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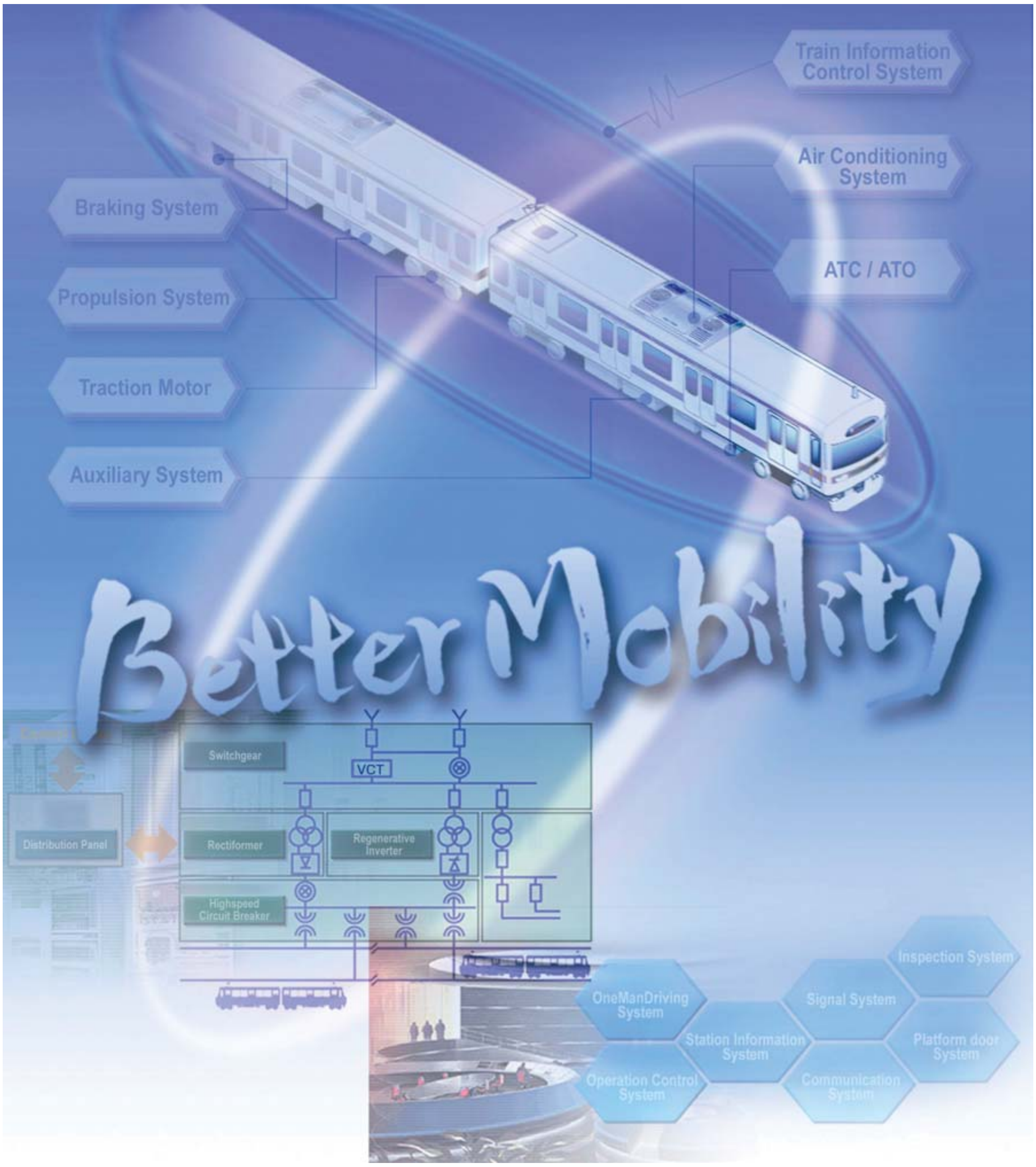
ADVANCE

Transportation Systems



MITSUBISHI ELECTRIC
Changes for the Better

Sep. 2004 / Vol. 107
MITSUBISHI ELECTRIC
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Cover Story

Better Mobility
Mitsubishi Electric Corporation (MELCO) provides every solution that is necessary for Transportation Systems; such as Electric Equipment for Trains, Power Supply Systems and Communication Systems etc. These Solutions will support Train Operation, Maintenance and Information for Passengers. Our solutions will realize the highly reliable, safe and stable Transportation Systems.

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Overview

Author: *Mitsuo Muneyuki**

Japan played a major role in the history of railways in the latter half of the 20th century, pioneering railway technologies of the world during the period. Japan has built safer, more accurate, and faster mass transportation systems earlier than any other countries. Nevertheless, railway systems in the 21st century need to be even faster, more comfortable, more environment-friendly and more human-friendly, for railways are an indispensable infrastructure of society. They must also meet the requirements for energy conservation and environmental preservation in conjunction with the movement of people.

Mitsubishi Electric's motto of "Better Mobility" reflects the company's commitment to creating products and systems that deliver sophisticated solutions, by considering the key transportation technologies that future generations will require. Today, railway companies and operators must meet strict social demands regarding energy and the environment; offer safer, faster, more reliable, and more comfortable transportation systems; and provide services that meet users' individual needs for transportation by railway. Mitsubishi Electric supplies products that have the performance and quality to satisfy such needs; provides solutions for the seamless movement of railway users based on state-of-the-art technology; and improves mobility.

In order to supply top-quality products and to ensure technological compatibility through integrated projects combining various systems, the divisions responsible for manufacturing railway-related products and system integration are integrated into Mitsubishi Electric's *Transportation Systems Center,* thus ensuring consistency of product concepts.

Mitsubishi Electric's product line includes propulsion control equipment, train information management systems, brake systems, and air conditioning equipment, thus encompassing the full range of transportation systems. In developing these products, Mitsubishi Electric has focused on improving their core functions and quality, as these are essential factors during production. The company, in close cooperation with the *Advanced Technology R&D Center,* has been aggressively innovating such processes as R&D, design, manufacture, and testing, while expanding its business globally.

Mitsubishi Electric, as the world's leading supplier of railway systems, will continue to develop transportation systems by utilizing the strengths of the entire Mitsubishi Electric Group.

* *Mitsuo Muneyuki is General Manager, Transportation Systems Div.*

Mitsubishi Electric's Operation for Overseas Railway Systems

Authors: *Yasuhiro Sekine** and *Hideyuki Takechi**

Summary

Railway systems have been adopted worldwide as a means of transportation. In particular, new railways are being constructed in many large cities to lighten the environmental burden and reduce traffic congestion, and new trains are being introduced to existing lines as well.

Mitsubishi Electric Corporation has been exporting electric equipment for various rail vehicles such as electric locomotives, suburban cars, subway cars, tramcars, and new transportation system vehicles worldwide since 1960. Our products are used in more than 20 countries, including Australia, China, India, Mexico and Spain.

The major concern of railway operators around the world is shifting from performance of individual equipment and trains to total system guarantee, including transportation service capacity and system maintenance capability.

In order to meet such changes in customer needs, enhanced engineering capacity is required not only to realize state-of-the-art performance of each equipment but also to meet total system requirements. Mitsubishi Electric Corporation, with traction and braking equipment, auxiliary electrical system, and air conditioning system for trains, now extends its activities to system integration. Utilizing its electric locomotive experience to centralize control systems and support train maintenance operations by applying train information management systems. In order to utilize these technologies effectively and to meet the needs of customers, we have established standardized RAMS management, EMI/EMC management, and LCC management technologies and relevant applications of those technologies to evaluate total systems.

The introduction of these new technologies has led to an increased number of orders in overseas markets where a high level of system integration expertise is required. Our recent business operations include manufacture and delivery of electric equipment for trains to be operated in the U.S.A., India, and Hong Kong. As for ground based systems, we have delivered a traction sub-station system to Singapore and a train depot management system to Hong Kong.

