ceiling lights installed in a typical A-train provide a simple and expansive interior space.

the interior of the train to be made larger, one of the features of the A-train (see Fig. 6).

LED HEADLIGHTS IN ADOPTION OF LED LIGHTING SYSTEM

Rolling Stock Headlights

Currently, halogen lamps or high-intensity discharge (HID) lamps are used for train headlights to improve forward visibility. However, these need to be replaced annually, and in the worst cases, once every three months. Because of their importance for ensuring safety, headlights must be replaced immediately if they fail, but this is a time-consuming job. For these reasons, not only do headlights need to provide excellent visibility and have a long life, they must also be easy to replace or upgrade. Fig. 7 shows the structure of a lighting unit.

Features of LED Headlights

Hitachi has drawn on know-how from development of interior lighting to achieve energy efficiency, reliability, long life, and ease of installation. This involves reducing power consumption by 70% to improve energy efficiency, using lenses proven in other products to ensure reliability, and conducting more than four years of exposure testing to select plastics that do not degrade under ultraviolet light. Redundancy has also been improved by using the high beam LEDs to provide a backup circuit for use in the event of the failure of the low beam LEDs (see Fig. 8).

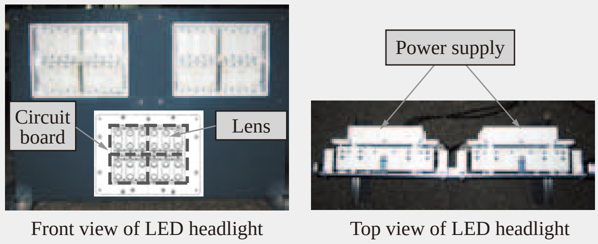

Fig. 7—LED Headlight Design.
The headlight is split into four blocks. The upper blocks are mainly used for high beam and the lower blocks for low beam. The power supply is fitted behind the lights.

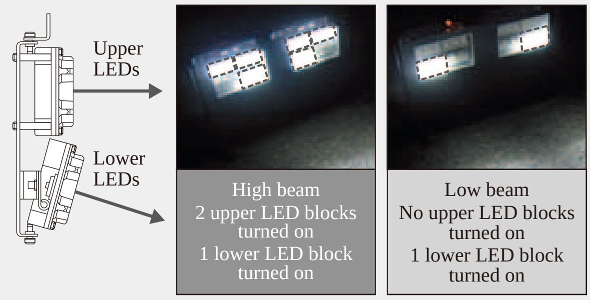

Fig. 8—High and Low Beam Operation.
The high beam light uses the two upper blocks and one lower block. The low beam light uses one lower block. If one block fails, the system can switch on an adjacent block as a replacement.

FUTURE LED SYSTEM DEVELOPMENTS

The following sections describe the potential future developments for the LED system.

(1) Adoption of common power supply

Two separate power supplies are used at present, an AC power supply and an emergency DC power supply. By adopting a single power supply, there is scope for measures such as consolidating the power supply units or operating all lights from batteries during an emergency to reassure passengers. Consolidating the power supplies will also make replacement easier and reduce costs.

(2) Modularization of ceiling-mounted equipment

Integrating other equipment such as internal ceiling cabling, radio transmitters, or speakers into the LED light fittings will not only simplify the ceiling design, it will also improve reliability and shorten lead times by making installation easier.

(3) Integration with monitoring equipment

Within the time, distance, and other constraints placed on monitoring equipment, the optimum lighting level can be varied depending on factors such as the time of day or whether the train is passing through a tunnel, with potential benefits including enhanced passenger comfort and further improvements in energy efficiency.

CONCLUSIONS

This article has described the purpose and features of LED lighting, LED interior lighting for rolling stock, and LED lighting systems.

Although more expensive than previous forms of lighting such as fluorescent and HID lamps, it is anticipated that LED lighting systems will be used increasingly in the future as mass production brings down costs, and because of their superior life cycle costs due to better energy efficiency and longer life. Rather than limiting use of LEDs to merely a replacement for existing lighting, Hitachi intends to continue developing and designing rolling stock systems for easier maintenance and superior energy efficiency in order to provide operators with efficiency improvements while also improving passenger comfort by taking account of the entire rolling stock system.

ABOUT THE AUTHORS

Isao Ishii

Joined Hitachi, Ltd. in 1989, and now works at the Kasado Works, Rail Systems Company. He is currently engaged in electrical and fittings design for public railways and conventional rolling stock.

Fumio Shimada

Joined Hitachi, Ltd. in 1971, and now works at the Sales & Marketing Division, Rail Systems Company. He is currently engaged in coordinating rolling stock systems for the Japanese market.

Mitsuru Asahara

Joined Hitachi Kasado Engineering Co., Ltd. in 1989, and now works at the Rolling Stock Engineering Department, Hitachi Transportation Technologies, Ltd. He is currently engaged in carbody and interior design and refurbishment projects for rolling stock, primarily for public and private railways and conventional rolling stock.

Shigenori Iwamura

Joined Hitachi, Ltd. in 1992, and now works at the Sales & Marketing Division, Rail Systems Company. He is currently engaged in coordinating rolling stock systems for the Japanese market.

Power Electronics Technologies for Railway Traction Systems

Yasuhiko Kono
Ken Ito
Hiroshi Okawara
Toru Fukuma

OVERVIEW: To satisfy a growing global market, Hitachi supplies a wide range of railway traction system products to meet diverse customer needs that extend from commuter to high-speed trains. This has included the development and commercialization of a standard medium-capacity inverter with a mass and external dimensions that are less than those of previous models by 20% or more. For high-speed rolling stock, Hitachi has developed an inverter that has roughly double the output of Japanese models, and that is designed for use with rolling stock, motors, and other components that comply with European specifications. This inverter is currently undergoing field trials. To improve rolling stock energy efficiency further and reduce maintenance requirements, Hitachi has also developed a traction system with 35% lower inverter losses, including the development of a highly efficient enclosed induction motor (efficiency improved from 91% to 95%) and SiC hybrid modules that combine SiC diodes with Si IGBTs.

INTRODUCTION

THE international trend toward energy efficiency is making railways increasingly important, and there is a need for the timely supply of a diverse range of traction systems that are not only highly efficient and reliable, but also satisfy the market requirements of each country.

In addition to offering a wide product range that meets these needs, Hitachi has also responded to the growing demand for energy savings by developing new traction technologies, including a highly efficient enclosed induction motor and silicon carbide (SiC) hybrid inverter.

This article describes the features of Hitachi's range of electrical components for the traction circuits used in traction systems for both conventional and high-speed trains, and also newly developed next-generation traction circuit technology.

HITACHI'S TRACTION SYSTEMS FOR ROLLING STOCK

Table 1 lists Hitachi's range of traction systems for rolling stock. The range extends from small-capacity models, used in applications such as monorails, up to units for use in the Shinkansen and other high-speed trains. The following sections describe the different types of systems.

MEDIUM-CAPACITY SYSTEMS

Hitachi offers four different medium-capacity traction systems to suit different applications. The following sections describe their technical features and examples of their use.

Standard Systems

Hitachi supplies a range of standard inverters(1) that are smaller, lighter, and easier to maintain than previous models thanks to use of components such as low-loss/low-noise insulated-gate bipolar transistors (IGBTs) and highly efficient cooling systems, the adoption of unit-based designs that make effective use of built-in components, and the elimination of components such as fans that have a limited operating life (see Table 1).

(1) Series 209 experimental train of East Japan Railway Company (MUE-Train)

TABLE 1. Hitachi's Range of Traction Systems for Rolling Stock
The six different types differ based on parameters such as control capacity and functions.

Small-capacity systems	Medium-capacity systems				High-capacity systems
	Standard	With brake chopper	For low-floor rolling stock	AC system / AC-DC dual system	
Subways, monorails, etc.	Urban transportation	Urban transportation (without regeneration)	Linear subways	Intercity transportation	High-speed rolling stock

AC: alternating current DC: direct current

MUE-Train: multi-purpose experimental train

Fig. 1—Series 209 Experimental Train (MUE-Train).
The MUE-Train commenced field trials in October 2010 using a standard inverter adopted for use in the next-generation rolling stock control system.

The East Japan Railway Company is developing a next-generation rolling stock control system for the experimental Series 209 [the multi-purpose experimental train (MUE-Train)]. The inverter for this system is a standard inverter for which the East Japan Railway Company was the first user. The control system uses Ethernet to transmit control signals (see Fig. 1).

(2) Additional units of the East Japan Railway Company's Series E233-3000

A standard inverter adopted for additional units of the Series E233-3000 featured smaller size and lighter weight than the inverter used in the earlier units (see Table 2 and Fig. 2). Despite this, the old and new inverters are mutually compatible in terms of installation and performance.

Systems with Integrated Brake Chopper

For urban services outside Japan, where it is often difficult to achieve an adequate regenerative load, Hitachi has commercialized an inverter for use with brake-generators that incorporates the brake chopper in the same housing. Integrating the brake chopper has reduced the weight by 14% compared to previous equipment.

Systems for Low-floor Rolling Stock

The restricted amount of space available for installing equipment below the floor of subway cars equipped with linear motors places a limit on the height of the inverter. Accordingly, Hitachi's range of standard models has been extended by revising the location of components, modifying the cooling system design, and optimizing the placement of parts inside the inverter unit to suit low-floor rolling stock, resulting in an inverter unit with a height of only 500 mm (24% less than standard model).

AC and AC-DC Dual Systems

By applying technologies from standard models to alternating current (AC) and AC-direct current (DC) dual systems, these have been made smaller, lighter,

TABLE 2. Comparison of Inverters Used on Series E233-3000
The table below compares the dimensions and weight of the old and new inverters used on the Series E233-3000.

Parameter	Initial rolling stock	Additional rolling stock
External dimensions (W × D × H) (mm)	3,390 × 740 × 725	2,950 × 740 × 650 (-22%)
Weight (kg)	1,030	790 (-24%)

Fig. 2—Inverters Used on Additional Series E233-3000 Units.
The inverters used for additional Series E233-3000 units were standard models. They were smaller and lighter than the inverters used on earlier units.

and easier to maintain than previous models. These systems include both converters that convert single-phase AC to DC and converter-inverter systems that incorporate an inverter.

A feature of Hitachi's converter-inverter systems is that they use T-shaped three-level converters to minimize power supply harmonics and noise. To make them smaller and more efficient, the T-shaped three-level converters have a simple design that also uses proprietary Hitachi circuit techniques to eliminate the clamping diodes used on previous three-level traction circuits(2).

The converter-inverter system on the East Japan Railway Company's Series E657 express trains for the Joban Line that entered commercial operation in March 2012 combines the T-shaped three-level converter with a DC rolling stock inverter power unit from the same series as that described above.

The converter power units for the Kyushu Railway Company's 817-2000 and 817-3000 Series use this three-level traction circuit and incorporate low-noise, snubber-less traction circuit technology that is implemented in the inverter. Thanks to the small size and UV phase integration, the converter-inverter system consists of two independent sub-systems to provide redundancy even on short trainset configurations.

TRACTION CIRCUIT FOR HIGH-SPEED ROLLING STOCK

While trains speeds are increasing to more than 300 km/h throughout the world, the following are the main differences between Japan and other countries.

In Japan, the proportion of driving wheels is increasing to reduce the mass per axle and ensure an adequate level of adhesion. The purpose is to reduce the effect on the railway track. As a result, individual converter-inverter systems tend to have a smaller output, with the control of four 300-kW motors being a typical configuration. Development trends include environmental considerations such as higher efficiency and making devices smaller and lighter while retaining the same capacity.

Overseas, meanwhile, where track foundations tend to be firmer, the main rolling stock configuration is to use central traction systems of the type used in Europe that have a high mass-per-axle. Even when a distributed traction system is used, the proportion of driving axles tends to be lower than in Japan and a higher capacity converter-inverter system, requiring a high-capacity configuration that controls four motors in the 600-kW range. The following sections describe examples of these two different types of system.

Small, Lightweight Systems for Use in Japan

Since the adoption of IGBTs in 1997 on the Central Japan Railway Company's Series 700 Shinkansen rolling stock, the predominant configuration for converter-inverter systems for the Shinkansen has consisted of three-level converter-inverters with 3.3-kV IGBTs.

The East Japan Railway Company's Series E5 Shinkansen rolling stock, which entered commercial operation in March 2011, is intended to be connected with the new Series E6 Shinkansen rolling stock (scheduled to commence commercial operation in the spring of 2013) that will operate through-train services on an existing line. There are plans to operate the Series E5 and E6 Shinkansen connected, with speeds to increase progressively up to Japan's maximum speed of 320 km/h after services commence.

Hitachi has prepared a common design for the converter-inverter systems used in both the Series E5 and E6 Shinkansen rolling stock, and has made the operation and maintenance of traction circuit equipment more efficient. Because the Series E6 Shinkansen rolling stock will also run on conventional lines, they require a small converter-inverter system to suit their small carbody.

The power unit of the converter-inverter system for the Series E5 has an integrated configuration consisting of two converter phases and three inverter phases. Its design, which allows the system to be attached to or removed from the side of the vehicle, not only makes effective use of the available installation space and helps make the equipment smaller, it also provides a significant improvement in ease of installation. The system is also designed to facilitate work on internal equipment that needs inspection or maintenance, with an inspection cover fitted on the air intake that is on the mountain-side of the converter-inverter system and all of the main internal devices being located together. The size of the system is also reduced by utilizing free space inside the converter-inverter system for components such as filter condensers and resistors that do not require frequent inspection (see Fig. 3).

High-output System for Overseas Use

A number of high-speed trains were developed in China in preparation for the 2010 opening of the Beijing–Shanghai high-speed railway, which is used exclusively for passenger services. As part of this,

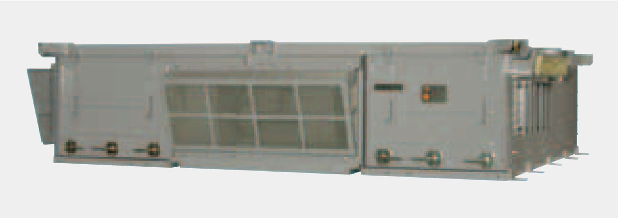

Fig. 3—Converter-inverter System for Series E5 Shinkansen Rolling Stock.
This system shares a common design with the system for the Series E6, with more efficient operation and maintenance of traction circuit equipment.

Hitachi received an order for electrical components for one of the trains built for this purpose, the CRH380CL, from CNR Changchun Railway Vehicles Co., Ltd. The order size was for 25 trainsets. The order for the first trainset was produced at Mito Rail Systems Product Division, and for the second and subsequent trainsets at Hitachi Yonge Electric Equipment (Xi'an) Co., Ltd. (HYEE). The specifications of CRH380CL rolling stock are shown in Table 3.

The CRH3 Series includes the CRH380BL (with an electrical system supplied by Siemens AG), which is produced based on CRH3 rolling stock that is already in service (ICE3 base). The purpose of the CRH380CL to which Hitachi's order related was to be a locally developed train for China that used the structure of European rolling stock as a base. A major issue in the development was that it required the systems to be compatible with rolling stock, motor, converter-inverter, and other components based on European technology (see Fig. 4).

The configuration of the traction system connects two converter-inverter systems to each main transformer, with each converter-inverter system driving four 615-kW motors in parallel. Another feature of the system is that an auxiliary power supply is connected to the intermediate DC section of the converter-inverter system so that, as well as delivering a maximum of 3 × 160 kVA, it has a configuration that enables the auxiliary power supply to operate using regenerative electric power from the inverter when passing through sections. The converter circuit of the converter-inverter system has a dual configuration for higher capacity and uses carrier phase-shift operation to reduce harmonics. Table 4 lists the specifications and main development requirements of the converter-inverter system.

As of September 2011, the first trainset had completed factory testing at the manufacturer's site and was undergoing tuning and field trials on the test line of the China Academy of Railway Sciences in Beijing.

NEW TECHNOLOGIES FOR ENERGY EFFICIENCY

Hitachi is working on a wide range of technology developments aimed at further improving the performance of railway traction systems. This section describes two such new developments: a highly efficient enclosed motor and a low-loss SiC hybrid inverter.

Highly Efficient Enclosed Induction Motor

The demand for making rolling stock motors more energy efficient, and easier to maintain with low noise has been steadily increasing. To achieve this, Hitachi has developed a new, highly efficient enclosed induction motor (see Fig. 5). The features are as follows.

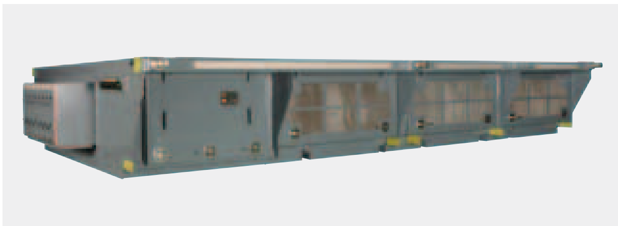

Fig. 4—Converter-inverter System for CRH380CL.
One inverter and two converters are housed in the same unit.

TABLE 3. CRH380CL Rolling Stock Specifications
The CRH380CL was developed specifically for use in China using European rolling stock as a base.

Trainset configuration	16 cars (8M8T)	
Trainset mass	1,000 t	
Electrification system voltage	25 kV	
Performance	Output at wheel: 600 kW × 32 axles	
	Maximum operating speed: 380 km/h	
Rolling stock manufacturer	CNR Changchun Railway Vehicles Co., Ltd.	

M: motor T: trailer

TABLE 4. Development Specifications
The configuration is similar to European rolling stock designs.

Output capacity	4 × 615-kW motors + 3 × 160-kVA auxiliary power supplies
Converter	2 × two-level, snubber-less converters with IGBTs (4.5 kV/900 A)
Inverter	1 × two-level, snubber-less inverter with IGBTs (4.5 kV/900 A)
Configuration, etc.	• Auxiliary power supplies connect to DC section, installed on anti-vibration rubber mounts • 4,300 × 2,716 × 700 mm, 3,380 kg

IGBT: insulated-gate bipolar transistor

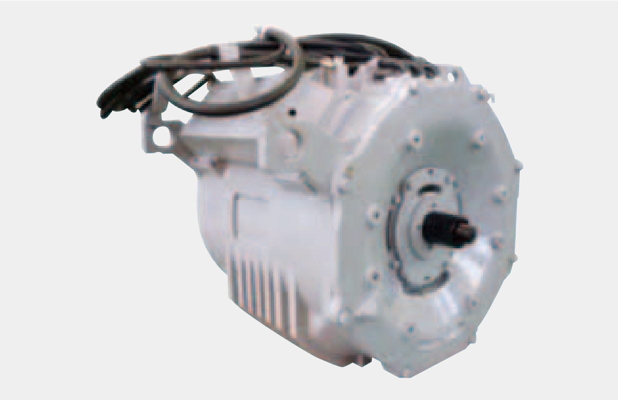

Fig. 5—Enclosed Motor.
An optimized fin layout was designed to cool the air inside the motor efficiently using the natural airflow of the moving train.

Fig. 6—SiC Hybrid Inverter.
The inverter was made 40% smaller and lighter by reducing the size and losses of the switching devices.

(1) Enclosed design with internal fan: Past induction motors have required regular cleaning because they draw in external air for cooling, which can allow dirt to get inside the motor. These motors are also louder because noise from the rotor inside the motor propagates through the cooling air.

In response, Hitachi has developed an enclosed motor that overcomes these problems. The major challenge with adopting this fully enclosed structure was the resulting increase in heat generation as cooling air cannot be drawn into the motor.

To deal with this problem, Hitachi set out to reduce motor losses and improve cooling efficiency. To reduce losses, electromagnetic analysis was used to optimize the design of the stator and rotor and to select a low-loss material for the rotor. This improved the motor efficiency from 91% to 95%. Developments aimed at improving cooling efficiency included using an analysis of air flow and temperature to optimize the design of the internal recirculation duct and external cooling fins, and using an auxiliary fan to improve the cooling efficiency of the bearings. Adopting this fully enclosed design eliminated the need for cleaning the inside of the motor and has reduced noise by 30 dB.

(2) Bearing design allows replacement without disassembly.

Hitachi has also devised a simple new design for the bearings that allows them to be worked on without removing the rotor.

Whereas motors in the past required a crane to remove the rotor, this is not necessary with the new motor because the rotor does not need to be removed. In addition to providing more flexibility in where maintenance work can be performed, this also significantly reduces maintenance time. The simple bearing design means that no special tools are required and this also removes constraints on work such as tool availability.

SiC Hybrid Inverter

Hitachi has developed an inverter that uses new SiC hybrid modules as its semiconductor switching elements (see Fig. 6).

While 1.7-kV SiC semiconductor switching elements had been developed for use with DC 750-V electrification system, there were no 3.3-kV devices suitable for use with the DC 1500-V electrification system common in Japan. This provided a strong incentive for their development.