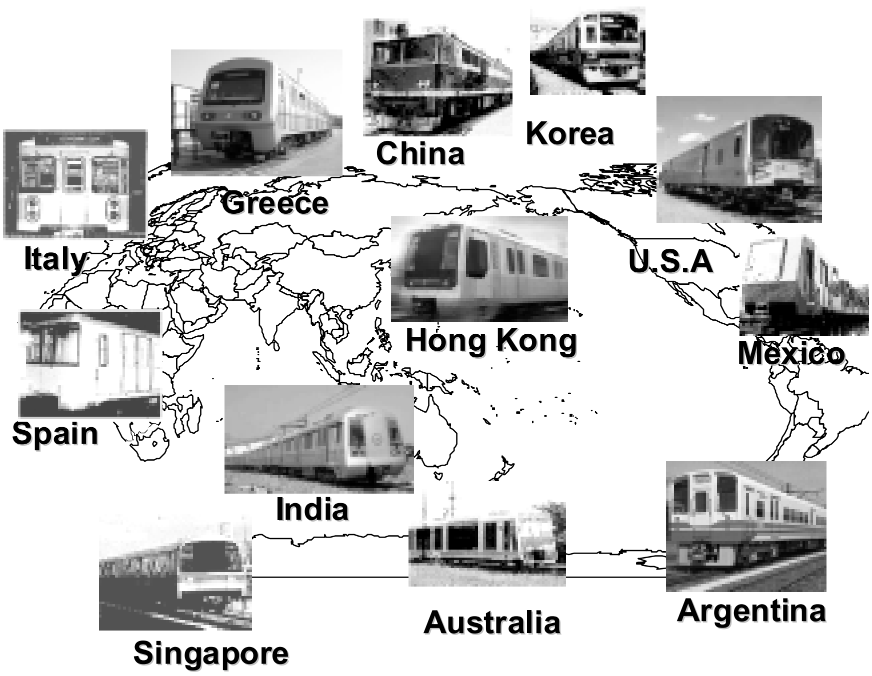

Fig 1 Mitsubishi's Main User Countries

Mitsubishi Electric Corporation has delivered electric equipment for almost 10.000 trains worldwide over the last fifty years.

1. Mitsubishi's Initiatives in Overseas Projects

Overseas railway projects usually require guaranteed specifications for individual electric equipment for trains. Now, however, guaranteed specifications are required for entire train systems as the performance of equipment has been greatly improved through the extensive use of power electronics technologies, and as the train information management system, or TIMS, has advanced. To cope with this trend in overseas markets, Mitsubishi Electric has started to incorporate management technologies such as

* *Transportation Systems Center*

RAMS (Reliability, Availability, Maintainability, and Safety), EMI (Electro-Magnetic Interference)/EMC (Electro-Magnetic Compatibility), and LCC (Life Cycle Cost) as standard tools, and has been improving the engineering platform in order to be able to provide guaranteed performance of entire railway systems.

1.1 RAMS management

With RAMS, balanced management of technological aspects such as reliability and cost performance is important. Since this balance is mostly defined in the design stage, sufficient examination with respect to the total system is indispensable in the design stage. Figure 2 shows the practical development of the design process of RAMS management. Determination of types of specifications and definitions in the initial phase as well as identification of the specifications and requirements of relevant systems and equipment are of primary importance.

Mitsubishi Electric has applied FMEA (Failure Mode Effects Analysis), FMECA (Failure Mode, Effect and Criticality Analysis), FTA (Fault Tree Analysis), and RBD (Reliability Block Diagram) as standard analysis tools in the design phase, and is endeavoring to improve RAMS management by constantly collecting field application data to increase the analytical capability in the design stage of RAMS.

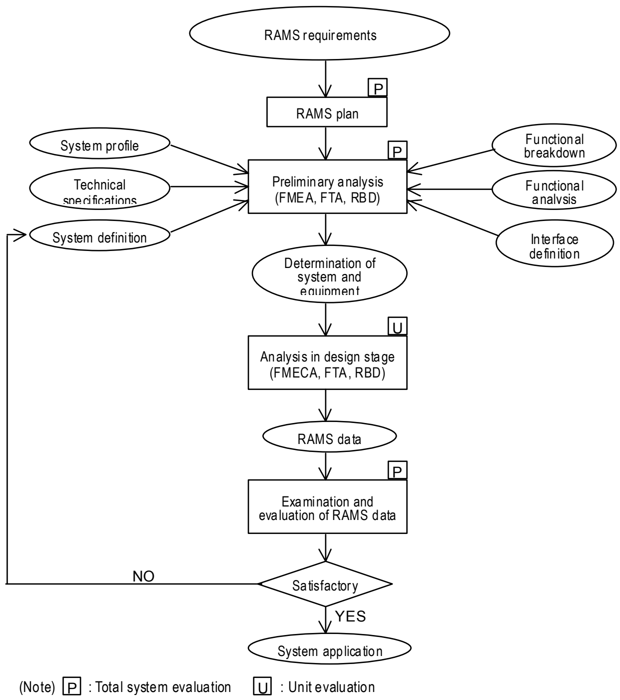

Fig. 2 RAMS Management Cycle

1.2 EMI/EMC management

For successful EMI/EMC management, it is important to clarify the specifications and requirements of each system and item of equipment. The specifications and requirements of newly constructed railways are often clearly defined. However, clarification of the specifications and requirements of existing railways such as an old-model signaling system, for example, requires the old standards that were valid when the system was installed to be checked. It is often difficult to trace the specifications and standards accurately of old equipment. In such a case, we have to assume specifications and requirements with a certain adjustable margin, which is finalized at the stage of total system adjustment.

The examination process of EMI/EMC can be expressed in a simplified chart as shown in Fig. 3.

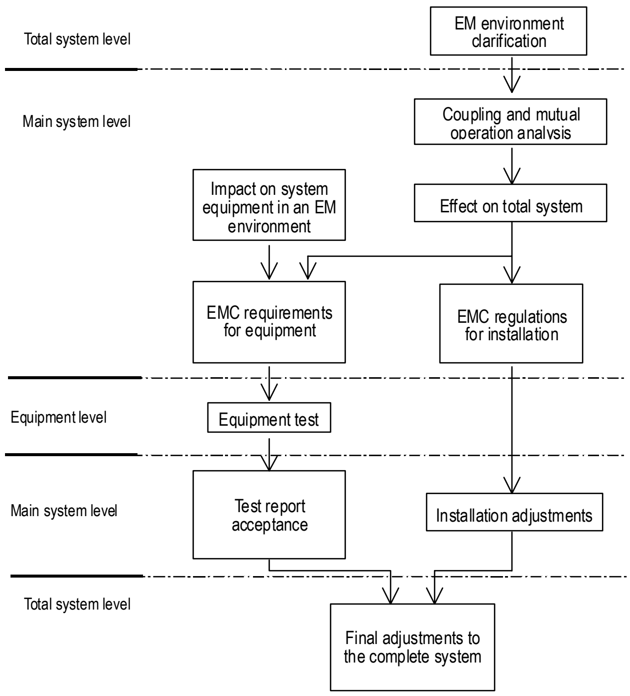

Fig. 3 EMI/EMC Management Process

1.3 LCC management

In addition to technological evaluation, LCC (life cycle cost of product) and estimation of the initial investment of the system have become key points in winning orders. LCC, based on the RAMS data, determines the life cycle cost of products. Table 1 shows an example of our calculation table of LCC. The LCC data accumulated during these periods help us identify clearly where the problem lies in terms of cost. The results thus obtained are fed back to and reflected in the system design and equipment design, so that LCC is optimized.

The measures taken for the optimization of LCC include the following, which are also associated with the measures related with RAMS.