Now, Hitachi has developed a 3.3-kV SiC hybrid module and used it in an inverter for 1500-V electrification system with a simple two-level configuration. The features of the inverter are as follows.

(1) Lower losses: Hitachi has developed an SiC hybrid module with the aim of reducing both diode switching loss and the turn-on switching loss that occurs when IGBTs turn on by combining SiC diodes with Si IGBTs. The result has been to reduce inverter losses by 35% by cutting diode switching loss to one-sixth and IGBT turn-on loss to less than one-half.

(2) Smaller size and lighter weight: Because of the low losses described above, the SiC hybrid module is only two-thirds the size of previous devices with the same current capacity. Features such as the reduction in heat generation and the smaller size of the cooling system, which was achieved by using thermofluid analysis to optimize the heatdissipating fin and heat pipe layout, have succeeded in reducing the volume and weight of the inverter by 40% compared to the previous model.

CONCLUSIONS

The railway market will become increasingly global in the future, and there will be demand for traction systems that are both easier to maintain and more energy efficient. Hitachi intends to respond to diverse customer needs with newly developed next-generation traction circuit technology and the range of railway traction systems described in this article.

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ABOUT THE AUTHORS

Yasuhiko Kono

Joined Hitachi, Ltd. in 1992, and now works at the Process Designing Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the development of inverters for rolling stock. Mr. Kono is a member of The Institute of Electrical Engineers of Japan (IEEJ).

Ken Ito

Joined Hitachi, Ltd. in 1986, and now works at the Rolling Stock Electrical Systems Design Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the design of inverters for rolling stock. Mr. Ito is a registered electrics and electronics professional engineer and is a member of the IEEJ.

Hiroshi Okawara

Joined Hitachi, Ltd. in 1994, and now works at the Rolling Stock Electrical Systems Design Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the design of inverters for rolling stock.

Toru Fukuma

Joined Hitachi, Ltd. in 2008, and now works at the Rolling Stock Electrical Systems Design Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the design of inverters for railway traction systems. Mr. Fukuma is a member of the IEEJ.

Energy-saving Technology for Railway Traction Systems Using Onboard Storage Batteries

Motomi Shimada
Yoshihiro Miyaji
Takashi Kaneko
Keita Suzuki

OVERVIEW: The first application for onboard storage batteries came with the commercialization of series hybrid drive systems that reduced the fuel consumption of diesel trains. Storage battery control has also been used for the absorption of regenerative electric power and to implement the regenerative brake with extended effective speed. Further progress has since led to the development of an efficient regeneration system for making effective use of electric power. Now, Hitachi has conducted operational trials of the regenerative brake with extended effective speed using storage batteries to boost the DC voltage at the inverter input, achieving an increase in regenerative electric power of up to 12.5% (for a 300-V boost). In the future, Hitachi intends to encourage the wider use of onboard storage batteries by achieving a good balance of return on investment, and by working on new energy-saving technologies that are closely aligned with customer needs.

INTRODUCTION

HITACHI is developing railway systems that use storage battery control technology to save energy and reduce carbon dioxide (CO_2) emissions.

The first application for onboard storage batteries came with the commercialization of series hybrid drive systems that reduced the fuel consumption of diesel trains on non-electrified railway lines. While collecting field data, Hitachi has also developed an efficient regeneration system to improve energy efficiency on trains, and has verified its effectiveness through operational trials.

This article gives an overview of storage battery technologies for railways, and describes a regenerative brake with extended effective speed control, which extends the operating speed range for regenerative braking by using storage batteries to increase the direct current (DC) voltage of the inverter, and which is used in the efficient regeneration system.

STORAGE BATTERY TECHNOLOGY FOR RAILWAYS[1]

Development of Hybrid Drive System

In collaboration with the East Japan Railway

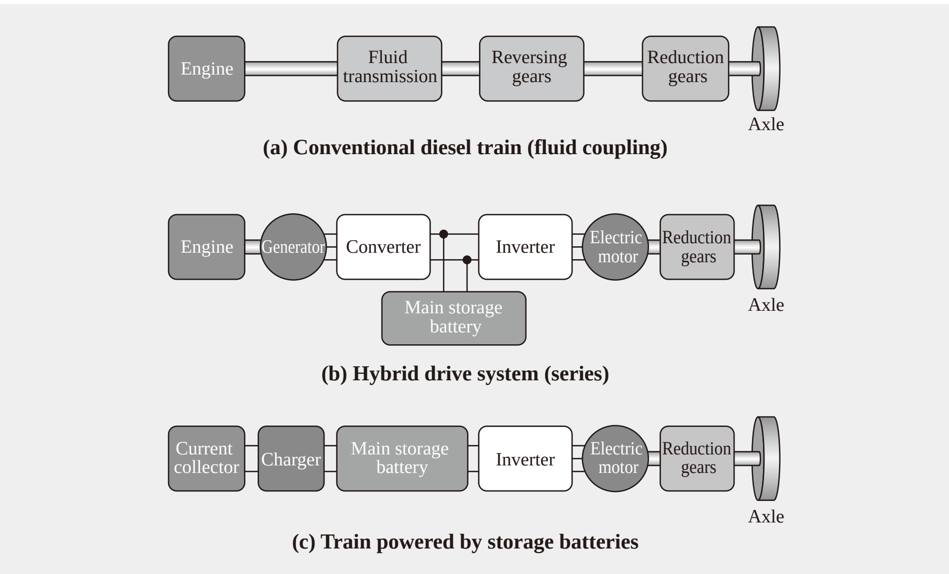


Fig. 1—Traction System for Non-electrified Railway Lines.
Trains that are powered by storage batteries and use a hybrid drive system have fewer mechanical components than conventional diesel trains. They also significantly reduce maintenance work through the standardization of major components between trains.

Company, Hitachi started developing a series hybrid drive system in 2001 that combined a diesel engine and lithium-ion batteries with the aim of reducing the fuel consumption and harmful exhaust emissions of diesel trains running on non-electrified railway lines (see Fig. 1). The system reduces fuel consumption and noise by using storage batteries to implement regenerative braking, engine idle stop, and constant engine speed operation, features that are not possible on diesel multiple units.

Implementation of Hybrid Drive System

A hybrid drive system has been built for use in the Series Kiha E200 trains of the East Japan Railway Company. The main storage batteries used in the system are high-output lithium-ion batteries designed for use in hybrid cars.

The Series Kiha E200 trains became the world's first hybrid trains to commence commercial operation when they entered service on the Koumi Line in July 2007. Hitachi then went on to develop a hybrid drive system for the Series HB-E300 resort trains in 2010. The Series HB-E300 operates in Aomori Prefecture (Tsugaru and Ominato Lines), Akita Prefecture (Gono Line), and Nagano Prefecture (Shinonoi and Oito Lines), where they are helping reduce the load on the environment in ways that include providing quieter and more energy-efficient operation (see Fig. 2). The system used in the Series HB-E300 is the successor to the series hybrid system implemented for the Series Kiha E200, and it has been designed to suit the requirements of a resort train. This includes providing redundancy in the auxiliary power supply (increased capacity and support for power supply induction), enhancing tolerance of low temperatures and structural strength for coping with snow, and providing additional traction capacity.

Storage-battery-powered Train

Trains powered by storage batteries charge their large-capacity onboard storage batteries while on electrified sections of railway line, and then use storage battery power only to drive the train and supply power to auxiliary systems. Because this eliminates the need for an internal combustion engine, these trains should be significantly more energy efficient than diesel trains, with better environmental performance and lower maintenance requirements. With the rapid growth in the market for storage batteries for use in vehicles, industry, and other applications in recent years, storage battery performance (capacity and output) continues to improve while costs are falling, and this has opened up the potential for trains powered by storage batteries to be built for use on railway lines where the terrain is gentle and the length of non-electrified line is short. As capacity is more important than output for main storage batteries, it is appropriate to use the lithium-ion batteries with high energy density produced for use in electric vehicles and industry. Utilizing the increased capacity, higher voltages, and control and monitoring techniques for lithium-ion batteries that it

Fig. 2—Series HB-E300 Resort Train.
This is the successor to the series hybrid drive built for the Series Kiha E200 trains. It features high-output lithium-ion batteries (15.2 kW).

has built up through its hybrid drive systems, Hitachi is proceeding with development work aimed at the early commercialization of trains powered by storage batteries.

EFFICIENT REGENERATION SYSTEM(2)

Concepts for Achieving Energy Efficiency

Hitachi is building railway systems that are taking the lead in moving to an energy-efficient society by improving the total efficiency of the traction drive in train systems (see Fig. 3).

Specifically, this is being achieved through the following three technologies:

(1) Improvements to equipment efficiency
(2) Use of control to improve efficiency
(3) Utilization of regenerative energy

This section describes the technologies for an efficient regeneration system that utilizes regenerative energy.

Improving Efficiency of Regenerative Braking

Regenerative braking works by using the traction motor as a generator during deceleration. The regenerative energy produced as a result is fed back to the overhead contact lines so that it can be reused to accelerate a nearby train. However, this regenerative energy may not be used fully during off-peak times when there are few nearby trains. The problem is how to use regenerative braking under light load conditions. To prevent the filter condenser voltage from rising in this situation, the inverter controls regeneration under light load in a way that throttles the regenerative current. Although this has the effect of minimizing the rise in the filter condenser voltage, it also reduces the regenerative braking force, and while this can be compensated for using the pneumatic brakes, it results in less regenerative energy being produced.

The energy efficiency benefits are maximized when all of the braking force required to decelerate a train to a stop are provided by the regenerative brake. At high speeds, however, regenerative braking force is limited by the motor output characteristics. As this component of the braking force that the regenerative brake is unable to supply at high speeds is provided by the pneumatic brake instead, the energy savings are smaller than they might have been. Accordingly, the problem is the performance limitations of the motor characteristics.

The efficient regeneration system uses the following methods to overcome these two problems.

(1) Solution for regenerative braking under light load conditions

The function for absorption of regenerative electric power uses storage batteries to absorb regenerative electric energy when there are no other trains able to receive it. The energy is then reused to power acceleration (see Fig. 4). The two potential locations for the storage batteries are onboard the train or on the wayside.

(2) Solution for performance limitations of the motor characteristics

The regenerative brake with extended effective speed extends the operating range of regenerative braking into higher speeds by using storage batteries to boost the DC voltage of the inverter, thereby increasing the output of the motor and inverter without changing the current through the various components. As shown in Fig. 5, this has the effect of increasing the voltage/frequency (V/f) top speed.

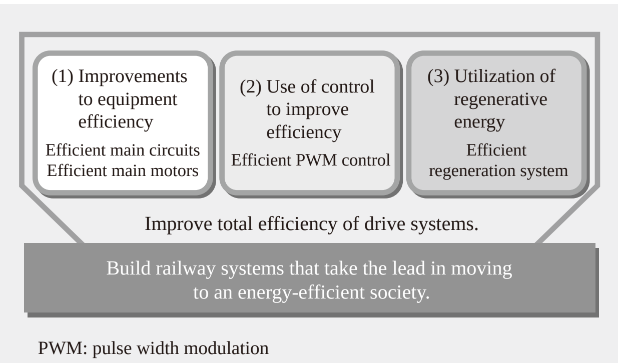


Fig. 3—Concepts for Achieving Energy Efficiency.
Hitachi is building railway systems that are taking the lead in moving to an energy-efficient society by improving the total efficiency of drive systems.

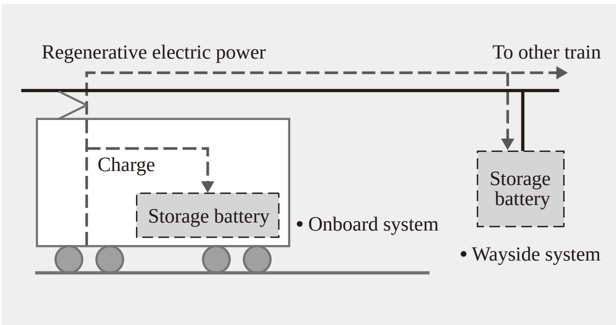


Fig. 4—Function for Absorption of Regenerative Electric Power.
Storage batteries absorb any regenerative electric power that cannot be returned to the overhead contact lines. The stored regenerative electric power is reused the next time the train accelerates to reduce power consumption by the inverter.

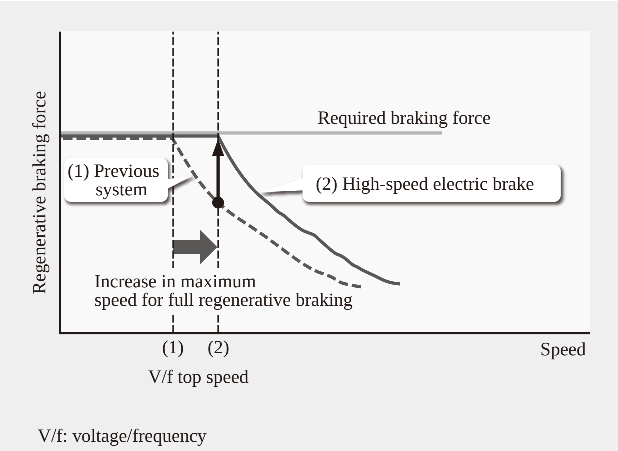


Fig. 5—Regenerative Brake Characteristics.
The storage batteries are used to extend the operating range of regenerative braking into higher speeds by boosting the DC voltage of the inverter, thereby increasing the output of the motor and inverter.

The efficient regeneration system is implemented by operating the function for absorption of regenerative electric power and regenerative brake with extended effective speed in an appropriate manner. Fig. 6 gives an overview of how the equipment operates.

CONTROL OF REGENERATIVE BRAKE WITH EXTENDED EFFECTIVE SPEED(3)

Overview

The efficient regeneration system has two functions. Operational trials have already been conducted for one of these: the absorption of regenerative electric power. The following section describes the operational trials and associated results for the other function: the regenerative brake with extended effective speed.

Principle of Operation

The performance of a regenerative brake for rolling stock deteriorates at high speed because of limitations in the motor output characteristics (once maximum voltage is reached, the braking force is inversely proportional to the square of the speed).

Although the input DC voltage for the inverter is determined by the voltage of the overhead contact line, it is possible to use the voltage from storage batteries to boost this input voltage, thereby increasing the voltage applied to the motor and allowing the output of regenerative braking to exceed the previous restriction. Fig. 7 shows the principle of operation for the regenerative brake with extended effective speed.

Circuit Design for Implementing Function

Fig. 8 provides an overview of the control mechanism and shows the circuit design for the system. The system works by inserting the storage batteries in series between the earth and the negative input terminal of the inverter. This pulls down the voltage at the negative input terminal from the earth voltage by an amount equal to the battery voltage (ΔV), thereby increasing the voltage applied to the inverter by the same amount. This voltage boost can be continuously varied between 0 V and ΔV by the

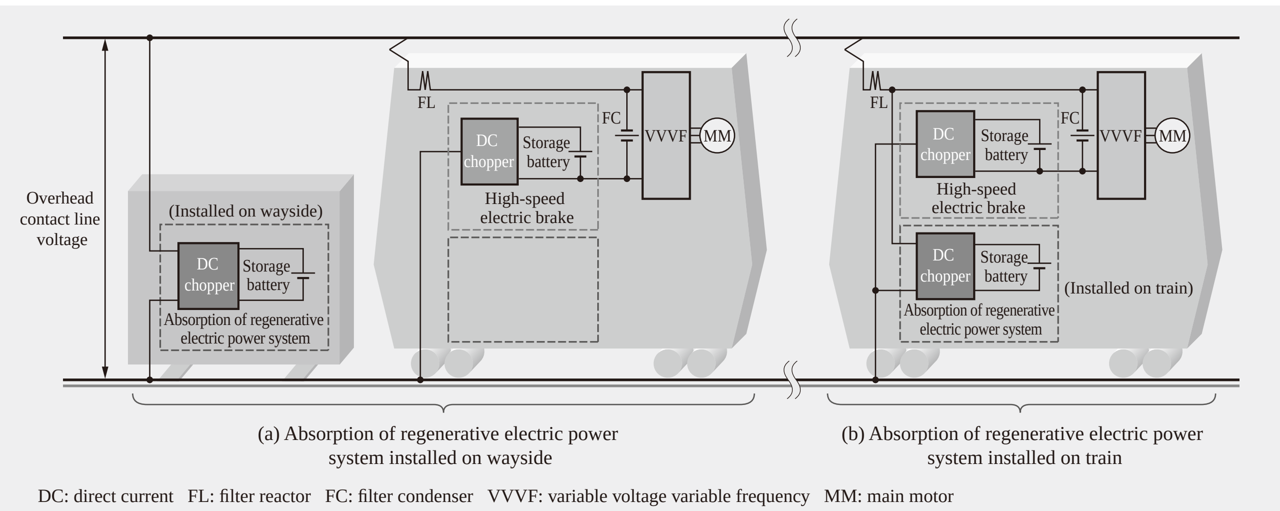


Fig. 6—Hardware Configuration of Efficient Regeneration System.
The storage batteries are inserted in series at the negative input terminal of the inverter when the regenerative brake with extended effective speed is used, and in parallel with the inverter via the step-up/step-down DC chopper when absorption of regenerative electric power is used.

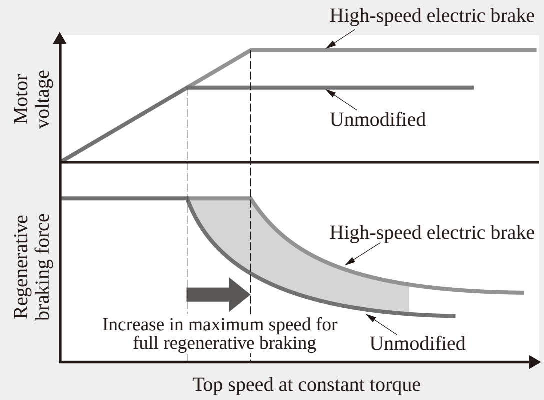
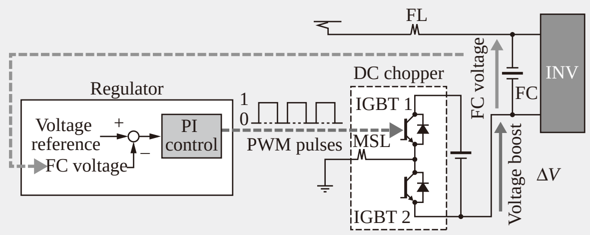


Fig. 7—Principle of Operation of Regenerative Brake with Extended Effective Speed.
As using the voltage from storage batteries to boost the DC voltage increases the regenerative braking power by an amount proportional to the voltage boost, the top speed for full regenerative braking is increased.

DC chopper to increase the filter condenser voltage by whatever amount required.

Field Testing of Prototype

A prototype of this system was installed on a 5050 Series train operated by Tokyu Corporation and operational trials were run between Tsukushino Station and Tsukimino Station on the Den-en-toshi Line. Fig. 9 shows the connection diagram for the main circuit. To simplify installation in the existing train, the prototype connected a DC chopper on the second of two 1C4M variable voltage variable frequency (VVVF) inverters, which control four motors each.



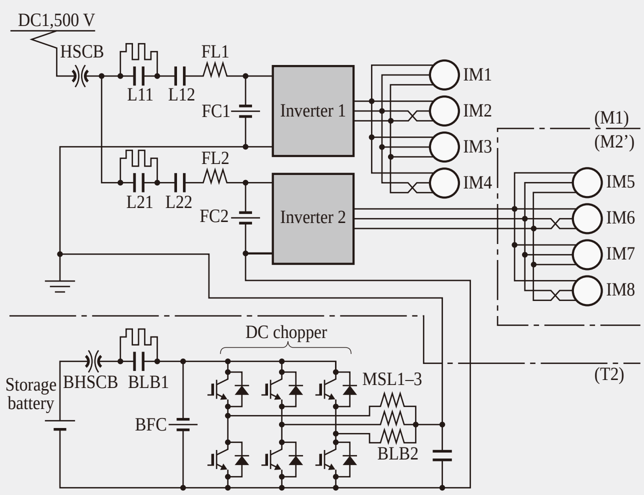
INV: inverter PI: proportional integral MSL: main smoothing reactor
IGBT: insulated-gate bipolar transistor

Fig. 8—Circuit Diagram of System and Overview of Control Mechanism.
The amount of storage battery voltage boost is adjusted to keep the DC filter condenser voltage equal to the voltage reference.

Lithium-ion secondary batteries with high energy density and output density were selected for the storage batteries. Two modules were connected in series to provide a maximum voltage boost of 340 V, each battery module having a maximum voltage of 170 V (see Fig. 10).

Energy Savings Achieved in Operational Trials

The inverter input voltage without boosting was 1,600 V. Fig. 11 shows a comparison of the regenerative electric power produced when braking to a stop from approximately 100 km/h for this and three other patterns in which the inverter voltage was boosted to 1,750 V, 1,850 V, and 1,900 V respectively. The results demonstrated that the higher the voltage boost, the wider the scope for regenerative braking and the greater the amount of regenerative electric power produced.