(1) Reduction in the number of components used in a system or item of equipment
(2) Change to equipment of higher reliability
(3) Structural change for shortening disassembling and assembling time

Table 1 LCC Data (Example)

	Upon start-up of maintenance	Maintenance period						
		1 year	2 years	~	10 years	~	20 years	....
1. Equipment								
(1) Individual tooling	XXXX							
(2) Special tool and diagnostic and test equipment	XXXX							
2. Spare parts and consumables								
(1) Preventive maintenance and overhaul		XX	XX	....	XX	....	XX	....
(2) Corrective maintenance				XX	XX	XX	XX	....
3. Engineering								
(1) Maintenance plan	XXXX							
(2) Maintenance documents and manuals	XXXX							
(3) Maintenance training	XXXX							
4. Labor cost								
(1) Preventive maintenance (Light Inspection, Reinforce Inspection, Primary Revision, Secondary Revision)		XX	XX	....	XX	....	XX	....
(2) Overhaul (Overhaul, Replacement)				XX	XX	XX	XX	....
(3) Corrective maintenance				XX	XX	XX	XX	....
Total cost/total sum	A	Y1	Y2	....	Y10	....	Y20	....

2. Mitsubishi Electric Corporation's Recent Major Overseas Projects

Table 2 shows the major specifications of trains for which we have received orders for installation of electric equipment such as traction and braking equipment, together with the names of our equipment actually delivered. Figure 8 shows the system configuration of our Train Depot Information System (TDIS), which was developed to improve the maintenance efficiency of trains and was delivered to Hong Kong MTRC as shown in Table 2.

Mitsubishi Electric Corporation is determined to strive for an ever higher status as the leader of railway industries, by closely observing market needs and changes in market trends.

Fig. 4 U.S.A. LIRR M-7 Train

Fig. 6 Hong Kong KCRC East Rail Train

Fig. 5 India DMRC Train

Fig. 7 Hong Kong MTRC Train

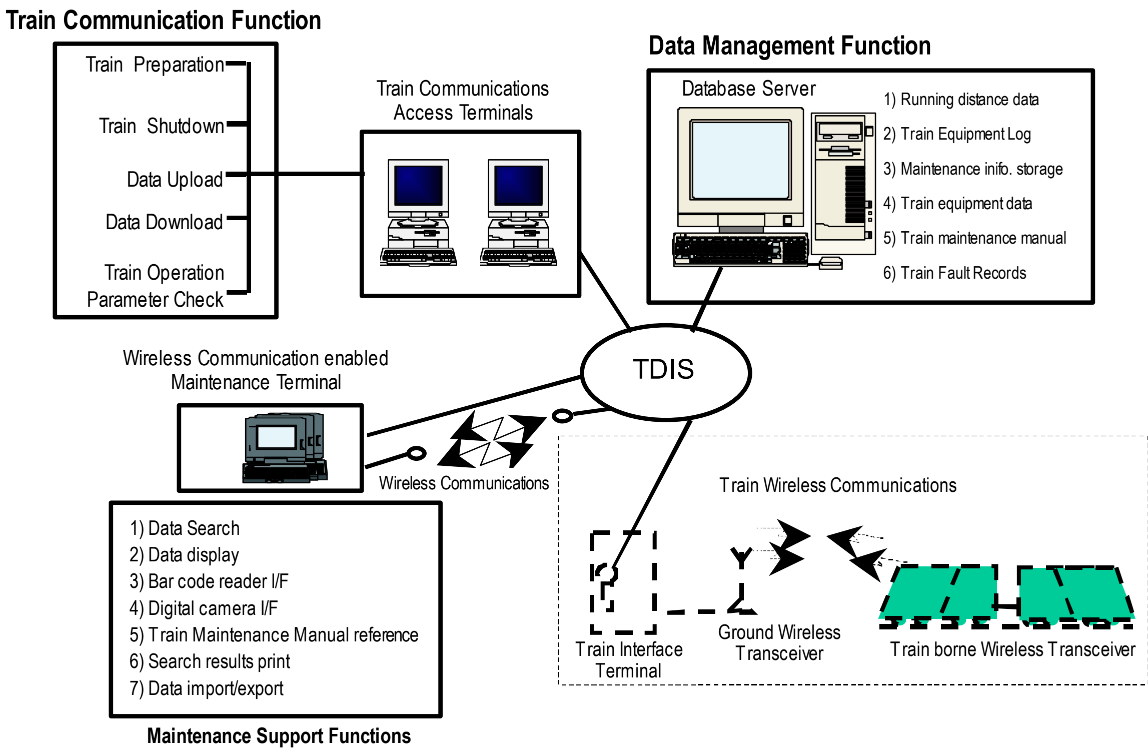

Fig. 8 TDIS System Configuration

Table 2 Main Specifications of Cars

Item \ Customer	U.S.A. LIRR	India DMRC	Hong Kong KCRC	Hong Kong MTRC
Power supply system	750 VDC (Third-rail method)	25 kVAC overhead wire	25 kVAC overhead wire	1500 VDC overhead wire
Track gauge	Standard gauge (1435 mm)	Broad gauge (1676 mm)	Standard gauge (1435 mm)	Standard gauge (1432 mm)
Train formation	Standard 6M (3MP: Married Pair)	2M2T M: Motored, T: Trailer	• East Line 6M6T • West Line 4M3T • Ma'anshan Line 2M2T	6M2T
Maximum speed	160km/h	80 km/h	130 km/h	80 km/h
Wheel diameter	36 inch	860 mm	840 mm	850 mm
Starting acceleration	2.0 m/h/s	0.82 m/s^2	1.0 m/s^2	1.3 m/s^2
Normal maximum deceleration	3.0 m/h/s (0-50 mph)	1.0 m/s^2	1.0 m/s^2	1.35 m/s^2
Emergency deceleration	3.2 m/h/s (0-50 mph)	1.3 m/s^2	1.3 m/s^2	1.4 m/s^2
Control method	IGBT VVVF inverter control	IGBT PWM converter/IGBT VVVF inverter control	IGBT PMW converter/IGBT VVVF inverter control	IGBT VVVF inverter control
Braking system	Regenerative brake/rheostatic brake/air brake blending control	Regenerative brake/air brake blending control	Regenerative brake/air brake blending control	Regenerative brake/rheostatic brake/air brake blending control
Mitsubishi Electric supplied equipment	• Traction and braking system (VVVF control unit, main motor, drive unit, etc.)	• Traction and braking system (Main transformer, main converter, main motor, etc.) • Auxiliary electrical system (SIV) • Train Information Management System (TIMS)	• Traction and braking system (Main transformer, main converter, main motor, etc.) • Auxiliary electrical system (SIV, battery charger) • Train Information Management System (TIMS) • Passenger Information System (PID) • Passenger Car Monitoring System (CCTV)	• Traction and braking system (VVVF control unit, main motor, etc.) • Auxiliary electrical system (SIV) • Train Information Management System (TIMS)

Current Status and Future Prospect of Train Systems

Author: *Hideo Obi**

1. Introduction

Train system comprises propulsion and driving equipment, information management equipment, a braking and safety system, and a service system. The propulsion and driving equipment includes a main motor to drive the train and an inverter/converter to control the driving operation. The braking and safety system includes a braking system and a motor-driven air compressor. The information management system includes a control transmission unit that transmits control commands and information in the train as well as types of display units. The service system includes air-conditioning equipment. This paper discusses the needs of the market such as easier maintenance and improved reliability, recent technical status, and future trends in this equipment.

2. Status and Trends in Train Systems

2.1 Market environment of recent train systems

With advances in power electronics, micro computers, and communications technologies, the equipment used for train-traction systems has rapidly been highly computerized, which has greatly contributed to improving reliability, saving labor and simplifying maintenance. In addition, such systems as TIMS (Train Integrated Management System) have been introduced to accelerate the trend in the consolidated management of information for an entire train system. With this technology, efficiency and ease of train inspection and servicing, train operation, and customer-related activities have greatly improved, and sharing information has also effectively improved.

These technological improvements are designed to meet the strict demands of railway management. These technologies are required to be further improved in the future. Train systems under these circumstances, including but not limited to individual electric equipment and units, will have to greatly contribute to realizing integrated train systems involving train information network systems as well as ground facility systems to further improve safety in operating train systems, make transportation more stable and reliable, and improve passenger services.

Current methods of evaluating new trains are very diverse; not only conventional initial cost evaluation but also life cycle cost evaluation and RAMS (Reliability, Availability, Maintainability, and Safety) evaluation are employed to accommodate the diverse factors of evaluation.

Mitsubishi Electric's basic concept for developing equipment and units that compose recent train systems includes the following four aims.

- To secure the safety and stability of transportation
- To reduce life cycle cost
- To improve service level
- To secure environmental compatibility

Technological status and trends in the development of equipment and trains are introduced below, considering the four above aims.

2.2 Status of traction system and systematization

Traction system for trains employ an induction motor as the main driving motor and a VVVF inverter as a control unit, and they have improved remarkably as AC equipment especially because the main circuit semiconductor elements have rapidly improved. Today, more than 20 years after the initiation of application, new equipment is 100% designed for AC driving.

Since the history of the shift to AC has largely depended on the technological advancement of main circuit semiconductors, Mitsubishi Electric Corporation is in an advantageous position in the industry, with the development of main circuit semiconductors, the manufacturing of chips, and the assembly tests of conductors all performed systematically within the company.

These days, main circuit semiconductors typically employ a two-level main circuit configuration, consisting of an insulated gate bipolar transistor (IGBT) that can perform driving control with low power consumption, and an intelligent power module (IPM) that is equipped with a driver and protection functions. The main circuit semiconductors available today are becoming closer to ideal converters, having much more refined mechanisms. Figure 1 shows the configuration of the snubber-less simplified main circuit and the IPM element.

* *Transportation Systems Center*

Fig. 1 IPM Device and Main Circuit Configuration

These achievements, which promise highly reliable, cost-effective equipment, are essential in realizing the four aims listed above.

When it comes to control operation, the 8-bit CPUs employed at the initial stage of the AC driving scheme are replaced by 32-bit DSP (digital signal processor), with almost a double-digit improvement in the processing time. With the main circuit element that has realized high-speed operation, the processors have made it possible to improve the performance of various types of equipment.

Power electronics equipment, with the design aims mentioned above, shares the same engineering objectives as those of propulsion control equipment and auxiliary power supply equipment (SIV). A stand-alone unit that can be operated with the driving inverter and SIV switched in the event of failure is also being manufactured.

Main motors have also improved by optimizing induction motors with a simple configuration and high rigidity for use in variable-speed driving, with engineering emphasis also placed on weight reduction, easier maintenance, an extended maintenance period, and low-noise operation. The following are the development targets.

- Frameless structure with an integrated cooling duct
- Development of a silencer
- Elimination of the speed sensor through control system development

Figure 2 shows the induction motor that employs a frameless structure with an integrated cooling duct. We have further developed the frameless structure into a fully enclosed motor using heat exchange between the interior and exterior air. In addition to the high reliability of the open type, low-noise operation and long-term operation without the need for overhaul have been realized.

Fig. 2 Appearance of Induction Motor Employing Frameless Structure

2.3 Future trends in main circuit equipment and systematization

Today's train system market demands environmental compatibility with further improvement in the low-noise operation of equipment, the prevention of electromagnetic induction-caused interference, reliability in securing the safety and stability of transportation, and the reduced life cycle cost of equipment that includes reduced maintenance requirements and an extended regression period.

Mitsubishi Electric Corporation has been developing products with the target items such as reduction in size and weight, improved efficiency, maintenance-reduced operation, low-noise operation, and low environmental impact from different engineering angles, to meet market needs. At the same time, to enhance product reliability, we have aggressively incorporated a variety of development and design methods, special facilities to validate design reliability, and other test facilities to demonstrate the feasibility of individual construction.

2.4 Status of information management equipment and systematization compatibility

Our Train Integrated Management System (TIMS), representing types of information management equipment, has a variety of functions such as control command transmission, monitoring, operation and inspection/repair support, automatic on-train testing, a passenger service, and a train vision system (VIS). The integrated management and function sharing of the equipment are optimized by utilizing software logic and a series transmission system to control respective sub-systems.

Mitsubishi employs a JRIS transmission system that is designed to realize world standard transmission protocol and high reliability, as well as offering higher-speed, higher-reliability systems than TCN or LonWorks.

The standard framework, PLATINA, is used for the system software, by whose prearranged menu high reliability is secured and various customer needs can be met. PLATINA can be interfaced with various types of ground units, featuring strong affinity with Internet protocol.

Figure 3 shows an example of system configuration, and Fig. 4 shows an example of media display.

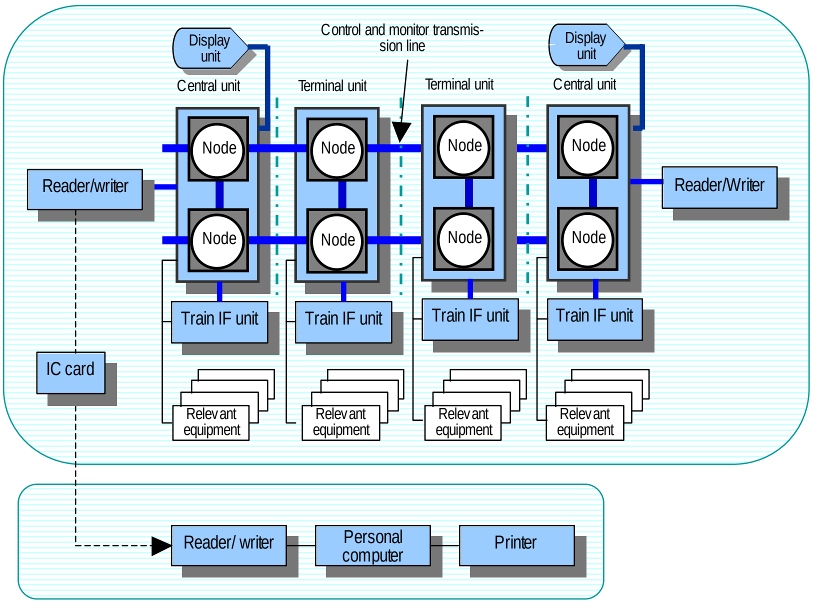

Fig.3 TIMS System Configuration

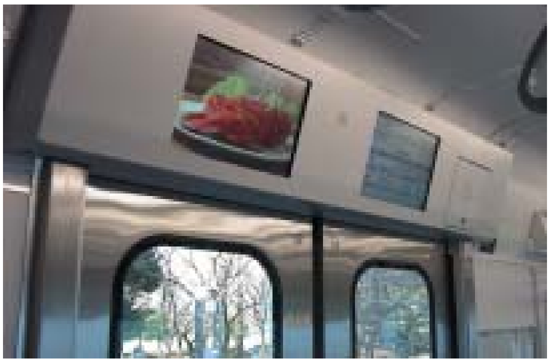

Fig. 4 VIS Media Display Unit

2.5 Status of service equipment and systematization

Air-conditioning equipment and the air compressor unit are also electronically controlled today. The air-conditioning equipment in particular has been developed into a unit cooler that can be controlled in accordance with the optimum power supply selected for each application requirement, thus realizing improved comfort and service quality on trains. With passenger expectations becoming increasingly diverse, passenger compartment air conditioning will be subject to increased demand. More sophisticated control of air conditioning will have to be realized by interlocking the operation with the TIMS system for not only compartment-based temperature control but also control patterns corresponding to train formation, operation routes, and passenger forecasts.

We are also developing a new series of motor-driven air compressors for trains based on air-conditioning compressor technology. The series, featuring high reliability and designed using the multi-compressor method, can contribute greatly to the safety and stability of transportation as well as expanding the degree of freedom with respect to formation patterns.

3. Future Trends in Train Systems

Technical trends in equipment have been discussed above, and we at Mitsubishi Electric Corporation give the highest priority to realizing safe, stable transportation systems while improving the performance of each equipment function, considering the four basic aims mentioned above. We conduct RAMS activities to evaluate the degree of each engineering achievement, especially for the projects in Europe and America. We believe we should continuously evaluate activities for safe, stable transportation systems using this logical quantitative evaluation method.