HSCB: high-speed circuit breaker IM: induction motor BHSCB: battery high-speed circuit breaker
BLB: battery line breaker BFC: battery filter condenser

Fig. 9—Connection Diagram of Main Circuit.
A DC chopper is connected to the second of two 1C4M VVVF inverters to boost the voltage.

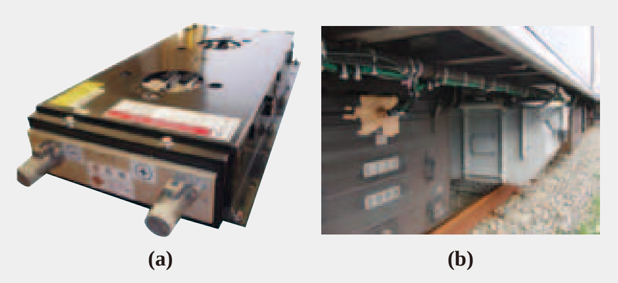


Fig. 10—Hardware for Control of Regenerative Brake with Extended Effective Speed.
The system uses 16 lithium-ion battery modules (a). Photograph (b) shows the chopper (front) and MSL (rear).

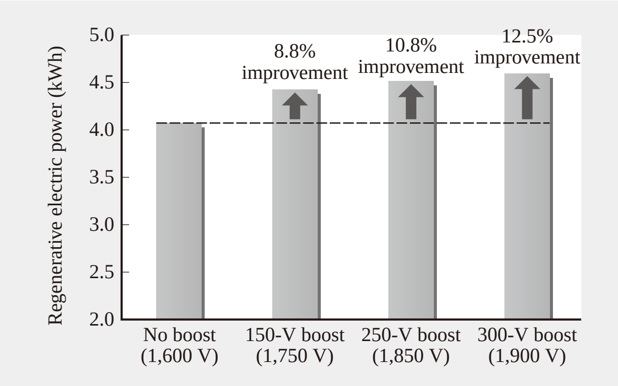


Fig. 11—Comparison of Regenerative Electric Power Produced for Different Voltage Boosts.
Increasing the voltage boost increases the maximum speed for full regenerative braking. The results of this trial, in which the train braked to a stop from 100 km/h, demonstrated that the amount of regenerative electric power increases the higher the voltage boost.

Hitachi is now working on enhancing energy management control and making the system smaller and lighter to ready it for use in commercial trains.

FUTURE ENERGY SAVING TECHNOLOGIES USING STORAGE BATTERIES

In actual rolling stock systems, trains on the same feeding section are supplied from the same substation via the overhead contact lines. In the near future, if all trains are fitted with storage batteries, in addition to considering the benefits of energy efficiency in terms of individual trains, it will also be possible to utilize the network of overhead contact lines to optimize the onboard storage battery systems by, for example, having nearby trains share stored electric power via the overhead contact lines.

Following this approach, Hitachi has developed a railway integration evaluation system that can be used to study systems optimization for the case when more than one vehicle fitted with storage batteries is present on the same feeding section.

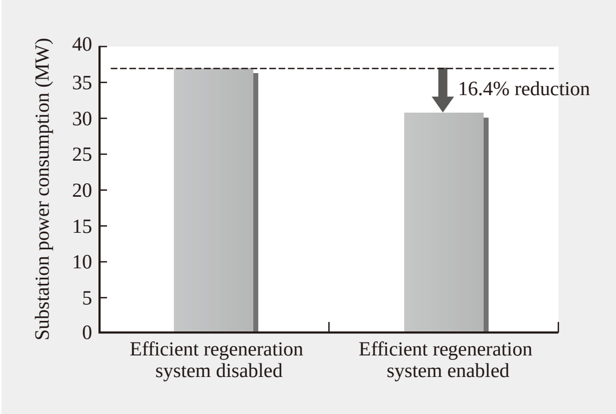


Fig. 12—Benefits of Installing Efficient Regeneration System.
It is anticipated that installing the efficient regeneration system will result in better energy efficiency.

A simulation was conducted to evaluate the benefits of installing an efficient regeneration system on a line with a mean distance between stations of 1.7 km, and assuming use of rolling stock designed for use on urban commuter lines.

The simulation assumed a distance between substations of 5 km, trains running every 5 minutes, and that trains stopped at all stations. Fig. 12 shows the benefits of installing an efficient regeneration system under these conditions. With energy savings of 16.4% compared to conventional inverter drive systems, the results demonstrated the benefits of installing an efficient regeneration system.

CONCLUSIONS

This article has given an overview of storage battery technologies for railways and described regenerative brake with extended effective speed control for inverters, which is used in the efficient regeneration system.

Technology for using onboard storage batteries to save energy was first commercialized in the form of a series hybrid drive system for reducing the fuel consumption of diesel trains running on non-electrified railway lines. In addition to collecting field data, Hitachi has also developed an efficient regeneration system with the aim of further improving the energy efficiency of rolling stock, and verified the energy savings provided by absorption of regenerative electric power and the regenerative brake with extended effective speed through operational trials. In the future, Hitachi intends to encourage the wider use of onboard storage batteries by achieving a good balance of costs and benefits, and by working on new energy-saving technologies that are closely aligned with customer needs.

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ABOUT THE AUTHORS

Motomi Shimada

Joined Hitachi, Ltd. in 1995, and now works at the Process Designing Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the development of vehicle control systems. Mr. Shimada is a member of The Institute of Electrical Engineers of Japan (IEEJ).

Yoshihiro Miyaji

Joined Hitachi, Ltd. in 1989, and now works at the Rolling Stock Electrical Systems Design Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the design of inverters for electric train drive systems. Mr. Miyaji is a member of the IEEJ.

Takashi Kaneko

Joined Hitachi, Ltd. in 1993, and now works at the Rolling Stock Electrical Systems Design Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the design of inverters for electric train drive systems.

Keita Suzuki

Joined Hitachi, Ltd. in 1999, and now works at the Rolling Stock Electrical Systems Design Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the design of inverters for electric train drive systems. Mr. Suzuki is a member of the IEEJ.

Evaluation Technology for Energy Consumption and Traffic Volume on Railway Traffic Systems and Hitachi's Energy-saving Efforts

Mikihiko Hata
Tsutomu Miyauchi
Atsushi Oda
Yutaka Sato

OVERVIEW: Having produced a wide range of different subsystems for railways, Hitachi is able to combine these to offer total railway system solutions. Hitachi also recognizes that reducing energy consumption and ensuring sufficient capacity to satisfy user requirements are important considerations when offering these total solutions. To this end, Hitachi has developed (1) a railway total simulator, the main objectives of which are to predict energy consumption and traffic volumes, and (2) energy-efficient operational technologies that reduce energy consumption. The railway total simulator is made up of building block models for each subsystem, including the rolling stock, signalling system, traffic control system, and power supply system, so that these models can be combined as required to predict energy consumption and traffic volumes under a wide range of different conditions. Hitachi is also working to save energy, having developed energy-efficient operational technologies that use eco-brakes to obtain the maximum benefit from electric braking, driver support technologies, and operational control methods that take account of other trains on the line. This article describes these two technologies.

INTRODUCTION

AS a means of transportation that is conscious of the environment, demand for railways has grown in recent years, with countries around the world planning the construction of railway systems. In the past, Hitachi has used a wide range of different evaluation techniques in the engineering of subsystems such as signals, rolling stock, and propulsion systems. Meanwhile, there has been an ongoing demand in recent years for the supply of total systems made up

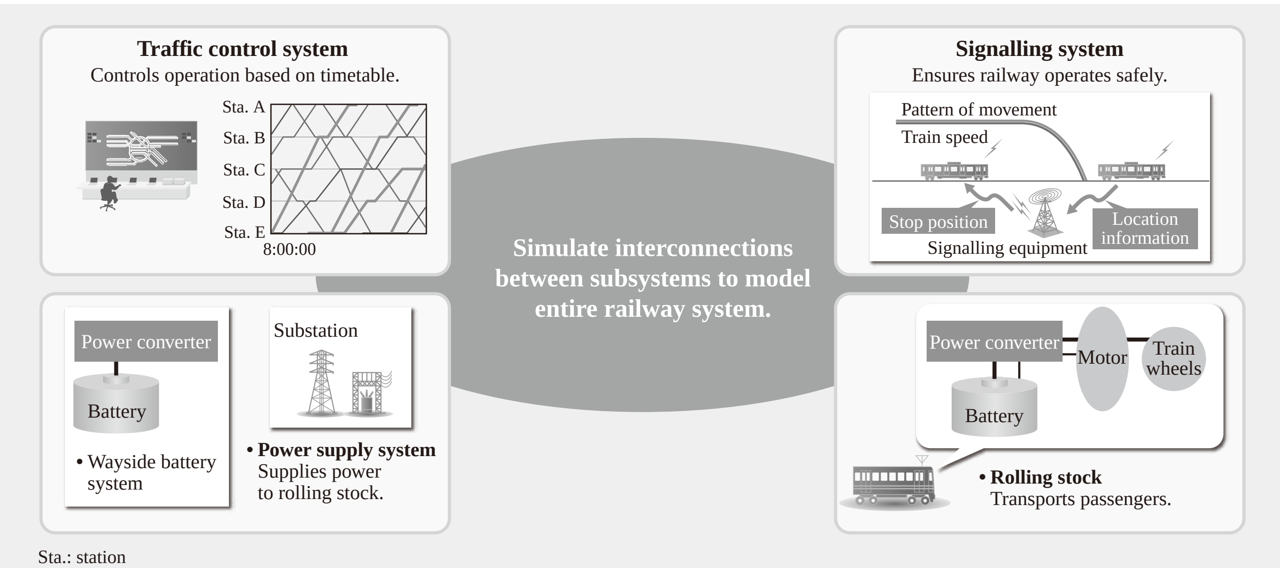

Fig. 1—Overview of Railway Total Simulator.
It is possible to calculate quantitative estimates of the energy costs and traffic volumes for a complete railway system by simulating the standalone operation of the rolling stock, signals, traffic control, electric power, and other subsystems that make up the system, and also the interlock control and other interoperation between subsystems.

of a combination of these subsystems. In Japan, this demand has been for energy efficiency. Elsewhere, particularly in emerging economies, the demand for energy efficiency has also been accompanied by a requirement to deliver sufficient capacity to satisfy customers.

In response to these needs, Hitachi is developing specific energy-saving systems along with a simulator able to perform integrated simulations of entire railway systems so that it can offer solutions based on energy efficiency and railway capacity.

RAILWAY TOTAL SIMULATOR(1)

Features of Railway Total Simulator

A wide range of different simulations can be performed by dividing the railway system into subsystems, including the rolling stock, signalling system, traffic control system, and power supply system; developing models for each of these subsystems and functions; and then running various combinations of these models on a common framework (see Fig. 1). For example, it is possible to simulate the operational performance of rolling stock using models of individual vehicles. Similarly, the energy consumption that will result from a particular timetable can be estimated by combining the rolling stock, traffic control system, and power supply system, as shown in Fig. 2.

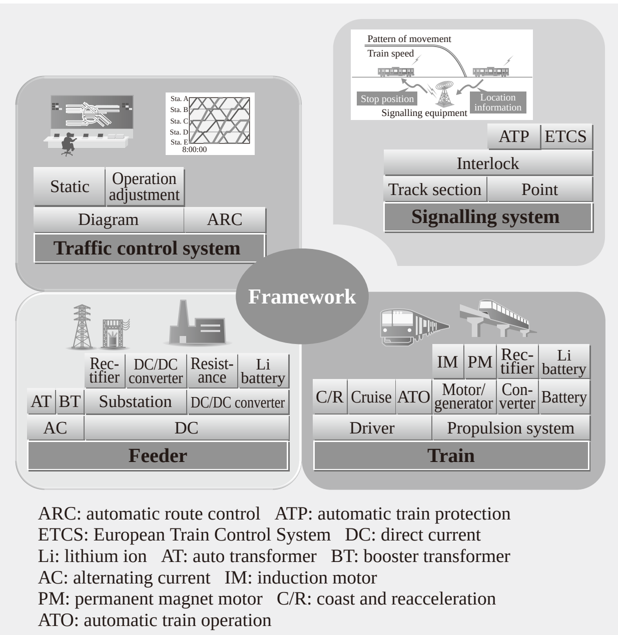

Fig. 2—Features of Railway Total Simulator (Building Block Configuration).
By allowing the user to select the subsystems and other equipment required for a particular simulation, evaluations can extend from individual equipment to the entire system.

It is also possible for the user to select which model to use for each subsystem based on the purpose of the analysis. Examples of rolling stock models include diesel cars and variable-voltage variable-frequency (VVVF) cars. Examples of signals models include automatic train protection (ATP) and the European Train Control System (ETCS).

Example Simulations Using Railway Total Simulator

This section describes three examples of actual simulations run using the railway total simulator. Unless otherwise stated, the simulations are based on the power supply system layout and operating conditions (determined by the timetable) specified in Table 1 and Fig. 3. The simulation also assumes

TABLE 1. Simulation Conditions for Railway Total Simulator
The table lists the equipment conditions used in the simulation.

Equipment conditions	Substations	Rated voltage	DC 1,500 V
		Rated output	3,000 kW
		Regulation	6.7%
	Rolling stock	Operation method	Coasting and repeat traction
		Max. motor output	224 kW
		Configuration	4M2T
	Traffic control	Headway	10 min

M: motor T: trailer

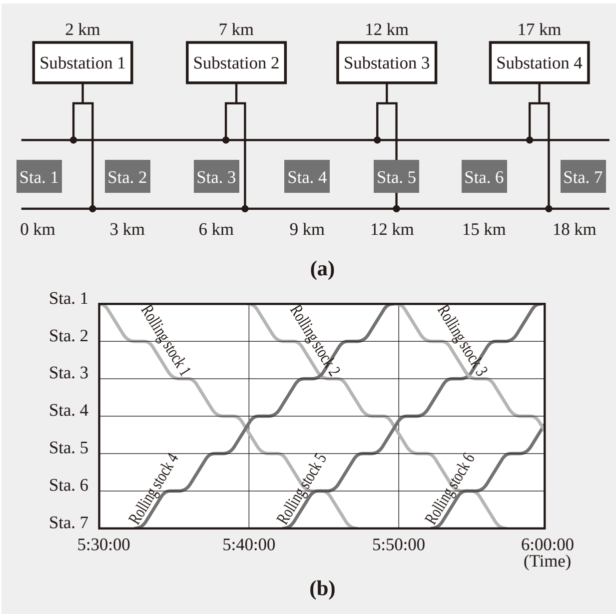

Fig. 3—Specific Simulation Conditions for Railway Total Simulator.
Electric power results for power supply system (a) and operating conditions (b) are shown.

use of VVVF rolling stock and the ability to transfer power generated by regenerative braking to other rolling stock.

(1) Prediction of energy consumption using proposed timetable

Fig. 4 shows the simulation results. Fig. 4 (a) shows the pattern of operation, the catenary voltage, and current for rolling stock 1 when it travels from station 1 to station 2 as specified in Fig. 3 (b), and the catenary voltage and current at the substation for each timing. As this involves a single train only, as indicated in the schedule in Fig. 3 (b), the supply of electric power from the substation is determined by the operation of rolling stock 1. Although a heavy current is supplied from the nearest substation (substation 1) when the train is under traction, substations 2 and 3 also supply a certain amount of current, and the results demonstrate that the simulation has modeled the drop in catenary voltage due to the current flow.

Fig. 4 (b) shows the voltages and currents at each substation for an extended simulation time scale, running from 5:30:00 to 6:00:00. The results show that the output current from each substation varies depending on factors such as the location of the rolling stock and the number of configurations, which change over time. The results also show an overload at 5:45:00, with a sudden drop in catenary voltage occurring at substations 2 and 3. The cause of the overload can be seen to be the simultaneous departure of two trains at 5:45:00, as shown in the Fig. 3 (b) timetable, which means that both trains are under traction at the same time. In this way, the capabilities of the simulation include being able to calculate factors such as the peak electric power demand for a given timetable and when

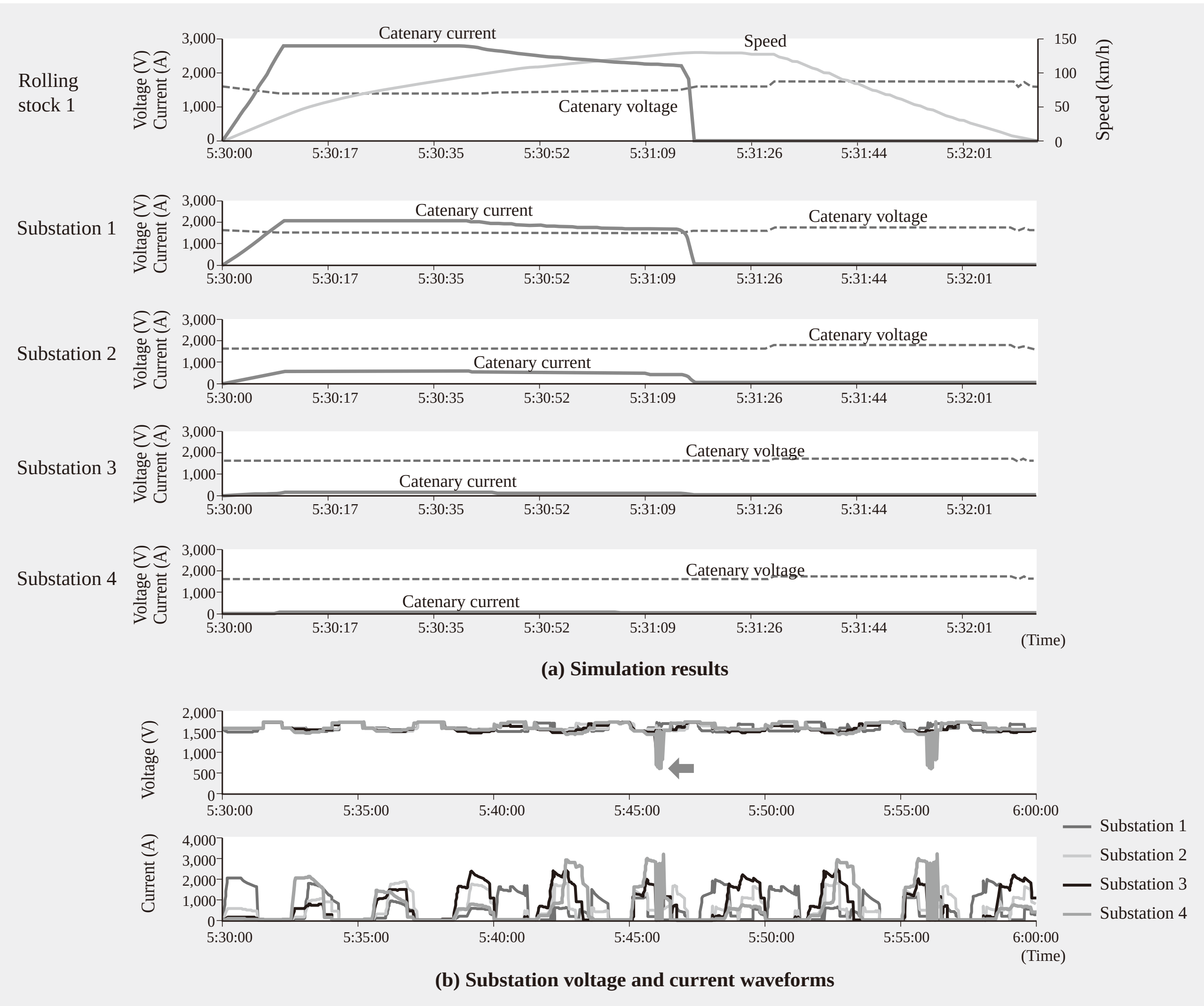

Fig. 4—Example Simulation Using Railway Total Simulator (1).
These results show the rolling stock and substation energy consumption for a proposed timetable.

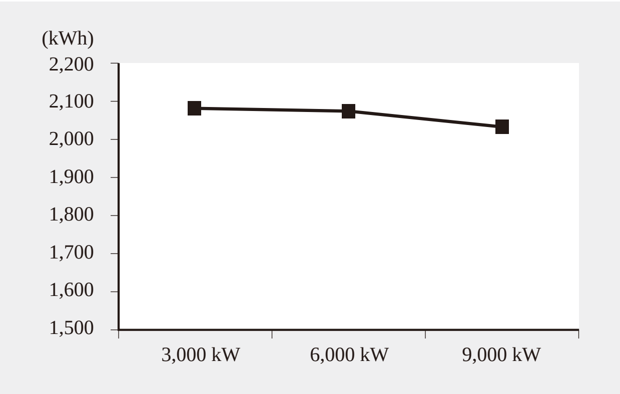

Fig. 5—Example Simulation Using Railway Total Simulator (2).
This shows the relationship between substation capacity and energy consumption.

this demand will occur. This indicates that one use for the simulator is to assist the design of timetables that take account of peak electric power demand.