4. Conclusion

This paper discusses the recent technological trends of railway train systems, mainly the propulsion and driving equipment, information management equipment, and service equipment that Mitsubishi Electric Corporation develops and delivers.
Power electronics and information technology will advance much further in the future. We are going to continuously study and use these technologies to meet various needs such as safe, stable railway transportation, higher-grade services, and much more efficient railway operation

Current Status and Future Prospect of Power Electronics Equipment for Trains

Authors: *Hideo Terasawa** and *Syouichi Kawamoto**

1. Article Introduction

Power electronics technology for the VVVF inverter equipment and auxiliary power supply equipment used in railway trains began over 20 years ago and such equipment has rapidly advance along with the rapid advance of main circuit semiconductor. Two-level modulation methods using IGBT and IPM have become common for main circuit which has cleared basic functions to be required and are reaching technological maturity.

Due to global attention to the environment and strict criticism in conjunction with public transportation systems, market needs are closely associated with environmental compatibility and the improved reliability as a prerequisite for safe and stable transportation.

The term "environment" in connection with railway trains here refers to the following examples.

- Global environment in which energy conservation and/or easy recycling are possible
- Surrounding environment including low noise or consideration of EMC
- Passenger compartment environment including riding comfort and noise in the compartment
- Working environment including train operation and maintenance

Mitsubishi Electric Corporation has considered environmental compatibility from these various point of view, has developed technologies for reduced size and weight, improved efficiency, easy maintenance, low-noise operation, and low emissions of equipment, and has introduced advancing design methods and validation facilities to further improve reliability.

This paper discusses the typical technological achievements and their future trends.

2. Power Electronics

2.1 Converter/inverter equipment

(1) Running air cooled dry panel under the floor

To enable downsizing of equipment and improved reliability, Mitsubishi Electric Corporation has proposed a power unit using aluminum dry panel fins that is designed to be automatically cooled by the running air flow caused during the operation of the train. The power unit has the following features.

- The cooling unit is lighter and smaller as it depends mainly on the airstream.
- Reliability and environmental compatibility are increased without using refrigerant.
- Environmental compatibility is secured by using aluminum, which is highly recyclable.

Mitsubishi Electric Corporation has employed aluminum dry panel cooling fins that use the airstream on trains since 1998, with many practical achievements in applications. However, the market now requires that the part of a train under floor level be covered in a skirt-like housing to reduce the noise generated during train operation. To meet this need, Mitsubishi Electric Corporation has developed a dry panel making use of the airstream generated under the floor during train operation.

Cooling methods using the airstream under the floor have the following problems.

- The amount of air is not sufficient.
- The airstream is likely to interfere with other equipment.
- The heat source is located in a higher position and it is difficult to cool it by the convection of refrigerant.

Mitsubishi Electric Corporation solved these problems by the use of the dry panel design optimization technique based on accumulated simulation technology, application of low-loss type IGBT/IPM which use third-generation chips, and equipment layout consideration conducted jointly with the car body manufacturers. The product was installed on a New York subway train and evaluated in the one year from 2000 through 2001. The prototype products have also been employed in commercial operation of the railway systems in Hong Kong and India since 2001. The products are now employed for use in Japanese domestic railway trains.

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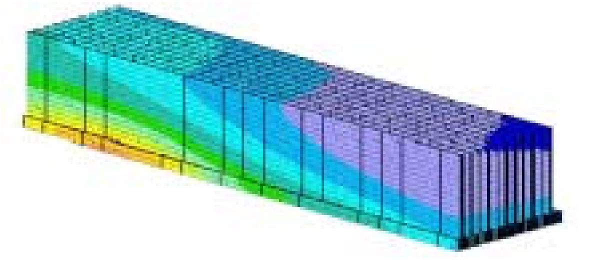


Fig. 1 Example of Analysis of Temperature Simulation in Dry Panel

Fig. 2 Two-Level Converter Power Unit Using Running Air Cooled Dry Panel under the Train Floor

(2) Two-level converter

With main circuit elements having sufficient withstand voltage, two-level modulation systems that improve reliability and decrease weight and size (as a result of decreasing the number of parts used in equipment) are generally more advantageous than three-level systems. Two-level modulation systems became common with inverters after IGBT/IPM for 3.3-kV withstand voltage were introduced.

Mitsubishi Electric Corporation, ever since the appearance of 3.3-kV IGBT/IPM on the market, has continued efforts to develop two-level converters, aside from inverters. Two-level converters were considered less feasible than inverters because converters always operate in multi-pulse mode to result in larger generation loss, the noise from the main transformer is large, and the return-line current harmonic influences the signal units. However, with the train-side skirt realized by the use of the under-floor cooling method as mentioned in Item (1) above, IGBT/IPM of low loss level, and filters optimized for relevant signal system, we have implemented two-level converters to overseas commercial applications.

2.2 Auxiliary power supply equipment (SIV)

As with inverter equipment, two-level type auxiliary power supply equipment has been the goal of manufacturers. However, the noise generated from the output reactor (ACL) is required to be quieter and improved in quality with respect to increased harmonics.

Table 1 Specifications of Converter/Inverter Control Equipment for Overseas Markets (Example)

Supply Voltage	50Hz, 1058Vac × 1 (Catenary 25kV)
Output Voltage	3 phases, ～200Hz, ～1450Vac
Capacity	Main motor 240kW × 2
Link Circuit	1900Vdc, neutral point earth
Converter	3.3kV1200A (IGBT/IPM) × 1s1p 2level modulation
Inverter	3.3kV1200A (IGBT/IPM) × 1s1p 2level modulation
Ventilation	Running air flow

Mitsubishi Electric Corporation has successfully reduced the noise by 5 dB from the conventional level with 75-kVA equipment by employing the optimum design technique for the current density of coil and the magnetic flux density of iron core and further by improving the structure.

We have improved the quality of the sound by dispersing the noise peak of certain frequencies producing offensive sound through the application of zero-vector modulation technique, which has been proved effective for propulsion inverters.

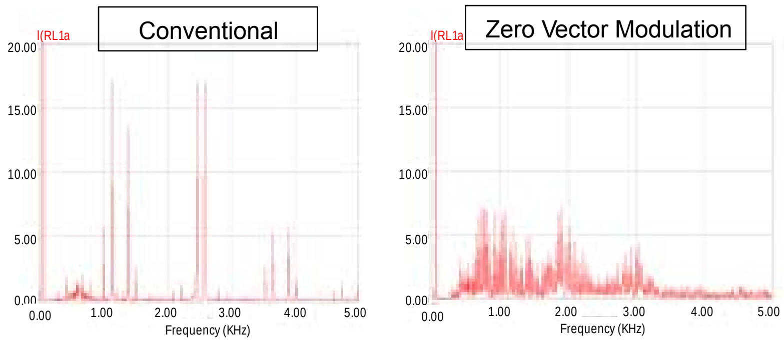


Fig. 3 Results of Noise Frequency Analysis of Auxiliary Power Supply Equipment

2.3 EMC/EMI test facilities

EMC issues, mainly discussed in the field of communications, are also taken into consideration today for the engineering of power electronics equipment for vehicles; IEC62236, EMC international standards for in-vehicle equipments, has been officially registered. There are various regulations applicable to signal equipment in conjunction with the in-vehicle equipment in railway systems. Actual load verification (loading test) in manufacturing plants is required today.

Mitsubishi Electric Corporation has conducted EMC/EMI testing and verification in the facilities provided with a large radiowave darkroom, in which objects to be tested such as traction control equipment and auxiliary power supply equipment are accommodated and high-voltage power supply and load are connected, thus these equipments that have been verified as complying with international standards.

The interference to signal equipment such as ATS can be evaluated using this radiowave darkroom, and the reliability of the evaluation measures can be improved.

3. Microelectronics

3.1 Sensorless vector control

The most typical induction motor control method for railway trains is based on the motor frequency detected by the speed sensor installed at the end of the induction motor shaft. However, this control method is not very reliable because the speed sensor is installed under the spring to be exposed to vibrations and the wiring for low-voltage signals extends to the control unit. With the speed sensor installed at the end of the motor shaft, the motor capacity itself is limited in connection with space constraint. To cope with these shortcomings, we are developing a speed sensorless vector control technique in which the motor frequency is estimated from current measurement of the induction motor and the inverter is controlled without using a speed sensor.