(2) Relationship between substation capacity and energy consumption

It is also possible to simulate how the energy consumption varies when the substation capacity is changed. Fig. 5 shows the total energy consumption across all substations when the simulation conditions for (1) above were repeated three times with substation capacities of 3,000 kW, 6,000 kW, and 9,000 kW respectively. The results indicate that increasing the rated substation output decreases total substation energy consumption. This occurs because increasing the rated substation output raises the voltage output by each substation, and this in turn holds up the catenary voltage at the rolling stock. The higher the catenary voltage at the rolling stock, the lower the current drawn under load, and this reduces substation energy consumption by cutting the losses that occur during transmission.

(3) Relationship between headway and energy consumption

The effect of headway on energy consumption can also be simulated. Fig. 6 shows the total energy consumption across all substations when operation over a one-and-a-half-hour period was simulated for three different conditions: a four-car configuration with a headway of four minutes, an eight-car configuration with a headway of eight minutes, and a ten-car configuration with a headway of ten minutes. Each of these provides the same hourly capacity. The results show that increasing the frequency of service reduces total substation power output. This is because increasing the number of configurations increases the number of rolling stock under traction or regenerative braking, and this increases the opportunities for utilizing the regenerative electric power.

These simulations of the relationship that substation energy consumption has with substation capacity and headway provide examples of how the railway total simulator can be used. By setting a wider range of conditions, it is also possible to study numerous other situations. Examples include calculating headway, which is the critical number when designing timetables, or studying the energy savings that could be achieved by installing storage batteries in the rolling stock or on the wayside.

EVALUATION OF TECHNOLOGIES FOR ENERGY-EFFICIENT OPERATION

Hitachi has been using the railway total simulator described above to evaluate technologies for achieving energy-efficient operation while maintaining traffic volume (timetables). This section describes three aspects of this use of the simulator to perform energy efficiency assessments.

(1) Identification of optimum runcurves
(2) Operational support evaluation based on runcurves
(3) Assessment of effect on other trains

Identification of Optimum Runcurves

Energy efficiency is not necessarily taken into account when making runcurves, which typically consider factors such as traffic volumes and journey time requirements. However, growing awareness of the environment and the need to save electric power have created a demand for more energy-efficient runcurves, and one example of this is how to make the best use

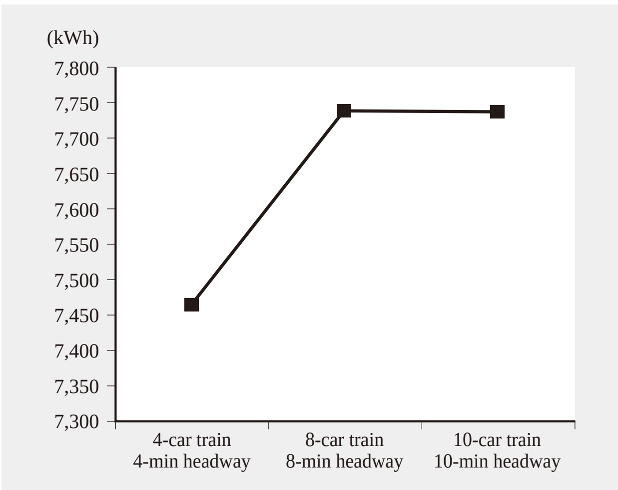

Fig. 6—Example Simulation Using Railway Total Simulator (3).
This shows the relationship between headway and energy consumption.

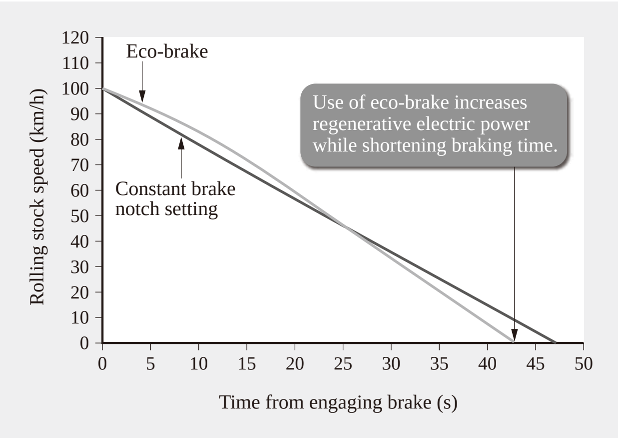

Fig. 7—Example Runcurve Optimization.
Even for the same braking distance and speed when brake is initially applied, the braking time and amount of regenerative electric power are different depending on the brake notch settings.

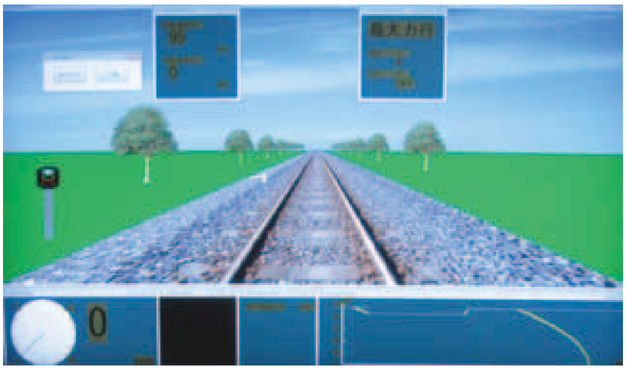

Fig. 8—Example Operational Support and Method for Evaluating Operational Support Technologies.
Operational support technologies are evaluated by providing operational support based on the optimum runcurves calculated using the simulator, and comparing energy consumption values from the modeling results and simulator.

of regenerative energy. The braking components of most current runcurves assume use of a constant brake notch from the time the brake is applied until the train stops. This requires use of the pneumatic brake at high speeds where the electric brake is unable to provide the full braking force needed, and this means that the available regenerative energy is not fully utilized. In response, Hitachi has developed an energy-efficient eco-brake that optimizes the brake notch setting to decelerate the train using the electric brake only. When evaluated on a simulator, using the eco-brake for deceleration not only reduced energy consumption, it was also able to shorten the braking time (see Fig. 7). It can be assumed that the benefits of the eco-brake will depend on the load conditions. As the simulator allows the weight of the rolling stock to be varied, it can be used to obtain quantitative estimates of the benefits of using the eco-brake under different load conditions.

Another energy-efficient technology is the optimization of runcurves between stations. The simulator described above, which allows line conditions, rolling stock characteristics, and notch settings to be changed as required, is used to determine the optimum runcurve from among the different options, which might include runcurves that involve frequent cruising, frequent coasting, or downhill gradients.

Operational Support Evaluation Based on Runcurves

It is comparatively easy to implement the optimum runcurves obtained using the simulator on sections of line with auto train control (ATO). Implementing optimum runcurves on lines that do not have ATO, on the other hand, requires some form of driver support (see Fig. 8). Hitachi believes that it is possible to develop more effective methods for supporting drivers by comparing the optimum runcurves obtained from the simulator with the actual runcurves used by the driver when operational support is provided.

Assessment of Effect on Other Trains

As a train that halts at a non-scheduled stop between stations needs to operate under traction again to restart, this increases the amount of power it consumes. It is possible to save energy by sending information about a delayed train to the trains behind it so as to prevent these oncoming trains from getting too close to the delayed train, and to avoid unnecessary acceleration and deceleration (see Fig. 9).

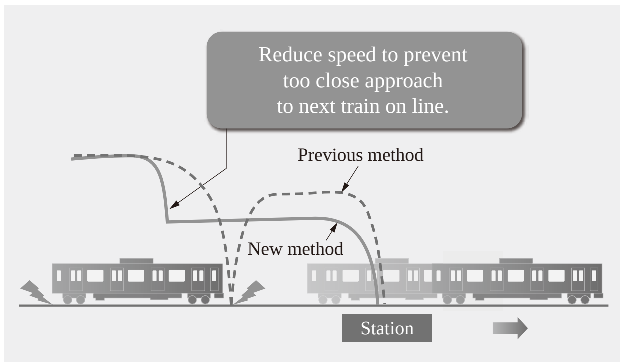

Fig. 9—Example Assessment of Effect on Other Trains.
In practice, train operation is affected by the trains ahead. The railway total simulator can be used to evaluate energy-saving technologies that control the train based on the movement of other trains.

As the simulator models functions like signals and traffic control as well as the rolling stock, it can also be used, for example, to assess the impact that the movements of a train will have on the trains behind it. Hitachi is using the simulator to work out how best to modify the runcurves of trains in response to the movements of the train ahead of it so as to save energy while also minimizing the disruption to the timetable.

CONCLUSIONS

Numerous opportunities for achieving energy-efficient operation are possible using wayside-to-train communication. One possibility is to save energy by reducing the dwell time at stations used by few passengers and allocating the time saved to travel time. In the future, Hitachi intends to contribute to further improvements in the energy efficiency of railway systems by analyzing actual data and other information to identify problems, and by using total-system simulators to study increasingly complex railway systems.

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ABOUT THE AUTHORS

Mikihiko Hata

Joined Hitachi, Ltd. in 1985, and now works at the Transport Management Systems & Solutions Department, Transport Management & Control Systems Division, Rail Systems Company. He is currently engaged in the development of rail system solutions. Mr. Hata is a member of the Information Processing Society of Japan (IPSJ).

Tsutomu Miyauchi

Joined Hitachi, Ltd. in 1999, and now works at the Green Mobility Research Department, Hitachi Research Laboratory. He is currently engaged in the research and development of a railway total simulator and railway energy-saving systems. Mr. Miyauchi is a member of The Institute of Electrical Engineers of Japan (IEEJ).

Atsushi Oda

Joined Hitachi, Ltd. in 2008, and now works at the Green Mobility Research Department, Hitachi Research Laboratory. He is currently engaged in the research and development of on-board railway systems. Mr. Oda is a member of the Society of Automotive Engineers of Japan (JSAE).

Yutaka Sato

Joined Hitachi, Ltd. in 1992, and now works at the Rolling Stock Electrical Systems Design Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the development of rolling stock electrical systems. Mr. Sato is a member of the IEEJ.

Rail and Contact Line Inspection Technology for Safe and Reliable Railway Traffic

Takafumi Hisa
Motonari Kanaya
Mitsuo Sakai
Keishin Hamaoka

OVERVIEW: To help ensure safe, reliable, and comfortable railway service, the inspection of railway line infrastructure is an essential task for railway operators. Hitachi High-Technologies Corporation has long been involved in helping ensure the safety of railway transportation, and is utilizing laser and other technologies to develop methods for inspecting the condition of railway track and overhead contact lines. Hitachi High-Technologies Corporation has also used these technologies to commercialize a railway inspection car that can run alongside commercial services, and can perform railway track and overhead contact line inspections in realtime at Shinkansen speeds. To allow for frequent inspections to be performed, Hitachi High-Technologies Corporation also plans to commercialize systems that can be fitted to operating trains to collect inspection measurements.

INTRODUCTION

AS deviation in rail height or warping of the railway track diminish the ride comfort of trains, it is necessary to specify control limits and perform inspection and correction work[1]. Meanwhile, deviation in the position of overhead contact lines are an impediment to reliable operation because they cause abnormal wear on the lines and risk damage to the pantograph[2]. For these reasons, railway operators perform regular railway track and overhead contact line inspections to maintain and improve safety, reliability, and comfort.

In response, Hitachi High-Technologies Corporation has been jointly developing and commercializing railway track and overhead contact line inspection equipment with the Japan Railway companies, including the Railway Technical Research Institute, with the aim of satisfying the long-term needs of railway operators. Hitachi High-Technologies Corporation is helping ensure the safety of railway transportation while also working with its customers to make further improvements.

This article describes technologies for railway track and overhead contact line inspection.

RAILWAY TRACK INSPECTION TECHNOLOGY

In addition to the precise, high-speed measurement of rails' longitudinal level, alignment, gauge, cross level, and distortion of track, the railway track inspection system commercialized by Hitachi High-Technologies Corporation can also display these measurement results in realtime. A wide range of other optional functions are also available. The following section describes how irregularity in the railway track is measured[1].

Railway Track Inspection

In the measurement of railway track irregularities, the method used to measure longitudinal level irregularity and alignment irregularity is called the leveling line method (differential method). It involves measuring how far the rail deviates from a fixed length of string stretched along the length of the rail.

Cross level irregularity, meanwhile, is measured using a spirit level and inclinometer (instrument for measuring gradient). Gauge irregularity is determined by using a measuring stick (called a gauge) to measure the gap between the left and right rails (see Fig. 1).

Performing these measurements manually is very inefficient and finding the time to perform measurements over a wide area becomes more difficult as the frequency of trains increases. This has created a need for a more efficient way to perform railway track inspection. In response, railways companies have built special-purpose inspection cars fitted with an inspection system to perform inspections based on the principles described above.

Principles of Railway Track Inspection

The inspection system installed in the inspection car measures longitudinal level irregularity by using the carbody as the longitudinal reference line and

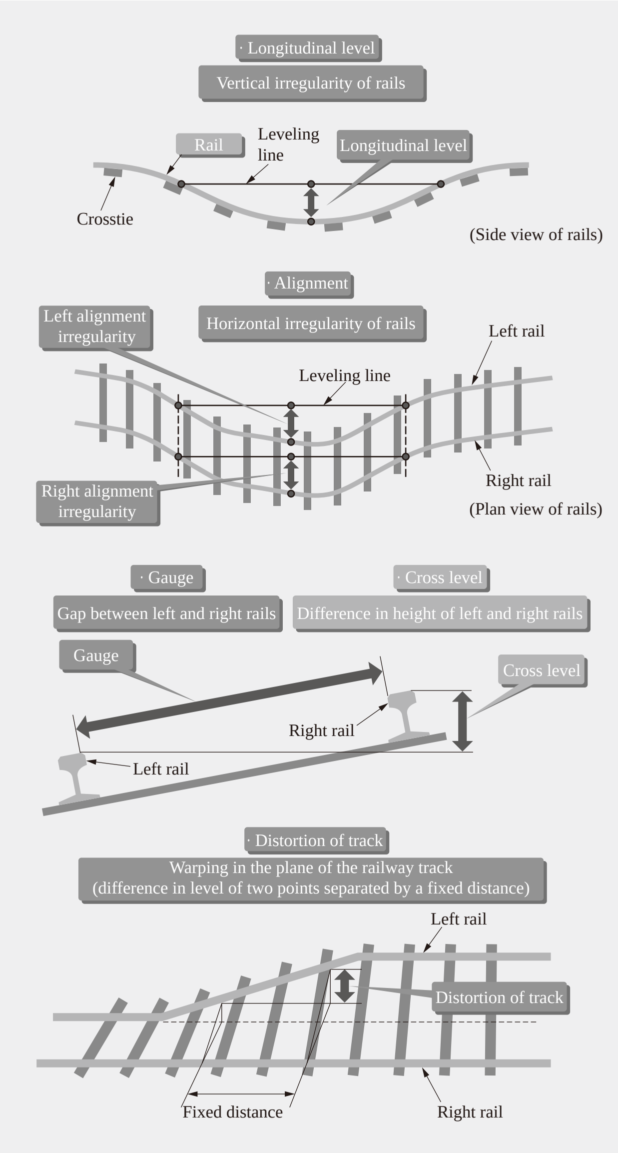


Fig. 1—Measurements Required for Railway Track Inspection.
These figures show the various railway track positions to be measured and inspected.

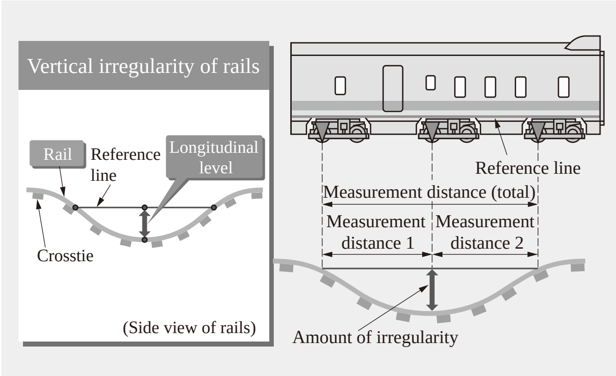


Fig. 2—Example Use of Sensor to Measure Difference in Longitudinal Level.
A system able to satisfy the requirement for automation, and based on the same principles as manual measurement, was implemented using the carbody.

attaching sensors to the carbody above each train wheel axle [at three points (axles) for each rail] to obtain the longitudinal level irregularity from the vertical movement of the wheel (see Fig. 2).

The total measurement distance is 10 m and this method is called the 10-m mid-chord offset method, with measurement distances 1 and 2 being 5 m each.

Although measurement of alignment irregularity also uses the carbody as the longitudinal reference line, the train wheels cannot be used to measure this type of railway track irregularity because of the play that exists between the wheel flange and rail. Instead, a special-purpose sensor is required. Both contact and non-contact sensors can be used. Contact sensors work by installing a special measurement wheel on the carbody that comes into direct contact with the inner side of the rail and measures the amount of irregularity. However, the difficulty of achieving accurate measurements using this method at Shinkansen speeds has created a need for non-contact sensors. For these reasons, it is now non-contact sensors that are most commonly used, and Hitachi High-Technologies Corporation has commercialized an optical rail irregularity sensor that works by the optical cutting method(3). The optical rail irregularity sensor directs a band of light from a laser onto the side of the rail and detects the light to determine the amount of irregularity. These sensors are also used to measure gauge irregularity (see Fig. 3).

For cross level measurement, the difference in longitudinal level between the left and right rails is determined by detecting the angle of tilt of the carbody and measuring the separation between the carbody and rail at this time.

OVERHEAD CONTACT LINE INSPECTION TECHNOLOGY

Overhead contact lines are given a horizontal zigzag pattern to provide a uniform contact with the pantograph.

The overhead contact line inspection system commercialized by Hitachi High-Technologies Corporation can perform fast and accurate measurements of the wear, deviation, and height of the contact line, and can display the results in realtime. A wide range of other optional functions are also available. The following section describes how each measurement is performed (see Fig. 4).

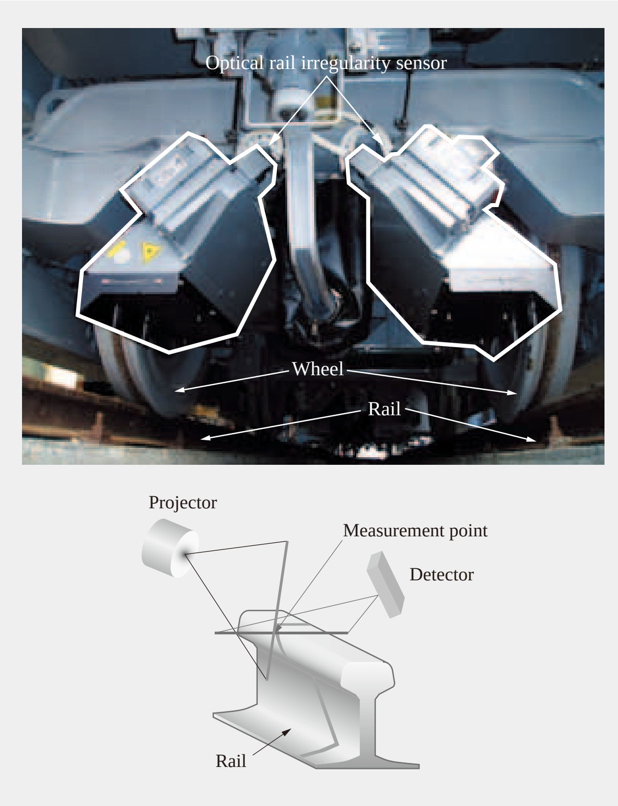


Fig. 3—Optical Rail Irregularity Sensor Based on Optical Cutting Method and its Principle of Operation.
Non-contact sensors are now the most commonly used type because they can provide precise measurements at high speeds.

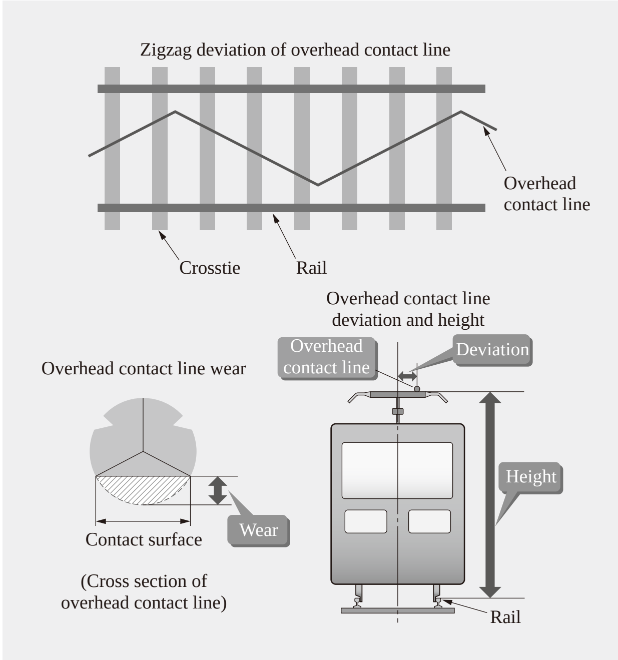


Fig. 4—Measurements Performed for Overhead Contact Line Inspection.
These diagrams give an overview of the required overhead contact line inspection measurements.