At present, a complete sensorless control system without any speed sensor on the induction motor being implemented on a commercial railway, and favorable results are being obtained including the performance of skidding control.

3.2 Software design integration

Since the software used for train traction control equipment is required to perform high-speed processing and be compatible with complicated external input/output processing, the system specifications have been manually developed to be then described by the assembler. However, as the system grows much more sophisticated, such a method is reaching its limit.

On the other hand, control system CAD/simulators, which can simulate by describing the block diagram directly, have been used worldwide. It has become possible to directly develop an object program from this CAD drawing. Mitsubishi Electric Corporation has developed a platform that uses this object and built a system that designs, produces, verifies, and controls software at the block diagram level of the control system CAD/simulator.

With this system completed, software design integration environment is now available for software development directly from the block diagram, which is inspected by simulation; efficient software design has become possible.

3.3 Main circuit simulator

With the advance of microcomputer control features, it has also become necessary to improve relevant design verification technology. However, the main circuit combination test method has limited condition setting and is inefficient with respect to labor and time. In addition, desktop simulations only cannot verify the system integrity completely including the hardware.

Using a commercially available board with DSP or other high-speed processor, Mitsubishi Electric Corporation has developed a main circuit simulator that simulates the main circuit and load (main motor, overhead wire, train, and railway conditions) in the traction control equipment for trains in real time. Using this simulator, tests of 50/60-Hz commercial frequency power supply system, linear motor control, wheel-diameter difference test for motors connected in parallel which were all impossible with the conventional main circuit combination testing have been conducted and verification at the design stage of various types of control functions, which were only possible with real-train testing, has become possible. The simulator has greatly contributed to improving design verification procedures.

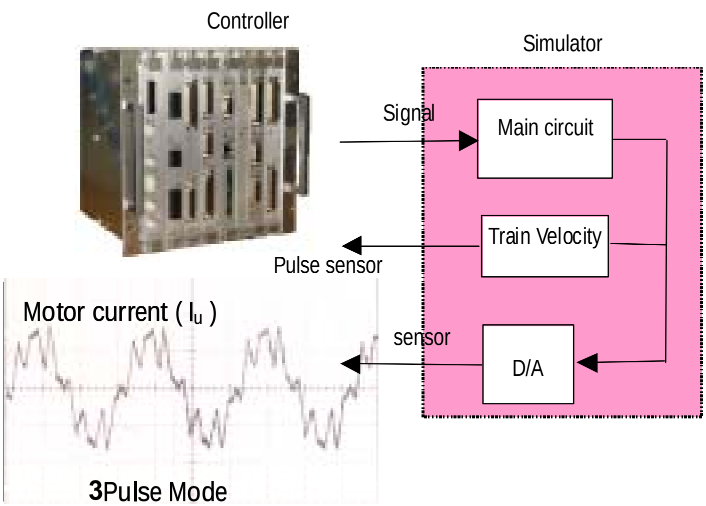


Fig. 4 Concept Drawing of Real-time Simulation by Main Circuit Simulator

4. Totally Enclosed Motor and Motor Control

4.1 Outline of totally enclosed motor

Totally enclosed type motors are designed so that outside air is blocked for high reliability of the insulated part and prevention of dust entrance and accumulation inside. General- purpose motors have already applied this design. Totally enclosed motors are used for many trains overseas, however, the application is limited in Japan. Totally enclosed motors, when used for trains, also contribute greatly to improved reliability, effective protection and improvement of the global environment, passenger compartment environment, and working environment of railway systems and are expected rapid increase of application.

4.2 Features of totally enclosed motors

(1) Use without disassembling for a long time

Conventional motors are mainly self-ventilated type in which outside air enters the inside of motors and are required periodic cleaning of the motors during overhaul. The application of totally enclosed motors can eliminate the need for cleaning inside and if the service life of the bearing is extended, the period between overhauls can be extended to 16 years (2.4 million km). So, the maintenance work environment can be significantly improved.

(2) Low noise operation

Even with open-type motors, various types of noise-reduction measures have been employed. However, since the sound generated from the fan or the like is released outside together with the exhaust air, it is difficult for big reduction of this noise.

In the case of totally enclosed motors, the noise generated inside the motor is not released outside, which allows effective noise reduction. To increase cooling effect, an external fan ventilates the air around a totally enclosed motor. If the cooling efficiency is increased with the airflow by the external fan, the amount of airflow can be decreased and noise can be reduced by about 10 dB. So, the environment of the passenger compartment can be improved.

(3) Higher efficiency and higher energy saving effect

Since totally enclosed motors are cooled by heat exchange caused around the periphery of the motor, it is necessary to reduce the heat loss generated on the rotor in particular inside the motor, by using low-resistance copper alloy as a conductor. As a result, slip decreases but motor efficiency is improved by approximately 2%.

It has also become clear that change in the shape of the groove in the rotor further reduces harmonic loss, which is referred to as stray loss.

Reduction of loss equals reduction in the required electric power on the assumption that the train performance is maintained , and means improvement in efficiency. In short, totally enclosed motors with the reduced loss or improved efficiency as mentioned above not only reduce the power consumption for the train operation but also improve the train performance or fuel efficiency of DEL. In all cases, totally enclosed motors have remarkable energy saving effects.

4.3 Low-slip control

The output torque of induction motors is controlled by regulating slip, which is equivalent to the difference between the mechanical r.p.m. and electrical r.p.m. of motors. In the case of totally enclosed motors, low-slip control is necessary as slip is reduced by a low-loss technique. As a result, the control dynamic range is narrowed and much faster control response becomes necessary.

Mitsubishi Electric Corporation has developed a new electronic control unit applicable to this low-slip type motor and applied it to products. Increased control response speed has resulted in not only its application to totally enclosed motors but also increased response speed for sudden changes in overhead wire voltage or light-load regeneration, which allows continuous control without the need for over-voltage protection or the like. In addition, use of an all electric stopping brake, effective control of slides and slip, easy operation procedures, and high riding comfort are all realized.

Fig. 5 Totally Enclosed Motor

5. Conclusion

Electric power technologies are maturing and but they are still expanding.

For example, Mitsubishi Electric Corporation has developed its original low-loss type trench gate IGBT (CSTBT) equipped with an accumulation layer, and its practical application to railway trains is forthcoming. Reduction in loss by CSTBT allows us to expect further environmental compatibility, through the application of dry panels to systems of much larger capacities and reduction in noise with higher frequencies.

Running air-cooled dry panels have been applied to Shinkansen bullet trains on a trial basis, with the result that the panels can be used without problems during ordinary train operation. Blowerless bullet trains are expected to be well received both by clients and users.

Mitsubishi Electric Corporation are resolved to develop products that incorporate our own technical achievements discussed above, aiming at realizing higher reliability and environmental compatibility.

Reference:

Hisatomi et al.: "*Speed Sensor-less Control Technique*", Rolling Stock and Technology, No. 81, pp 17-24

Current Status and Future Prospect of Train Information Systems

Authors: *Yoichi Masubuchi** and *Masao Oki**

Most railroad companies expect to implement reliable, versatile train information systems using computers. To meet these needs, Mitsubishi Electric has standardized system specifications to improve the reliability of hardware and software and has developed next-generation systems that interface with general-purpose systems. This paper discusses Mitsubishi Electric's engineering activities in the past and future prospects.

1. History and Current Status of Train Information Systems

The history of Mitsubishi Electric's development of train information systems is presented below.

(1) First generation (1980 through 1989)

Train monitor system equipped with operation-support, inspection and repair-support, and passenger services

(2) Second generation (1990 through 1994)

Train Control and Information Management Systems (TIS) were developed with control command transmission systems and auto on-vehicle testing in addition to the train monitor system

(3) Third generation (from 1995)

Integrated train management systems were developed as represented by the Train Information Management System (TIMS) incorporated in JR East's E231-system commuter trains. Fig. 1 shows an example of the configuration of a recent train information system.

To meet the requirements of railway companies, Mitsubishi Electric made the following efforts based on the latest information processing technologies.

(1) Realization of safe and stable transportation

Reduction of the number of parts by integrating the functions of devices mounted on trains has contributed to improved reliability. In addition, use of a duplex system or a redundant control method provides auto recovery in the case of a failure within the system, thus enhancing the availability of the entire system.

(2) Reduction of life cycle cost

Conventional train control logic functions consisting of respective relays and wires have been integrated into TIMS to result in reduction of the number of train parts, wires on each train car, and wires extended over different train cars.

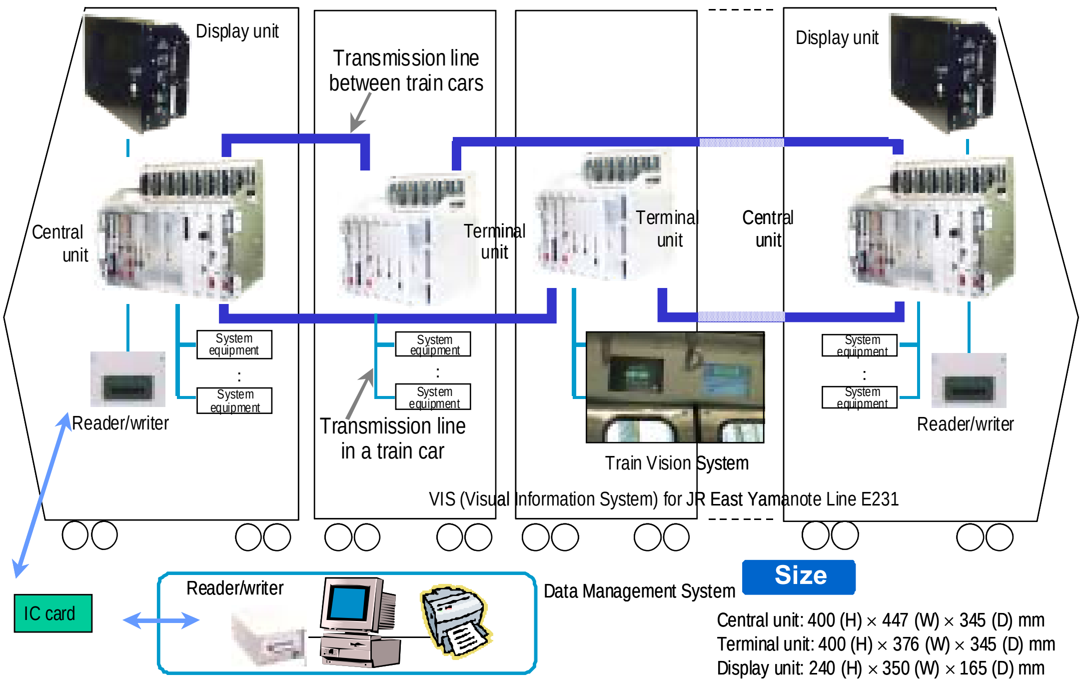


Fig. 1

* *Transportation Systems Center*

These enhancements led to reduced cost in manufacturing trains and lower power consumption due to the reduced weight of train cars. Furthermore, the number of parts mounted on train cars has been reduced and types of maintenance functions including auto on-vehicle testing have been furnished, with the result that maintenance labor is saved and maintenance cost is reduced.

(3) Improved service quality

Decision making in view of total performance of train operation has become possible by integrating all the information output from each piece of equipment, which have actually contributed to realizing detailed operation support and inspection and repair support. In addition, Mitsubishi Electric recently introduced a Train Vision System (LCD units installed above the doors displaying image data such as destination guide, advertisements, and news of the day).

2. Challenges and Efforts Related to Train Information Systems

Mitsubishi Electric is attempting to resolve two contradictory targets by designing an open but flexible train information system.

For openness, we have standardized the specifications to use market-proven train information systems and at the same time, have provided a common system architecture for all railway companies. We expect this infrastructure to improve both reliability and cost performance. Present activities regarding openness include the registration of international standards for the system functions.

On the other hand, for flexibility, Mitsubishi Electric constructed a system that consists of a universally applicable portion such as the basic configuration of the system and another customizable portion in accordance with the specifications of the train or user's original concept. With this flexibility furnished, both improved system reliability and high compatibility with respect to user needs are expected.

2.1 Standard registration activity

Mitsubishi Electric's train information system has been widely adopted by railway operators in Japan, and has proven highly effective. Therefore, this system has been used as the basis for standardization of domestic train information systems, and we have participated in standardization and normalization efforts.

As a result, Mitsubishi Electric and East Japan Railway Company jointly prepared and submitted a draft standard in 2002. The Japan Association of Rolling Stock Industries evaluated the draft as a 2002 Rolling Stock Industries Standard and registered it as "JRIS-D1001 (train information management system for railways)."

Common needs of both Japanese and overseas users include higher system reliability, lower implementation costs, and various functions to provide enhanced convenience. To meet these needs, we are aiming to build balanced systems that make optimal use of each component. In order to develop a system architecture that can feature both openness and flexibility as discussed above, we have been preparing to carry out international standardization activities to define the core of these systems.

As a concrete step toward international standardization, we have been working on the standardization of a high-speed, large-capacity data transmission system between trains.

2.2 Standard framework "PLATINA" (PLAtform for TIms Nucleus with Advanced technology)

Mitsubishi Electric have developed a standard framework "PLATINA" which makes it possible for to produce a program without any influence on the basic system and to be applicable to different specifications depending on types of trains or railway operators (see Fig. 2).

The architecture of this program has three main features described below.

(1) Software package

Employing object-oriented programming technique

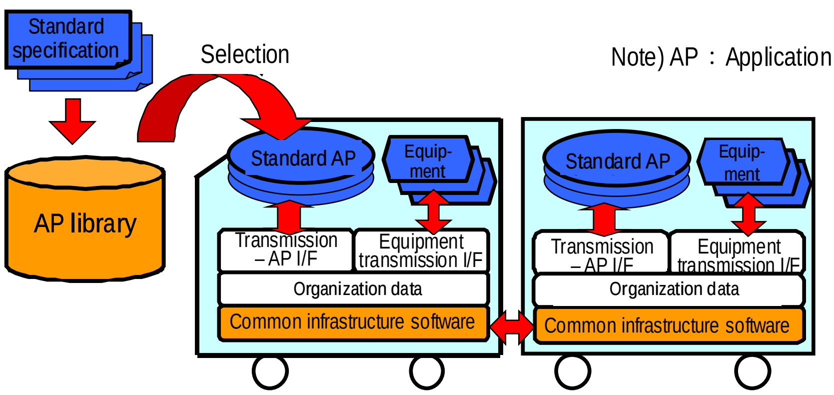


Fig. 2

in software design, each function is prepared as a standard application; the component application programs are packaged into a form of software.

To improve software reusability, each function is designed to run independently without affecting any other function. As a result, it becomes possible to make use of a component program without changing the contents for subsequent PLATINA-based systems. With the respective component programs running independently without affecting other component programs, the completed program is not likely to have bugs; developing quality programs in a short time becomes easy. As the completed programs are circulated widely in the markets, the assets of component programs increase to provide a rich variety of function menus for train information systems.

(2) Auto generation of data structures

On the basis of the results of the analysis of data on its technical achievements in the market, Mitsubishi Electric have defined the items (organization data) for the portion such as interfaces with equipment and organization conditions that vary depending on trains. Then, based on the definition, Mitsubishi Electric has patternized interfaces with equipment in accordance with the required specifications of respective railway companies and organization conditions. With this data arrangement utilized, data structures and programs that use the data structures are automatically generated by only inputting the organization data. The labor required for program design and coding is thus reduced remarkably, with the result that the software production time is dramatically shortened and the program quality is improved.