Contact Line Wear Inspection

The overhead contact lines supply electric power to the rolling stock through direct contact with the pantograph. Wear on the overhead contact line can be divided into mechanical wear caused by rubbing against the pantograph, and electrical wear caused by arcing when the overhead contact line and pantograph become separated. Because of the risk of the overhead contact line snapping if this wear exceeds a certain limit, it is essential that maintenance be done before this limit is reached.

Contact Line Deviation Inspection

As the overhead contact line is in contact with the pantograph, if this contact is restricted to one particular location on the pantograph, this part of the pantograph will wear down. To prevent wear from being concentrated at a particular location, the supports at each power pole create a horizontal zigzag pattern to ensure a uniform spread of contact with the pantograph. However, if the amount of horizontal zigzag in the overhead contact line exceeds the length of the pantograph, there is a risk of the overhead contact line getting caught on the edge of the pantograph, and this could result in the overhead contact line snapping or a train accident occurring. To prevent this, it is necessary to set a limit on the amount of horizontal zigzag in the overhead contact line, and to conduct inspections to confirm that this limit is not exceeded.

Height Inspection

Because overhead contact lines expand and contract with seasonal temperature changes, this varies the amount of flexing in the lines. This flexing causes changes in the longitudinal level of the overhead contact lines, and changes in height can cause the pantograph to bounce and become separated. Because separation from the overhead contact line causes electrical wear, as described above, height inspections are also needed.

Pantographs also experience aerodynamic lift depending on the speed of the train. Because this pushes up the overhead contact lines, it is essential that measurements be made under operating conditions.

Principles of Overhead Contact Line Inspection

As the overhead contact lines are located above the train, factors such as sunlight need to be considered when performing measurements from an inspection

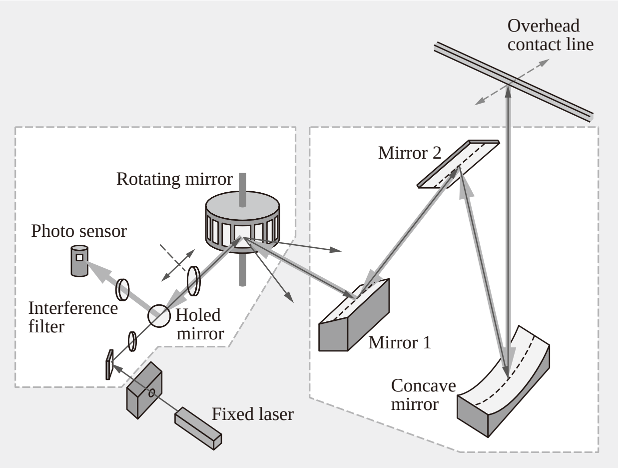


Fig. 5—Principles of Overhead Contact Line Inspection Measurements.
Measurements can be performed with a pitch of 50 mm, even at Shinkansen speeds.

Fig. 6—Railway Inspection Car for Shinkansen Lines.
Inspection systems fitted on the Doctor Yellow inspection cars used on the Tokaido and Sanyo Shinkansen lines (right) and the inspection car used on the Shinkansen lines operated by the East Japan Railway Company (left).

car. The overhead contact lines also have a horizontal zigzag pattern, as described earlier, and this means that measurements need to be conducted over a long length of line. To overcome these problems, Hitachi High-Technologies Corporation has commercialized an overhead contact line wear detector(2). The detector works by using laser light from a point light source that is scanned to the left and right by a rotating mirror and then converted by a concave mirror into a parallel beam that is directed at the contact surface of the overhead contact line. This laser beam reflects off the contact surface and travels back along the same route and through an optical filter to a photo sensor to measure the amount of wear and deviation (see Fig. 5).

Methods used for height measurement include measuring the angle of the main pantograph axle, which indicates the up and down motions of the pantograph, or using a laser beam to measure the height of the underside of the slider plate on the pantograph that contacts the overhead contact line.

RAILWAY INSPECTION SYSTEM

Hitachi High-Technologies Corporation has commercialized numerous track inspection and overhead contact line inspection systems that use the technologies described above to satisfy the requirements of railway operators. This includes performing inspections using railway inspection cars for the Shinkansen fitted with top-of-the-range systems (see Fig. 6).

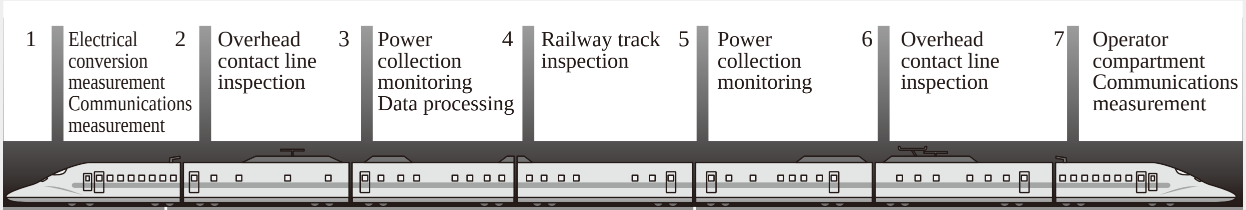
The inspection cars for use on the Tokaido and Sanyo Shinkansen lines are known informally as “Doctor Yellow” and consist of a 7-car configuration. Each car is fitted with a variety of inspection equipment, and most of these are systems in which Hitachi High-Technologies Corporation has had an involvement (see Fig. 7).

The measurements performed by these systems are listed in the bottom half of Fig. 7. A total of 25 different railway track inspection measurements are performed, including noise and axle-box accelerations as well as the main measurements, and these measurements are made at 25-cm intervals. The overhead contact line inspection system, meanwhile, performs a total of 13 measurements at 5-cm intervals. These include the main measurements. Inspection can be performed at speeds similar to those used by regular train services (270 km/h).

FUTURE DEVELOPMENT

Current practice is to perform regular inspections from special-purpose cars using the inspection technologies described above. However, it is anticipated that frequent inspections will be performed in the future with the aim of making further improvements in inspection efficiency, reliability, and ride comfort.

One requirement that has arisen as a way to perform inspections frequently is to fit the inspection systems to the rolling stock used for commercial service so that measurements can be performed during normal operation. To make this possible, Hitachi High-Technologies Corporation has already commercialized an inertial mid-chord offset track inspection system for railway track inspection, and is working on the commercialization of an overhead



	Railway track inspection system	Overhead contact line inspection system
Measurements	(1) Longitudinal level, (2) Alignment, (3) Gauge, (4) Cross level, (5) Distortion of track, (6) Other measurements	(1) Overhead contact line wear, (2) Overhead contact line deviation, (3) Overhead contact line height, (4) Other measurements
Measurement interval	25 cm	5 cm

Fig. 7—Configuration of Doctor Yellow Cars.
These inspection cars for use on Shinkansen lines provide world-class high-speed, realtime processing. Because they use cars with the same dual-bogie configuration as the actual Shinkansen, railway track inspection uses a laser beam rather than the carbody as a reference for measurements (dual-bogie method).

contact line inspection system suitable for installation on standard rolling stock.

The intention is to reduce the size of the overhead contact line inspection system for standard rolling stock by modifying the measurement methods and making major changes to the components used by the system.

The inertial mid-chord offset track inspection system replaces the differential measurement method used in the railway inspection car and other applications with inertial mid-chord offset measurement, a form of inertial measurement. Inertial measurement(4) utilizes a basic principle of mechanics (that irregularity can be obtained by twice integrating acceleration) to obtain irregularity from acceleration, and mid-chord offset measurement was developed to produce the same output as the previous system by performing a calculation in which the characteristics of the 10-m mid-chord offset method are combined with the inertial measurement method(5) (see Fig. 8).

This method saves space by replacing the large number of detectors required for the measurements described earlier with just three detectors and combining them into a single unit so that they can be installed on standard rolling stock.

A bogie-mounted version of the inertial mid-chord offset track inspection system has already been implemented, and a version for mounting on the carbody is currently undergoing field evaluations in preparation for commercial operation. These systems have been well received by customers (see Fig. 9).

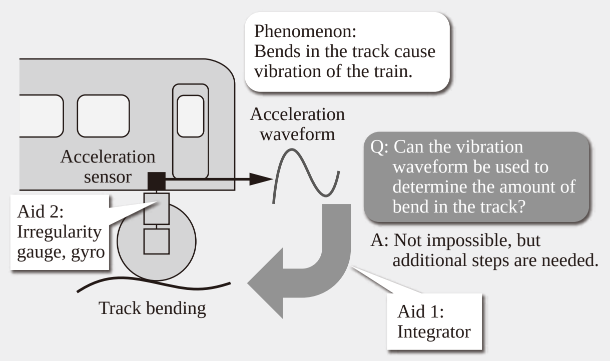


Fig. 8—Principle of Inertial Mid-chord Offset Track Measurement.
The system integrates acceleration measurements to determine irregularity.

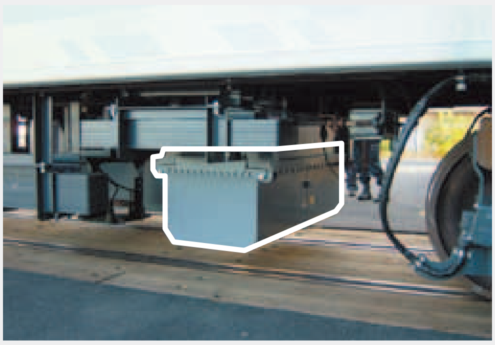


Fig. 9—Inertial Mid-chord Offset Track Measurement System for Mounting on Carbody.
This version of the inertial mid-chord offset track inspection system intended for mounting on the carbody is currently undergoing field evaluations.

Once these field evaluations have been completed, it is anticipated that the systems will help improve the frequency of inspection through their use on major railway lines serving large cities and elsewhere.

CONCLUSIONS

This article has described technologies for railway track and overhead contact line inspection supplied by Hitachi High-Technologies Corporation, together with the inspections performed by railway operators to ensure safe, reliable, and comfortable railway service.

By providing the market with even better products in the future, Hitachi High-Technologies Corporation intends to continue making a contribution to the development of comfortable railway service that is safe and highly reliable.

Finally, the authors would also like to express their deepest thanks to everyone involved for their advice and assistance.

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ABOUT THE AUTHORS

Takafumi Hisa

Joined Hitachi Electronics Engineering Co., Ltd. in 1987, and now works at the 3rd Group of Test System Design Department, Fine Technology System Business Group, Hitachi High-Technologies Corporation. He is currently engaged in the design of software for railway track and overhead contact line inspection.

Motonari Kanaya

Joined Hitachi Electronics Engineering Co., Ltd. in 1974, and now works at the 3rd Group of Test System Design Department, Fine Technology System Business Group, Hitachi High-Technologies Corporation. He is currently engaged in the design of electrical systems for railway track and overhead contact line inspection.

Mitsuo Sakai

Joined Hitachi Electronics Engineering Co., Ltd. in 1990, and now works at the 3rd Group of Test System Design Department, Fine Technology System Business Group, Hitachi High-Technologies Corporation. He is currently engaged in the design of electrical systems for overhead contact line inspection.

Keishin Hamaoka

Joined Hitachi Electronics Engineering Co., Ltd. in 1989, and now works at the 3rd Group of Test System Design Department, Fine Technology System Business Group, Hitachi High-Technologies Corporation. He is currently engaged in the design of electrical systems for railway track inspection.

Shinkansen Traffic Management System for Mutual Direct Operation of Sanyo Shinkansen and Kyushu Shinkansen

Muneyuki Harada
Hideaki Mori
Hideki Osonoi
Takahiro Ohira
Takanori Koike
Naohiko Iwama

OVERVIEW: The SIRIUS supervisory system for the Kyushu Shinkansen manages traffic, rolling stock, and other aspects of line operation. The system was commissioned in March 2004 to coincide with the commencement of operations on part of the Kagoshima route of the Kyushu Shinkansen (between Shin-Yatsushiro and Kagoshima-Chuo Stations). The system was subsequently upgraded in November 2010 in readiness for the commencement of operations along the entire line (between Hakata and Kagoshima-Chuo Stations) in March 2011. To support through-trains running on both the Sanyo and Kyushu Shinkansen railway lines, the system includes interconnections with the COMTRAC traffic management system for the Tokaido and Sanyo Shinkansens. To provide the high level of reliability demanded by a Shinkansen system, the automatic route control equipment at the heart of the system features the new CF-1000/FT fault-tolerant model with synchronization control of four-fold CPU redundancy at the OS level.

INTRODUCTION

OPERATION between Hakata and Kagoshima-Chuo Stations along the Kagoshima route of the Kyushu Shinkansen commenced when the full line opened in March 2011. The line connects to the Sanyo Shinkansen line at Hakata Station. Some trains provide mutual direct operation, called the Sanyo-Kyushu Shinkansen service. This operation improves customer service, including avoidance of any need to transfer at Hakata Station.

To ensure that this through-train service operates smoothly, the respective control centers for the Sanyo and Kyushu Shinkansens must simultaneously monitor the progress of each train and perform integrated management (see Fig. 1). The traffic management system for the Tokaido and Sanyo Shinkansens is called the computer-aided traffic control system (COMTRAC), and the traffic management system for the Kyushu Shinkansen is called the super intelligent resource and innovated utility for Shinkansen management (SIRIUS). To achieve integrated management across both control centers, these two systems interconnect and share the information they require in realtime. Specifically, the shared information includes train diagrams (train operation schedules), operating conditions and predictions, and train running results.

Because the Kyushu Shinkansen has an important role as a major railway artery in the region, it demands a system with a high level of reliability and availability. The equipment used in the system includes highly reliable servers and clients, and the traffic management system in particular uses the new CF-1000/FT fault-tolerant model in the programmed route control (PRC) subsystem.

The new CF-1000/FT model features four-fold central processing unit (CPU) redundancy using four blade servers and voter units that use the majority voting system to implement the redundancy function. It also features synchronization control at the operating

Fig. 1—Control Room for Kyushu Shinkansen.
The control room that manages train operation provides various user interfaces for coordinating train movements and performing manual control from operation desks. The control room also provides enhanced visual presentation with large display panels that provide an overview of information such as train position and equipment status.

system (OS) level to implement a fault-tolerant model that is not hardware-dependent.

This article describes how the interconnection between Shinkansen traffic management systems is used to support through-train service, and the adoption of a fault-tolerant model to ensure a high level of reliability.

SYSTEM OVERVIEW

The SIRIUS supervisory system for the Kyushu Shinkansen was installed in 2004 to coincide with the opening of a section of the Kagoshima route of the Kyushu Shinkansen. The system consists of the following four subsystems, and the upgraded system for the full line uses the same configuration.

(1) Planning subsystem

This is used to produce the patterned diagram and revised diagrams (to accommodate special trains and other unscheduled situations) for Shinkansen operation. These include the train association, the rolling stock plan, and the crew plan.

(2) Operations subsystem

In addition to producing the actual diagram based on the patterned and revised diagrams produced by the planning subsystem and augmented by the trainset configuration plan, this subsystem also manages the train running result and records of rolling stock operation. It also performs automatic control of trains based on the diagram, including notifying affected locations of any changes in the diagram in accordance with actual operating circumstances (see Fig. 2).

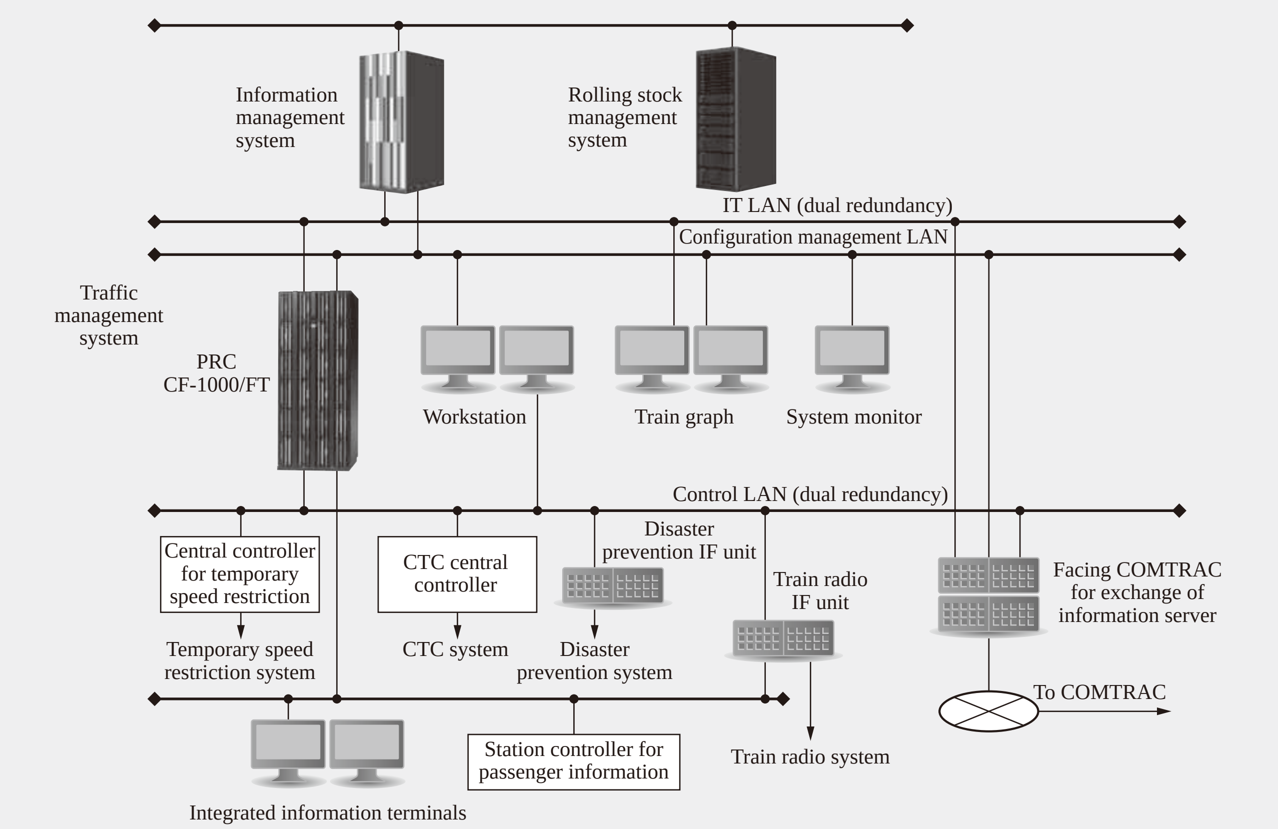
(3) Work management subsystem

This controls use of electric power by the Shinkansen trains and by wayside equipment. It also prepares and manages plans for performing rolling stock inspections and other daily maintenance work.

(4) Monitoring subsystem

This supplies information for preventing disasters along the line to relevant locations, such as rainfall, wind speed, seismic data, and rail temperatures. This subsystem also monitors position and status information from in-service rolling stock.

The newly implemented interconnection between systems primarily involves the operational subsystem. The operational subsystem consists of an information management system, traffic management system, and



IT: information technology LAN: local area network PRC: programmed route control CTC: centralized traffic control IF: interface
COMTRAC: computer-aided traffic control system

Fig. 2—Configuration of SIRIUS Supervisory System for Kyushu Shinkansen (Operations Subsystem).
The main components are an information management system and traffic management system.

train radio system, with the information management and traffic management systems being responsible for exchanging data with COMTRAC.

This exchange of data with COMTRAC is performed by the “facing COMTRAC for exchange of information server.” This server has an active/standby configuration to ensure communications reliability.

USE OF SYSTEM INTERCONNECTION FOR DATA COORDINATION

The information exchanged between SIRIUS and COMTRAC by the operations subsystem can be broadly divided into daily information such as the scheduled and actual diagrams managed by the information management system, and information that varies in realtime such as the operational status and predictions managed by the traffic management system.

The following sections give an overview of the information that each system exchanges with COMTRAC.

Information Managed by Information Management System

The railway tracks used by the Kyushu Shinkansen are also used by trains run by other operators. For this reason, the information management system must maintain rolling stock plans for all rolling stock permitted to travel on the Kyushu Shinkansen railway line as part of through-train service. In the case of SIRIUS, this means maintaining train diagrams and rolling stock plan diagrams for services running between the Osaka Rolling Stock Depot and Hakata Station as well as services that operate on the line between Hakata and Kagoshima-Chuo Stations used by the Kyushu Shinkansen.

To maintain data consistency between the two systems and ensure data reliability, SIRIUS receives the train diagrams and rolling stock plans for the Kyushu Shinkansen held by COMTRAC and cross-checks this information with its own train diagrams and rolling stock plans.

Similarly, SIRIUS and COMTRAC exchange their train running results of rolling stock plan to ensure that these records remain mutually consistent.

Information Managed by Traffic Management System

Although the traffic management system maintains diagrams covering the railway line from Osaka Rolling Stock Depot to Kagoshima-Chuo Station, it is only responsible for control of the line between Shin-Tosu and Kagoshima-Chuo Stations. So that the traffic management system will have access to the operating conditions and predictions for through-trains, including for sections of track that are outside its scope, the following four types of information are exchanged in realtime via the interconnection between the two systems.

(1) Result data on train departures and arrivals
(2) Order of train departures
(3) Train position and delay information
(4) Train running predictions

Result data on train departures and arrivals are received from COMTRAC and stored in SIRIUS’s diagram data for display on the train graph in the control room.

Information on the order of train departures from Hakata Station and Hakata Rolling Stock Depot received from COMTRAC is combined with departure order information held in the SIRIUS diagram for display on workstations in the control room. Also, departure order information from the two systems is cross-checked as part of automatic route control.

Train position and delay information for the railway between Osaka Rolling Stock Depot and Hakata Rolling Stock Depot is received from COMTRAC.

Finally, for the train running predictions, because these need to take into account the operational status along the Sanyo Shinkansen railway line, the predicted diagram is received from COMTRAC and used to produce the prediction for the Kyushu Shinkansen railway line. The predictions from the two systems can also be coordinated by sending the prediction generated by SIRIUS to COMTRAC (see Fig. 3).

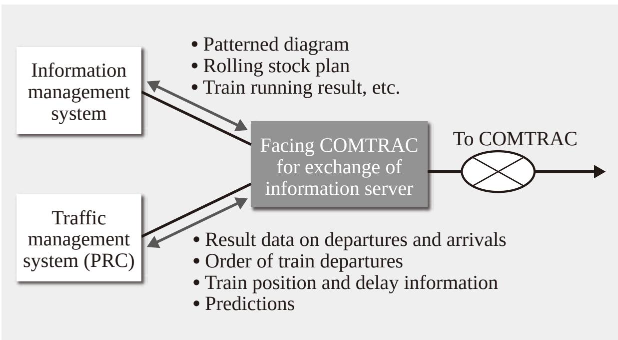


Fig. 3—Overview of Information Exchange Using Facing COMTRAC for Exchange of Information Server.
The facing COMTRAC for exchange of information server connects to the information management and traffic management systems via the network to relay information to and from COMTRAC.

CF-1000/FT FAULT-TOLERANT MODEL INFORMATION AND CONTROL PLATFORM

Hitachi has supplied numerous realtime servers for control system applications that demand high reliability and realtime control, with experience stretching back over 30 years. For systems that require even higher levels of data reliability and continuity, Hitachi has also released a fault-tolerant model that is designed for data consistency and system availability.

Developed by Hitachi based on know-how it has built up over time, the CF-1000/FT delivers a high level of availability and data reliability using a loosely coupled architecture with four-fold redundancy. The architecture consists of a CPU unit with four-fold redundancy provided by four blade servers and a four-way voter unit that uses the majority voting system to implement redundancy, with all of these components being linked together via a network (see Fig. 4).

Separate instances of the application program run in parallel on the four CPUs and pass their respective processing results to the voter unit. The voter ensures that data processing is performed with high reliability by using the majority voting method to compare the received data and output them to the external network.

Use of four CPUs for parallel execution means that the majority voting method will produce the correct output if one of the CPUs has a fault. This ensures high availability as parallel execution can continue while also maintaining data reliability. Moreover, because synchronization of the parallel application programs is handled at the OS level, synchronization is not hardware-dependent and this allows ongoing performance improvements to be implemented by upgrading the processors. The synchronization control method also ensures that things like process execution sequence and input are kept in step at the OS level to eliminate any variation between CPUs, meaning that parallel execution can be implemented without requiring the applications to perform their own synchronization.

The voter unit handles majority voting on the data from parallel execution. It achieves a high level of reliability by running a highly reliable proprietary Hitachi realtime OS and by using hardware that features extensive fault detection functions, such as error checking and correction for the memory and internal buses. To ensure an even greater certainty of data reliability, each voter unit consists of two separate computers that cross-check their majority voting results. The voter units also have redundant subunits that can switch over instantaneously to the backup in the event of a fault. This means that the system can continue to operate while also ensuring data continuity.

This loosely coupled architecture with four-fold redundancy and OS-level synchronization control gives the CF-1000/FT a high level of fault tolerance and expandability (which provides the flexibility to keep up with ever-improving hardware), delivering the data reliability, continuity, and other features demanded by information and control systems.

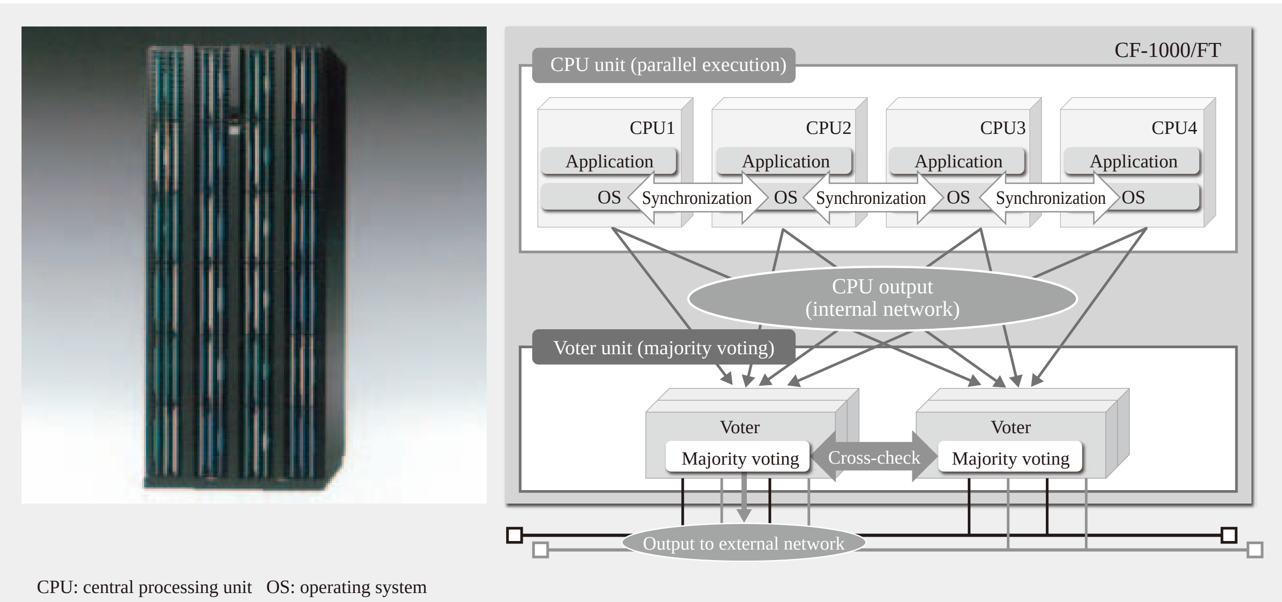


Fig. 4—Architecture of CF-1000/FT Fault-tolerant Model.
The photograph on the left shows the CF-1000/FT hardware, and the diagram on the right shows how parallel execution and majority voting are performed.

CONCLUSIONS

This article has described how the interconnection between Shinkansen traffic management systems is used to support through-train service, and the adoption of a fault-tolerant model to ensure a high level of reliability.

One year after service commenced along the full Kagoshima route of the Kyushu Shinkansen, SIRIUS continues to operate successfully. Hitachi intends to continue working on system development using the fault-tolerant model and other technologies, as well as the newly developed interoperation functions provided by system interconnections.

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ABOUT THE AUTHORS

Muneyuki Harada

Joined Kyushu Railway Company in 2004, and now works at the Planning Department, Railway Operations Headquarters. He transferred to his current post in 2012 after working on the development of SIRIUS.

Hideaki Mori

Joined Hitachi, Ltd. in 1981, and now works at the Transportation Control Systems Engineering Department, Transportation Information & Control Systems Division, Infrastructure Systems Company. He is currently engaged in the development of train traffic management systems.

Hideki Osonoi

Joined Hitachi, Ltd. in 1996, and now works at the Control System Platform Design Department, Control System Platform Development Division, Infrastructure Systems Business Management Division, Infrastructure Systems Company. He is currently engaged in the development of hardware for information and control systems.

Takahiro Ohira

Joined Hitachi, Ltd. in 1998, and now works at the Control System Platform Design Department, Control System Platform Development Division, Infrastructure Systems Business Management Division, Infrastructure Systems Company. He is currently engaged in the development of operating systems and middleware for information and control systems.

Takanori Koike

Joined Hitachi, Ltd. in 2000, and now works at the Transportation Control Systems Engineering Department, Transportation Information & Control Systems Division, Infrastructure Systems Company. He is currently engaged in the development of train traffic management systems.

Naohiko Iwama

Joined Hitachi, Ltd. in 1989, and now works at the Kansai Transportation Systems Department, Transport Management & Control Systems Division, Rail Systems Company. He is currently engaged in the development of train traffic management systems.

Current and Future Applications for Regenerative Energy Storage System

Hirotaka Takahashi
Katsushige Aoki
Akihiro Maoka
Young Ik Kim

OVERVIEW: Railways are a key form of public transportation, yet the electric power shortages resulting from factors such as the impact of the Great East Japan Earthquake on nuclear power plants have made it more necessary than ever that they seek to save electricity. Another issue is the action being taken around the world to deal with the problem of global warming. Hitachi has developed a system for the storage of regenerative power that uses the same lithium-ion batteries as hybrid cars to store and reuse this energy in trains. The system was commercialized in 2007. In some cases, the installation of this system produced savings of more than 10% in power consumption. Hitachi intends to accelerate the deployment of this system to reduce railway power consumption in Japan and other markets.

INTRODUCTION

INITIATIVES involving the use of electrical storage devices in the wayside systems of direct-current electric railways have a long history, with battery posts being used in Japan between 1912 and 1928 to augment the unreliable power supplies of that era. Along with an increase in the demand for electric power from railways, the expansion of transportation capacity during Japan's rapid economic growth also brought problems such as loss of regenerative braking power and voltage drops in feeder circuits. One countermeasure to this was the development of electric power storage systems that combined electrical storage and conversion equipment, and such a system entered practical use in 1988 using a flywheel for storage.

Production of hybrid vehicles by the automotive industry has been rising since 2008, and the batteries that have a core role in these vehicles are a subject of ongoing technical innovation and cost reduction.

In 2004, Hitachi developed a system that uses automotive lithium-ion batteries for the storage of regenerative power (system storing regenerative electric power in wayside storage batteries). The system subsequently underwent successful field trials on the Seishin-Yamate Line of the Kobe City Subway, leading to the installation of a commercial system at the line's Itayado substation in 2007. Another system supplied to Seoul Metro9 subway in South Korea commenced operation in 2011.

This article gives an overview of the system, describes an example of its use outside Japan, and considers its future prospects.

PRODUCT OVERVIEW

System storing regenerative electric power in wayside storage batteries uses lithium-ion batteries of the same type as those in hybrid vehicles to store regenerative power (see Fig. 1).

A feature of regenerative power from trains is that it is produced as a sudden surge. This means that, along with the discharge characteristics, the charging characteristics when absorbing electric power are a key consideration in the choice of storage battery. After collecting data on battery life and other properties to compare the different types of secondary (rechargeable) batteries in terms of these characteristics, Hitachi selected lithium-ion batteries for use in this system.

The features of lithium-ion batteries that make them superior to the alternatives include being small and light with a higher energy density than other

Fig. 1—Lithium-ion Battery.
The system uses the same lithium-ion batteries as hybrid cars.

TABLE 1. Specifications of System Storing Regenerative Electric Power in Wayside Storage Batteries
The table below lists the main specifications.

Rated voltage*1 (V)	Rated capacity (kWp)	Rated current (A)	Load pattern*2	Lithium-ion battery			
				Module rating	Module configuration	Rating	Storage capacity
820 V	500	600	600 A 10 s + 300 A 10 s charging 300 A 30 s discharging	173 V 5.5 Ah	2S×10P	346 V 55 Ah	19 kWh
820 V	1,000	1,200	1,200 A 10 s + 600 A 10 s charging 600 A 30 s discharging	173 V 5.5 Ah	2S×20P	346 V 110 Ah	38 kWh
820 V	2,000	2,400	2,400 A 10 s + 1,200 A 10 s charging 1,200 A 30 s discharging	173 V 5.5 Ah	2S×40P	346 V 220 Ah	76 kWh
1,650 V	1,000	600	600 A 10 s + 300 A 10 s charging 300 A 30 s discharging	173 V 5.5 Ah	4S×10P	692 V 55 Ah	38 kWh
1,650 V	2,000	1,200	1,200 A 10 s + 600 A 10 s charging 600 A 30 s discharging	173 V 5.5 Ah	4S×20P	692 V 110 Ah	76 kWh
1,650 V	3,000	1,800	1,800 A 10 s + 900 A 10 s charging 900 A 30 s discharging	173 V 5.5 Ah	4S×30P	692 V 165 Ah	114 kWh

*1 Initial charging and discharging voltages can be varied on site (remote setting function available as an option).
*2 Standard pattern (for a 180-s interval period)

options such as electric double-layer capacitors or nickel-metal hydride batteries. Together with the fact that they are manufactured for applications that require repeated rapid charging and discharging, these features make them the ideal choice for railway loads. Technologies are also being developed to extend battery lifetime, including improvements to materials and optimum control of charging and discharging.

Product Specifications

The specifications of the system storing regenerative electric power in wayside storage batteries are listed below.

(1) Standards compliance: International Electrotechnical Commission/European Norm (IEC/EN), Japanese Electrotechnical Committee
(2) Rated capacity: 3,000, 2,000, 1,000, or 500 kWp
(3) Rated voltage: 1,650 or 820 V (the initial charging/discharging voltage can be varied.)
(4) Control method: Constant voltage control with current limiter

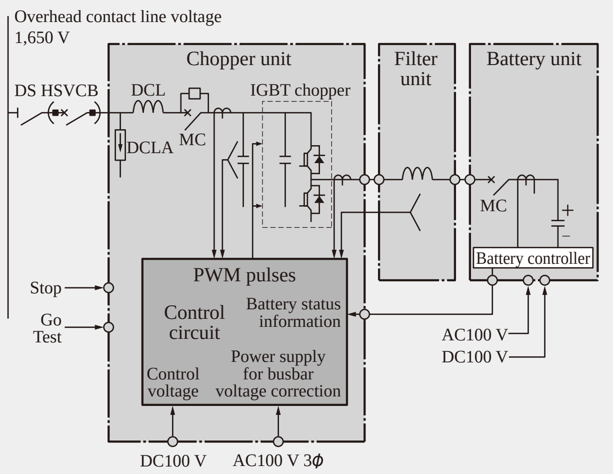
Other specifications are listed in Table 1.

Circuit Configuration

This regenerative energy storage system consists of chopper unit (including the filter units) and storage battery unit blocks. Fig. 2 shows the circuit diagram. A major feature is that it can be installed anywhere without creating space constraints.

The converter uses 3,300-V, 1,200-A insulated-gate bipolar transistors (IGBTs) on the 1,500-V system, consists of multiple bidirectional choppers, and is designed to minimize the flow of ripple current to the feeder power supply and batteries. It is also designed for quick recovery in the event of a fault, with a traceback function that can be used to analyze fault causes.

The system has been standardized on the use of lithium-ion battery modules, with the 1,500-V system using four cells in series. A sufficient number of these modules are installed in parallel to provide the capacity to absorb the required amount of current. Each lithium-ion battery has a battery controller that handles protection and monitors operating status parameters such as the state of charge (SOC), state of hysteresis (SOH) (an indicator of battery deterioration), and battery temperature. These data are also sent to the chopper unit to ensure optimum control of how the lithium-ion batteries are used.



DS: disconnecting switch HSVCB: high-speed vacuum circuit breaker
DCL: direct-current reactor DCLA: direct-current lightning arrester
IGBT: insulated-gate bipolar transistor MC: magnet contactor
PWM: pulse width modulation AC: alternating current DC: direct current

Fig. 2—Circuit Diagram.
This is the circuit diagram of the production model.

Operational control performed by the chopper unit includes feeder power supply voltage control, which involves charging or discharging the lithium-ion batteries, and SOC control, whereby the SOC is reduced when the system is idle in preparation for the next sequence of charging (absorption of regenerative power). This keeps the feeder power supply voltage constant while also managing battery operation to ensure a long operating life. To prevent overcharging or over-discharging due to fluctuations in the voltage from the power collection system, system storing regenerative electric power in wayside storage batteries also includes a voltage correction function that incorporates power collection system voltage elements into the system.

Optional functions include a schedule control function, a function for changing voltage settings from power management, and an emergency drive mode to provide traction power for the train in the event of an outage on the feeder power supply.

EXAMPLE OVERSEAS INSTALLATION—SEOUL METRO9

In recent times, central and regional governments in South Korea have identified railways as a form of transportation that helps prevent global warming, including through the reduction of carbon dioxide (CO_2) emissions. In their pursuit of greater energy efficiency, they have expressed considerable interest in technologies for utilizing the regenerative power produced when trains stop or decelerate. Some railway operators in South Korea have already installed systems for absorbing regenerative power that use electric double-layer capacitors for storage, and are trialing their effectiveness.

Seoul Metro9 is South Korea’s first urban railway provided in the form of a public capital development project utilizing private investment. The rolling stock, power system, and mechanical equipment are managed by Seoul Metro Line 9 Corporation under contract to Seoul City, with operation and maintenance outsourced to Seoul Line 9 Operation Co., Ltd.

Hitachi’s partner for the installation of system storing regenerative electric power in wayside storage batteries is POSCO ICT, a major South Korean engineering company that has an energy service company (ESCO) contract with Seoul Metro9. The business model involves collecting a base fee, the level of which was determined from simulations conducted by POSCO ICT of the energy savings that would result from installing this system.

Table 2 lists the specifications of the installed system. Because it is intended for use outside Japan, it complies with the IEC 60146 (semiconductor converters) standard.

The system was installed at two substations, numbers 909 and 921 (see Fig. 3), both of which are located underground. As the access provided for subway construction had already been closed off, the system had to be delivered to the site via ordinary stairways. Accordingly, the equipment was transported to the site in dismantled form.

Fig. 4 shows the waveform for the system storing regenerative electric power in wayside storage batteries in operation at substation 921. The system regulates the output current from the rectifier during discharging so that electric power is supplied preferentially from the system. This suppresses the amount of electric power drawn from the power company during traction and also has the effect of cutting peak demand.

While the results of simulating the installation of the system on this line estimated annual power savings of 510 MWh at substation 921, the actual savings in the first month of operation were 94 MWh (including savings at adjacent substations), indicating that performance will surpass the initial predictions. The results of this month of operation also included a reduction in rush hour power consumption, demonstrating the ability of the system to cut peak demand. Currently, POSCO ICT is continuing to assess the energy savings provided by the system.

TABLE 2. Specifications

The table below lists the specifications of the system storing regenerative electric power in wayside storage batteries.

Parameter		Value	Remark
Rated capacity		1,000 kWp	
Rated voltage		1,650 V	2,000 V max.
Rated current		600 A	606 A (current limit)
Batteries	Type	Lithium-ion battery	
	Module	4 series × 10 parallel	
	Rated voltage	692 V (173 V / module)	
	Rated current	55 Ah	
	Maximum charge/discharge current	±1,500 A	
Converter	Configuration	1S × 2 A × 4 units	
	Control method	Multi-carrier PWM control	
	Cooling	Heat pipe natural cooling	DCL forced air cooling
	Frequency	720 Hz	Synthesizing frequency: 2,880 Hz

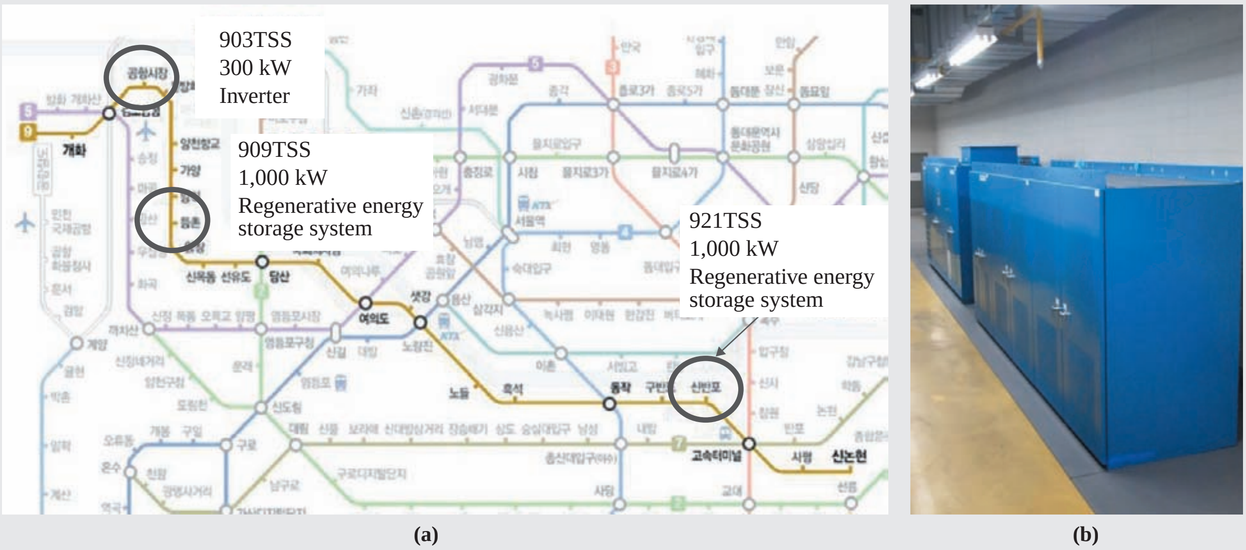


Fig. 3—Map of Seoul Metro9 (a) and Hardware (b).
The map shows the sites where systems storing regenerative electric power in wayside storage batteries were installed and the photograph shows a system that has commenced operation at the substation 921. Stations 909 and 921 are both located underground. From the left rear, the equipment shown in the photograph (b) comprises the chopper unit (a bank of filter units) and the battery unit respectively.

FUTURE PROSPECTS

Another application for the regenerative energy storage system that has arisen in Japan due to concern about electric power shortages caused by the shutdown of nuclear power plants after the Great East Japan Earthquake is the use of stored electric power to provide emergency traction power for trains in the event of a power outage. However, providing emergency traction power takes more than just installing storage batteries in the power system; it also requires discharge control, power system control, and traffic control in cooperation with other railway systems when a power outage occurs. As a total system integrator for railways, Hitachi plans to undertake further work on building

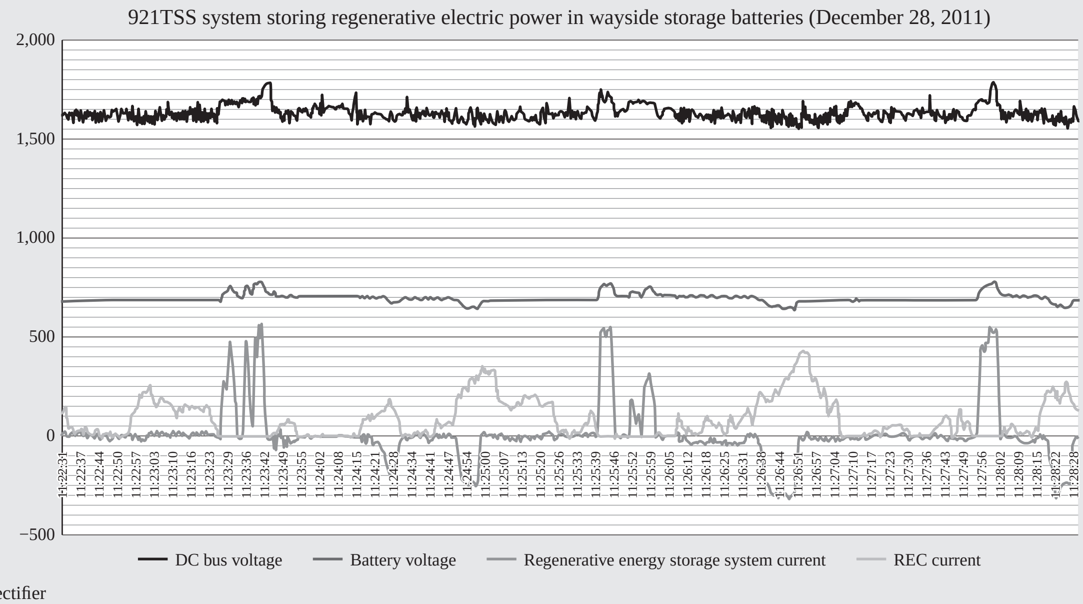


Fig. 4—Sampling Graphs of On-site Measurements.
The output current from the rectifier is regulated when regenerative energy storage system is discharging to cut peak demand.

railway systems capable of implementing such an emergency traction power capability.

System storing regenerative electric power in wayside storage batteries can also provide what is needed to construct a direct current smart grid. Rather than deploying the system as just another item of substation equipment, Hitachi intends to use the system as a core device for providing comprehensive energy management that enhances energy efficiency through interoperation with other railway systems in order to implement the sort of railway smart grids that only a total system integrator for railways could deliver.

CONCLUSIONS

This article has given an overview of the system storing regenerative electric power in wayside storage batteries, described an example of its use outside Japan, and considered its future prospects.

It is anticipated that demand for the prevention of global warming and other energy efficiency measures will strengthen further in the future, in markets both in Japan and elsewhere. Hitachi intends to continue contributing to overcoming environmental and energy problems through technical innovation in this field.

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ABOUT THE AUTHORS

Hirotaka Takahashi

Joined Hitachi, Ltd. in 1991, and now works at the Power Supply System Department, Rail Systems Company. He is currently engaged in the system engineering of power conversion systems for railways.

Katsushige Aoki

Joined Hitachi, Ltd. in 1992, and now works at the Power Supply System Department, Rail Systems Company. He is currently engaged in the system engineering of power conversion systems for railways.

Akihiro Maoka

Joined Hitachi, Ltd. in 1985, and now works at the Advanced Power Converter Engineering Center, Electrical Equipment Information & Control Systems Division, Infrastructure Systems Business Management Division, Infrastructure Systems Company. He is currently engaged in the design and development of power electronics equipment.

Young Ik Kim

Joined the Korea Branch of Hitachi, Ltd. in 2004, and now works at the Hitachi Korea Ltd. He is currently engaged in sales to the railway industry in South Korea.

Radio-based Train Control System

Yuichi Baba
Atsushi Hiratsuka
Eiji Sasaki
Osamu Yamamoto
Masakazu Miyamoto

OVERVIEW: Railways must operate safely and in accordance with their timetables, and the signalling systems responsible for ensuring safety have been progressively improved in response to demand for greater safety, reliability, and efficiency. Drawing on technology built up through its experience with signals and safety systems such as electric interlocking devices and digital ATP equipment, Hitachi has collaborated with the East Japan Railway Company on the development of the ATACS radio-based train control system. ATACS is designed to meet user needs while delivering both safety and lower costs, including by minimizing the use of track circuits and wayside equipment, and by providing a comprehensive range of functions for dealing with abnormal situations.

INTRODUCTION

EVER since railways were first constructed, the signalling systems responsible for the safety of railway transportation have adopted methods that use signals equipment to achieve this, including track circuits, signals, and interlocks that control railway switches. In addition to improving safety, the wayside equipment has become complex and expensive as a result of introducing a wide range of practices such as the automation of railway management and improvements to transportation efficiency through increases in the number of train movements and measures such as allowing services to share the same railway track. This situation has led to demand from users for a reduction in costs while still maintaining the existing level of safety that has been built up over time. One way of achieving this that has been under investigation is to make further improvements in safety and to implement other measures such as cost savings by operating the control methods that in the past have primarily used wayside equipment in a way that integrates wayside and on-board equipment based on information and control technology.

To simplify systems that have become increasingly complex and to implement cost saving, a system has been devised that eliminates track circuits, which incur maintenance and other costs, and instead uses radio communications to transmit information on train position that to date has been sent via these track circuits. This is the advanced train administration and communications system (ATACS) train control system of the East Japan Railway Company, which is the first such system in Japan to use radio communications. The system can reduce maintenance and other life cycle costs by using radio communications to minimize wayside equipment. Reducing the number

Table 1. Development Stages of ATACS Train Control System

The ATACS train control system went through these development stages in preparation for practical implementation.

1995	East Japan Railway Company commences development of ATACS.
1997 to 1998	Monitor run testing performed on the Senseki Line for the phase 1 system (basic functions)
2000 to 2001	Monitor run testing performed for the phase 2 system (application functions)
2001	Development of prototype commences (improve reliability and durability).
2003 to 2005	Monitor run testing of prototype performed on the Senseki Line
2008	Development of commercial system commences (including addition of functions for dealing with abnormal situations required for actual use).
March 2010	Monitor run testing of commercial system commences.
October 10, 2011	Operation commences on Senseki Line (step 1).

ATACS: advanced train administration and communications system of these devices can also be expected to improve reliability. Because the system does not use track circuits, it can be used to implement moving blocks and to allow a higher density of railway traffic.

This article gives an overview of the ATACS train control system and describes its development.

DEVELOPMENT OF RADIO-BASED TRAIN CONTROL SYSTEM

Based on the Computer and Radio Aided Train Control System (CARAT) developed by the Railway Technical Research Institute from 1987, the ATACS system has been under development by the East Japan Railway Company since 1995 with the aim of practical implementation. Table 1 lists the different stages of the project. The ATACS system is divided into three parts: wayside equipment, on-board equipment, and radio equipment. Hitachi was assigned the task of developing the wayside equipment.

OVERVIEW OF ATACS

Pilot Track Section

The Senseki Line of the East Japan Railway Company was selected as the pilot track section for system development. The main reasons for this choice were as follows:

(1) Whereas most regional railway lines have an alternating current (AC) power system, the Senseki Line operates on direct current (DC) and it does not share track with adjacent lines such as the Tohoku Line.

(2) The line includes underground as well as open railway track.

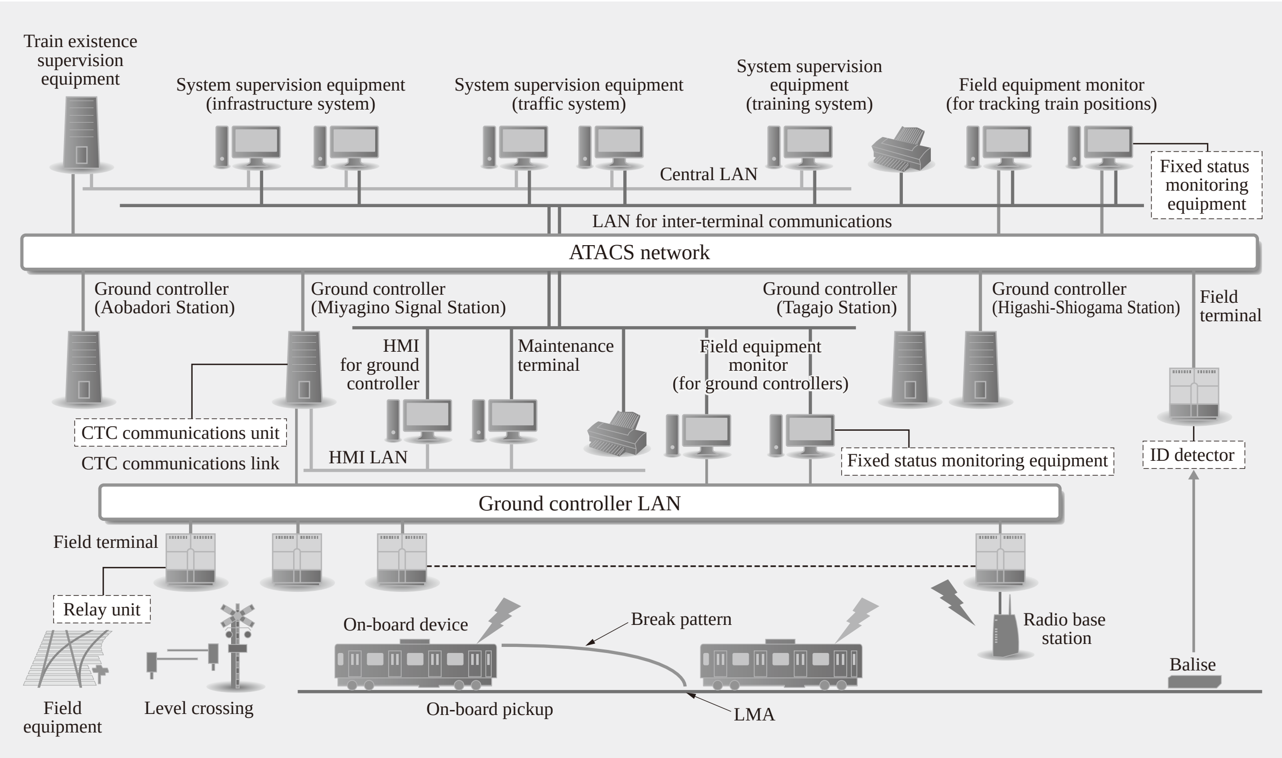
(3) The trainset configurations are comparatively simple.

(4) Because it runs through the commuter belt of

TABLE 2. System Specifications

The ATACS train control system for the Senseki Line of the East Japan Railway Company divides the approximately 18 km of track into four segments.

Line being controlled	Senseki Line (approximately 18 km between Aobadori and Higashi-Shiogama Stations)
No. of ground controllers	4
No. of radio base stations	8
Distance between base stations	Approximately 3 km
No. of trains	16 trains/ground controller
Radio frequency	400-MHz band



LAN: local area network CTC: centralized traffic control HMI: human-machine interface LMA: limit of movement authority

Fig. 1—Block Diagram of ATACS System for Senseki Line.
The wayside equipment used for train control by the Senseki Line system includes four ground controllers responsible for separate sections of track, and the train existence supervision equipment that acts as a central controller.

Sendai city, the Senseki Line has a reasonably high frequency of service.

It was chosen with a view to future deployments on railway lines in Tokyo and elsewhere.

Overview of ATACS System for Senseki Line

The ATACS installed on the Senseki Line covers approximately 18 km of track between Aobadori and Higashi-Shiogama Stations (the full line runs from Aobadori to Ishinomaki Station). It has four ground controllers, uses digital radio operating in the 400-MHz band, has eight radio base stations, and controls a total of 18 trainsets (see Table 2).

Fig. 1 shows a block diagram of the system configuration.

The wayside equipment includes ground controllers, field controllers, train existence supervision equipment, system supervision equipment, and human-machine interfaces (HMIs) for the ground controllers.

(1) Ground controllers

The ground controllers are installed at stations where interlocks are used. Based on electric interlocking devices (which are used for signalling and safety), they are computers with three-way redundancy and are used to perform interlock control as well as radio-based train control functions such as train interval control and tracking. They integrate ATACS and interlock control functions into a single system (alternatively, the interlock function can be split off, in which case they are configured to work with separate interlocking devices), and can also interconnect with the centralized traffic control (CTC) station equipment installed on local railway lines. In addition to using encryption for data sent via radio (implemented in the radio units), the controllers also have features for dealing with radio interference and for detecting falsified radio signals.

The functions of the field controllers include control of field equipment such as the railway switches installed at stations and also communications with the radio base stations. These field controllers connect to the ground controllers via the ground controller local area network (LAN), which uses optical fiber and has double redundancy (see Fig. 2).

(2) Train existence supervision equipment

The train existence supervision equipment tracks and supervises all of the trains controlled by the system. They include backup functions in the event of ground controllers shutting down, an identifier (ID) shift function in the event of faults or other abnormal

Fig. 2—Ground Controllers.
The functions of the ground controllers include controlling the intervals between trains and calculating LMAs.

Fig. 3—Train Existence Supervision Equipment.
The train existence supervision equipment tracks and supervises all of the trains controlled by the system, and provides backup functions in the event of a problem in the ground controllers.

circumstances on trains, and a function for setting temporary speed restrictions. The equipment connects to the ground controllers and exchanges data via the ATACS network, which uses optical fiber and has double redundancy (see Fig. 3).

(3) System supervision equipment

The system supervision equipment provides the user interface functions for the train existence supervision equipment, including monitoring of traffic and the interlocking devices at each ground controller site.

The HMI for the ground controllers provides interlock control panel functions at each site. It can also be used to operate the interlocking devices from stations if a problem occurs in the central CTC equipment (see Fig. 4).

(4) Radio equipment

The radio equipment consists of the radio base stations and the on-board radio units on the trains. The radio base stations are located at approximately 3-km intervals and perform bidirectional communications with the on-board radio units using antennas for space wave transmission on above-ground sections of track and leaky coaxial cable (LCX) for tunnels and underground sections. The following are some typical examples of data sent via radio.

(a) Data sent from wayside equipment to the on-board equipment

(i) Limit of movement authorities (LMAs)
(ii) Route information
(iii) Obstacle information
(iv) Temporary speed restrictions

(b) Data sent from the on-board equipment to wayside equipment

(i) Train information (train position, train number, etc.)
(ii) Direction of travel
(iii) Level crossing control commands

(5) On-board devices

The on-board devices are located in the driver's compartment of each trainset. In addition to calculating dynamic speed profiles based on the LMAs sent from the wayside equipment and displaying speed limits in the driver's compartment, they also trigger braking if the train exceeds its speed limit.

Overview of Radio-based Train Control

Instead of using signal indication as in the past, ATACS control of a train involves the ground controller using radio to transmit an LMA (which specifies the position to which the train can safely advance) to the on-board equipment. The on-board equipment then uses the received LMA to generate the optimal dynamic speed profile based on the performance capabilities of the train. Although the actual driving of the train is still performed by the train driver, the system is designed to apply the brake automatically if the train exceeds the speed specified in the dynamic speed profile. While the basic approach to train control is the same as digital automatic train protection (ATP), because there are no track circuits (blocks), moving blocks are implemented by controlling the interval between trains.

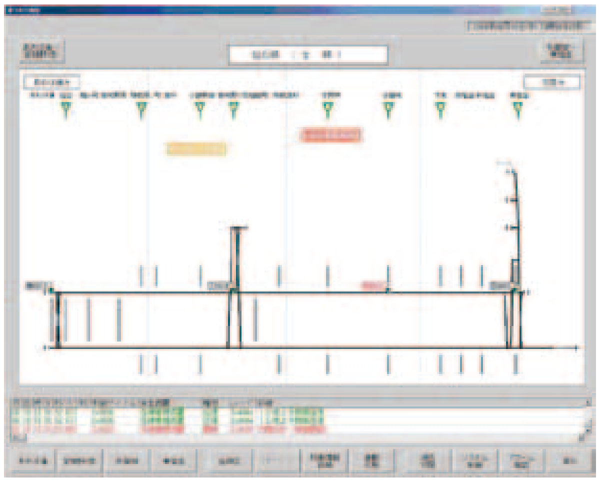


Fig. 4—System Supervision Equipment (Example Traffic Display Screen).
The screen shows the location of trains and LMAs in the system.

The following gives an overview of this method of train control.

(1) Using the track database, tachometer generator, and positioning correction balises, the on-board equipment determines the position of the train.

(2) This information is then transmitted by radio to the wayside equipment.

(3) The wayside equipment determines the LMA for each train based on factors such as the received position information and the status of route control, and transmits this information to each train by radio.

(4) The on-board equipment uses the received LMA to generate the dynamic speed profile and performs any braking control if needed.

This describes how control is performed under normal circumstances.

The following are some examples of the functions for handling abnormal circumstances.

(1) Function for sending emergency stop commands

This function sends an emergency stop command to affected nearby trains if a problem occurs on a train, such as an interruption to the system's radio communications.

(2) Backup function in case of fault in radio base station

This function maintains control operation in the event of detecting a failed radio base station by disconnecting the faulty base station and using adjacent base stations as backup for its coverage area (see Fig. 5).

(3) ID shift function

If a train has a fault such as an interruption to radio communications, this function tracks the train instead by using an on-board ID device on the train.

(4) Function for detecting rolling stock without ATACS device

This function detects any rolling stock without an ATACS device that enters the railway track controlled by the system and responds in ways that include issuing stop commands to any nearby rolling stock that is fitted with an ATACS device.

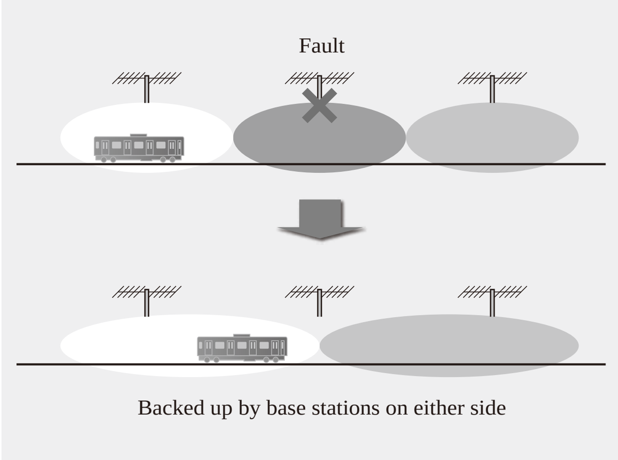


Fig. 5—Backup Function in Case of Fault in Radio Base Station.
Train service can continue to operate in the event of a radio base station developing a fault, because the adjacent base stations provide backup for its coverage area.

Level Crossing Control Function

The conventional method for controlling level crossings involves using track circuits or level crossing controllers located on the wayside to detect a train and to turn the warning on or off accordingly. The timing for turning on a level crossing warning is determined based on the maximum train speed, which means that the warning remains on for a longer time for slower trains. With ATACS, on the other hand, because trains know their own position and speed at all times and therefore can determine how long it will take them to arrive at a level crossing, it is possible for the trains themselves to issue level crossing warning commands to the wayside equipment.

Using radio in this way makes it possible to perform train-based control of level crossings based on factors such as train speed and type, and to determine an appropriate length of time for the warning to remain turned on.

Monitor Run and Control Run for Senseki Line

Day and night monitor run testing commenced in March 2010 to perform final checks, followed in April 2010 by nighttime control run testing.

Monitor run testing involves running ATACS in parallel with the existing automatic train stop (ATS) system (with output of braking by ATACS disabled). This form of long-run testing was performed to confirm that the operation of trains on the Senseki Line was consistent with the system, and to verify radio conditions throughout the year given the potential for seasonal, meteorological, and other influences.

Control run testing involved switching actual operation over to ATACS to check radio-based train control, the operation of various functions, and connections to field equipment under actual train operation.

The data produced by these tests were analyzed to confirm that there were no problems.

CONCLUSIONS

This article has given an overview of the ATACS train control system and described its development.

The ATACS for the Senseki Line will commence operation for both the step 1 and step 2 stages. Step 1 involves commissioning the basic radio-based train control functions and step 2 involves a plan for train-based control of level crossings.

The East Japan Railway Company has already started work on plans to introduce ATACS in the Tokyo metropolitan area in the future. There is also strong demand from other railway operators to eliminate track circuits, and the system has attracted attention for its potential to reduce maintenance costs.

Outside Japan, radio-based train control systems are becoming progressively more mainstream. Because ATACS corresponds to the European Train Control System (ETCS) Level 3, there is a prospect of expanding its market overseas as well as in Japan.

ABOUT THE AUTHORS

Yuichi Baba
Joined East Japan Railway Company in 1991, and now works at the Electrical & Signal Network System Department, Railway Operations Headquarters. He is currently engaged in the development of a radio-based train control system.

Atsushi Hiratsuka
Joined Hitachi, Ltd. in 1992, and now works at the Signalling Systems Design Department, Mito Rail Systems Product Division, Rail Systems Company. He is currently engaged in the development of a radio-based train control system.

Eiji Sasaki
Joined Hitachi, Ltd. in 1992, and now works at the Transport Management & Control System Division, Rail Systems Company. He is currently engaged in the development of a railway signalling system.

Osamu Yamamoto
Joined Hitachi Mito Engineering Co., Ltd. in 1995, and now works at the System Design Department. He is currently engaged in the development of a radio-based train control system.

Masakazu Miyamoto
Joined Hitachi Mito Engineering Co., Ltd. in 1997, and now works at the System Design Department. He is currently engaged in the development of a radio-based train control system.

Development of CBTC for Global Markets

Tomoaki Tazaki
Zhengyu Li
Kazuhiro Sanjo
Kenichi Sakai
Ikuo Shimada
Hiroshi Taoka

OVERVIEW: On December 30, 2011, on a monorail signals system for Chongqing in China, Hitachi commissioned its first CBTC system to be installed outside Japan. The Chongqing Monorail 3rd Line is a long-distance service with a total length of 55.6 km (39.1 km currently in use). Moving block control based on radio communications has been installed along the entire length of the line to allow high-density services with a headway (interval) between trains of only 120 seconds. The system was designed from the outset to allow for future enhancements, and incorporates the latest technology for driverless operation. Building on the success of projects such as this, Hitachi intends to continue operating its business globally in the future.

INTRODUCTION

IN 1997, Chongqing was designated China's fourth direct-controlled municipality (meaning it is administered by the central government), the others being Beijing, Shanghai, and Tianjin. The largest of the four, it comprises 19 districts, 15 counties, and 4 autonomous counties. In June 2010, it became the first inland national development zone with the establishment of an inland special taxation zone combining both port and airport. It has grown to become the largest industrial city in China's southwest, acting as an economic gateway to the west and providing the land and water transportation infrastructure vital to economic development.

Central Chongqing straddles two major rivers, the Yangtze and Jialing, with a topography characterized by limited land area and steep gradients that are unfavorable to the construction of railway lines. Accordingly, the city chose to install monorails, recognizing these as being best suited to the geographical conditions. Chongqing Monorail 2nd Line commenced operation in June 2005, and was followed in 2011 by Chongqing Monorail 3rd Line, which incorporates the latest technology.

Fig. 1—Map of Urban Transportation Services in Chongqing and Monorail Vehicle.
As indicated by the "3," Chongqing Monorail 3rd Line runs through the city from north to south. It has the highest number of passengers of all the city's lines, and includes stations that also serve lines 1, 2, and 6.

This article gives an overview of the communication-based train control (CBTC) system for Chongqing Monorail 3rd Line, the first such system supplied by Hitachi outside Japan, and describes the future prospects for the global deployment of CBTC.

OVERVIEW OF CHONGQING MONORAIL 3RD LINE

Project Summary

Chongqing Monorail 3rd Line runs from north to south across the city's two main rivers, with 39 stations along a total length of 55.6 km and a final termination at the city's northern airport (see Fig. 1).

Service commenced on stages 1 and 2 of the line (approximately 40 km between Ertang and Jiangbei Airport) on December 30, 2011. This made it the world's longest such line at that time. Table 1 lists the main technical specifications.

System Configuration

Fig. 2 shows the system configuration.

(1) Wayside equipment configuration

The wayside system consists primarily of traffic management equipment that manages the status of traffic on the line and issues commands for vehicle movement, interlocks that control vehicle movement based on the commands from the traffic management equipment, automatic train protection (ATP) equipment that uses position, movement, and other vehicle information to generate control information for each train on the line to control the headway between trains, and the base stations that provide radio communications with the trains.

(2) Onboard equipment configuration

Onboard systems include onboard ATP equipment that determines train position and performs brake control based on commands from the wayside, radio units for communications with the wayside, displays for presenting information to the driver, and a control panel for entering operational commands.

(3) Other components

In case of a fault in the CBTC system, Chongqing Monorail 3rd Line also has a separate backup system for train position detection. This backup system uses axle sensors to determine train position.

Table 1. Main Technical Specifications of Chongqing Monorail 3rd Line

In addition to the standard monorail specifications, the line also includes the latest CBTC technology.

	Parameter	Phases 1 and 2
Operations	Rolling stock system	Monorail (rubber tires)
	Operating mode	ATO with single driver (Driverless operation for reversing direction)
	Trainset configuration	Six cars
	Operation at rolling stock depot	Under driver control (with inhibit functions to prevent inappropriate operation)
	Operating speed	75 km/h
	Headway between trains	120 s
	Length of line	40 km
	Number of stations	29
CBTC specifications	Control system	Moving blocks
	Type of radio transmission	Radio (via access point)
	Radio frequency	2.4 GHz
	Vehicle position detection at system startup	Onboard: Onboard position confirmation when vehicle passes balise Wayside: Position acquired from onboard position notification

ATO: automatic train operation CBTC: communication-based train control

Overview of CBTC System Control Functions

(1) Moving block control

Whereas the track circuit method used in the past determined train position in terms of fixed track segments, the CBTC system uses moving block control whereby "limit of movement authorities" for each train are updated and sent to the trains in realtime, based on actual train movements.

(2) Use of onboard positioning for position detection and safety margin distances

Because it determined train position in terms of track circuit segments, the track circuit method used in the past did not have to deal with errors in train position. In the CBTC system, on the other hand, train position is determined by wayside ATP equipment and uses position information generated by onboard devices on each train that work by integrating speed sensor information. This means there is a potential for error in the positions produced by the onboard ATP equipment, and therefore that it is possible for a train's position in the system to be different to

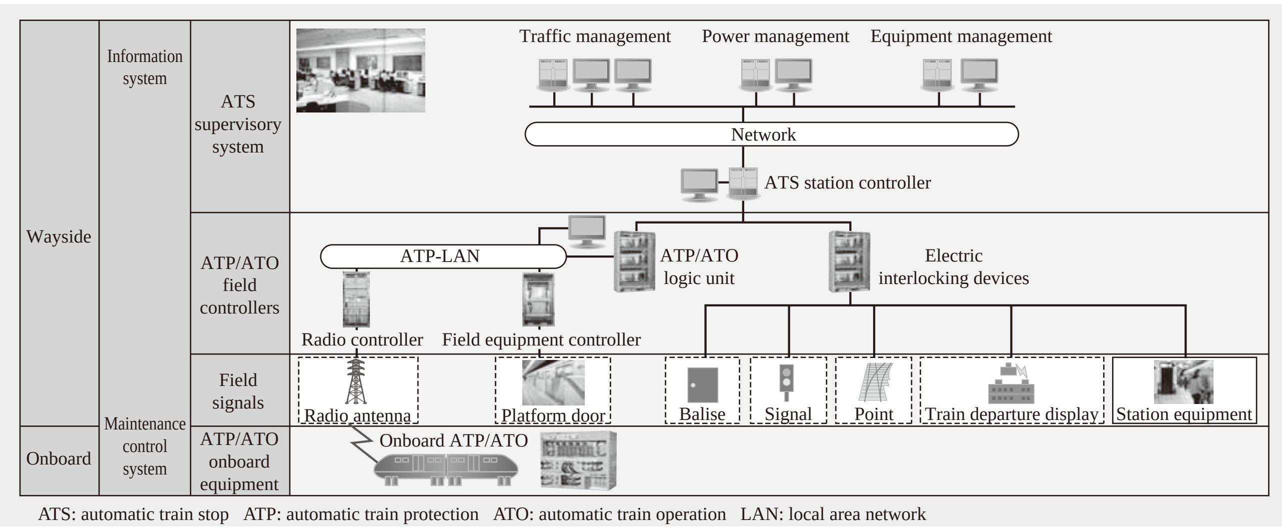


Fig. 2—Overall Configuration of Chongqing Monorail 3rd Line.

The CBTC system can be broadly divided into four levels, consisting of the ATS supervisory system, ATP/ATO field controllers, field signals, and ATP/ATO onboard equipment.

its actual position. Accordingly, a train positioning method that allows for position detection error when determining positions is needed. Also, this error in positioning needed to be considered when setting the safety margin distance between the reference points for the protection pattern for stopping by the onboard ATP equipment and the absolute stop position.

(3) Use of radio communications for positioning

The previous track circuit method used physical means to detect train position, which meant that the wayside equipment detected the train position itself, independent of any notification from the train. Also, because a fault in the track circuit was interpreted as the train being at that position, the train position was never uncertain. On the CBTC system, in contrast, because positioning needs to be done using positioning information from the onboard ATP equipment, relying on communications between train and wayside, the train position becomes uncertain if radio communications are interrupted. Consequently, the CBTC system allocates a fixed protection margin if radio communications are interrupted. Fig. 3 shows a flow chart of how the CBTC system works.

SOLUTION DESIGNED FOR GLOBAL MARKETS

While paying close attention to experience from Japan, the prospect of future sales in the global market was taken into account when determining the specifications for the signals system for Chongqing Monorail 3rd Line. The following sections describe the strengths of Hitachi's CBTC system.

Driverless Operation (UTO)

Emphasizing past experience with monorails in Japan, the signals system for Chongqing Monorail 3rd Line has been designed on the basis that the trains will mainly be operated by automatic train operation (ATO) with a single driver. As a special case, however, the system also incorporates an unattended train operation (UTO) function for use when reversing direction at a station. The purpose of this function is to avoid the time delay while the driver moves to the control console at the other end of the train (because the headway available for reversing direction is short). This requirement was included in the specifications from the initial design stage.

The sequence of operation is: traffic management issues automatic driving command → determine automatic movement to execute → select automatic control console → proceed to departure platform under automatic control. This provides all the elements required for UTO using established technology throughout.

The IEC 62267 standard of the International Electrotechnical Commission (IEC) defines four levels

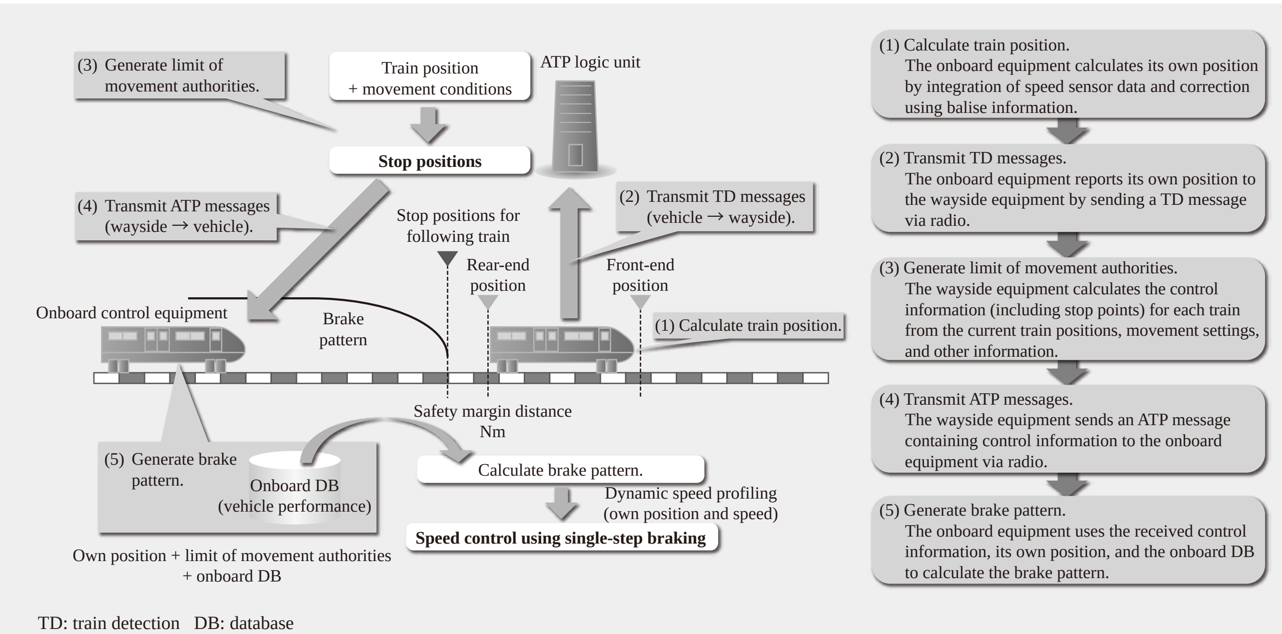


Fig. 3—Flowchart of CBTC System.
Moving block control is implemented using onboard position reporting devices that operate via the industry/science/medical space-wave radio band (2.4 GHz). The use of radio allows for the transmission of a high volume of control messages and continuous detection of train information.

of automation, and there is growing demand for UTO in new CBTC projects for urban transportation in other countries. In addition to the technology provided for Chongqing Monorail 3rd Line, Hitachi also has extensive operational experience with driverless operation in Japan (on the Nanakuma Line of the Fukuoka City Transportation Bureau, Nanko Port Town Line of the Osaka Municipal Transportation Bureau, Seaside Line of Yokohama New Transit Co., Ltd., and Tokyo Waterfront New Transit Yurikamome). Hitachi intends to combine these technologies to establish its own comprehensive CBTC solution.

Delivering on Requirements for Headway between Monorails

The requirement for the headway between trains is known to be more severe for monorails than those that typically apply on conventional undergrounds. The following are some of the reasons why achieving the required headway between trains is more challenging for monorails.

(1) The nature of monorail vehicles means that their accelerations, decelerations, and top speeds are slower than those of conventional underground rolling stock.

(2) The configuration of points used on monorail lines are such that speed limits are set slower, and the points take a longer time to switch.

(3) A section of siding track is commonly used at locations where the train reverses direction (as in the case of Chongqing Monorail 3rd Line).

The requirement for the headway between trains on other CBTC projects in China (for conventional headway lines) is typically 120 seconds, and this same requirement applies to Chongqing Monorail 3rd Line. This means that the CBTC for Chongqing Monorail 3rd Line needs to deliver equivalent performance to a headway system despite its being a monorail. Nevertheless, the ability of Chongqing Monorail 3rd Line to achieve a 120-s headway under these severe conditions was demonstrated both by simulation and through analysis of actual measurements of headway. This suggests that even shorter headway should be possible under the more favorable conditions that typically apply in conventional undergrounds.

Adoption of International Standards

(1) Radio system

The radio system for Chongqing Monorail 3rd Line uses orthogonal frequency division multiplexing over the general-purpose industry/science/medical radio band to provide the interface between the wayside and onboard systems. In readiness for future deployment in international markets, Hitachi supplies its own proprietary radio products that combine a high level of security and reliability with an architecture that is able to tolerate interference, and is able to install radio systems that can operate seamlessly in different countries regardless of the regulatory and other requirements of radio use that apply in that country.

(2) Balise system

The balise system for Chongqing Monorail 3rd Line complies with European standards. Because of the severe requirements that apply for monorails in terms of the separation between balises and onboard pickups, Hitachi has experience in balise installation, transmission methods, and the design of message data, and has established technology for interfacing between wayside and onboard systems.

Mixed Operation

As described above, the CBTC system uses radio to send information about train positions. If communications are interrupted by external interference or a fault within the radio system itself, position notifications from the onboard equipment are lost and the train position becomes unknown. While this can be thought of as an inevitable consequence of using a CBTC system, safety requirements are being made more stringent throughout the world, and the IEEE 1474 standard specifies an optional mixed operation function whereby the sending of train information via radio is augmented by a physical system for detecting train position.

Detailed design work is currently underway with the aim of providing Chongqing Monorail 3rd Line with such a mixed operation capability so that it can detect non-CBTC trains (trains without onboard radio) during normal CBTC operation. This function is to be offered as one of the options available for augmenting Hitachi's CBTC solution product.

CONCLUSIONS

This article has given an overview of CBTC system for Chongqing Monorail 3rd Line, the first such system supplied by Hitachi outside Japan, and described the future prospects for the global deployment of CBTC.

Railway signals systems used around the world can be broadly divided into those used on main lines that provide high-speed and long-distance services linking major cities [European Train Control System (ETCS)], and those for the undergrounds, monorails, and other new modes of urban transportation that provide short-distance services within cities (CBTC). A common feature of both of these is a shift to radio-based train control from the track circuit method used in the past for detecting train positions and transmitting control information. Hitachi commenced work on developing these internationally standardized signals systems from an early stage and has completed two separate signals control systems for China, one of each of the above types. Commissioned at roughly the same time at the end of last year, these two systems were supplied to different users and used different state-of-the-art technologies.

Hitachi anticipates installing the CBTC system for urban transportation described in this article in other major cities, in China and around the world, with the market for such systems being larger (in terms of both the number of projects and number of vehicles) than that for main line systems. Building on its success with Chongqing Monorail 3rd Line, Hitachi is seeking to extend its range of CBTC products.

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ABOUT THE AUTHORS

Tomoaki Tazaki

Joined Hitachi, Ltd. in 2001, and now works at the Signalling System Integration Department, Transport Management & Control System Division, Rail Systems Company. He is currently engaged in coordinating the engineering of signals systems for urban transportation in China.

Zhengyu Li

Joined Hitachi, Ltd. in 2003, and now works at the Signalling System Integration Department, Transport Management & Control System Division, Rail Systems Company. She is currently engaged in coordinating the engineering of signals systems for urban transportation in China.

Kazuhiro Sanjo

Joined Hitachi, Ltd. in 1981, and now works at the Rolling Stock Electrical System Design Department, Mito Rail System Product Division, Rail Systems Company. He is currently engaged in the engineering of onboard equipment for signals systems for urban transportation outside Japan.

Kenichi Sakai

Joined Hitachi, Ltd. in 1990, and now works at the Signalling System Design Department, Mito Rail System Product Division, Rail Systems Company. He is currently engaged in the engineering of wayside equipment for signals systems for urban transportation outside Japan.

Ikuo Shimada

Joined Hitachi, Ltd. in 1996, and now works at the Rolling Stock Electrical System Design Department, Mito Rail System Product Division, Rail Systems Company. He is currently engaged in the engineering of onboard equipment for signals systems for urban transportation outside Japan.

Hiroshi Taoka

Joined Hitachi, Ltd. in 2000, and now works at the Signalling System Design Department, Mito Rail System Product Division, Rail Systems Company. He is currently engaged in the engineering of wayside equipment for signals systems for urban transportation outside Japan.