(3) Development environment

In the conventional development procedure, it was only after completing hardware production that software was installed and verified on the particular hardware. In short, the hardware production process had a great influence on the software programming process. To solve this problem, Mitsubishi Electric developed a hardware simulator that debugs and verifies the software without running it on actual hardware. With this simulator, software programming is performed without considering the production schedule of the hardware and work periods are consequently shortened.

Mitsubishi Electric also developed an auto test execution environment (Fig. 3) for automatic execution of tests and evaluation of the test result. This environment is extremely effective in improving software quality.

3. Future Prospect of Train Information System

Railway operators continue to raise their requirements of train information systems. Mitsubishi Electric estimate that train information systems will be further developed with functions divided into “control functions” whose safety and reliability are closely related with the actual operation of trains and “information functions” which universally accommodate and process much information such as image data and Internet information (Fig. 4).

3.1 Prospect of control type system

The functions of the control systems must be developed with safety, reliability, and redundancy secured fully because a failure in such a system would significantly affect the operation of trains. With the concept and technique of RAMS (Reliability, Availability, Maintainability, and Safety) of the international standards of railway systems taken into consideration, safety and reliability of equipment will be much improved in the future.

In order to realize the objectives mentioned above, we are resolved to create safe, energy saving, highly efficient, and highly reliable train systems by applying technologies such as the duplex technique, dual-CPU method, and other failure-prevention methods for control systems.

3.2 Prospect of information type systems

Unlike the control type systems, information systems confront the challenge of application of universal technology to railway trains, but it will most presumably be solved by active utilization of the state-of-the-art IT technologies. The following functions are expected to be materialized in information systems.

(1) Improvement of the scalability of both ground facilities and trains: Creation of a system in which the closed information network on trains will be expanded and linked with ground facilities.
(2) Increase of communication rates between ground facilities and trains
(3) Improved quality of images by the use of digital transmission of image data, display of contents of high resolutions, and display of monitor images
(4) Shortening contents renewal periods in train vision system and implementation of multi-timing image broadcasting

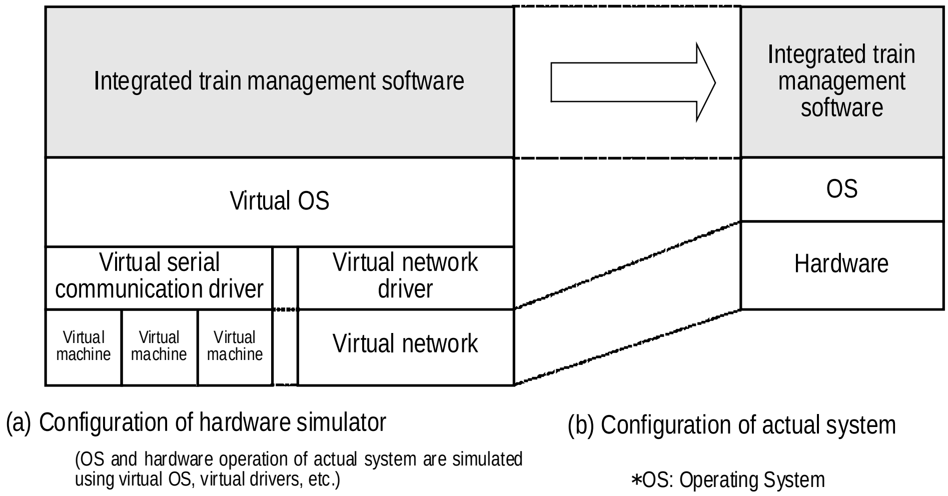

Integrated train management software
Virtual OS
Virtual serial communication driver
Virtual network driver
Virtual machine
Virtual machine
Virtual machine
Virtual network
Integrated train management software
OS
Hardware
(a) Configuration of hardware simulator
(OS and hardware operation of actual system are simulated using virtual OS, virtual drivers, etc.)
(b) Configuration of actual system
*OS: Operating System

Fig. 3

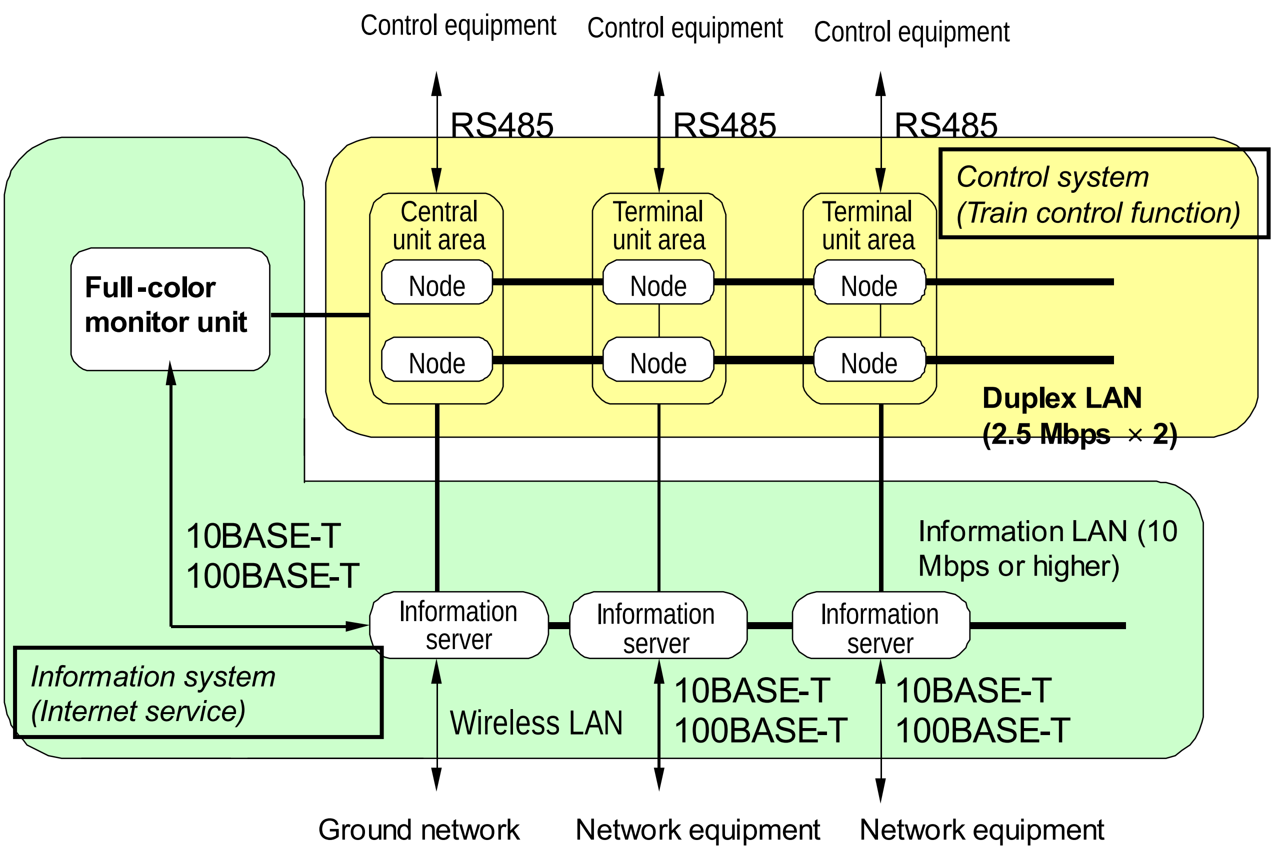

Control equipment
Control equipment
Control equipment
RS485
RS485
RS485
Control system
(Train control function)
Central unit area
Terminal unit area
Terminal unit area
Node
Node
Node
Node
Node
Node
Full-color monitor unit
Duplex LAN
(2.5 Mbps × 2)
10BASE-T
100BASE-T
Information LAN (10 Mbps or higher)
Information server
Information server
Information server
Information system
(Internet service)
Wireless LAN
10BASE-T
100BASE-T
10BASE-T
100BASE-T
Ground network
Network equipment
Network equipment

Fig. 4

Current Status and Future Prospect of Air Conditioning System Installed on Train

Author: *Yoshihiro Yamashiro**

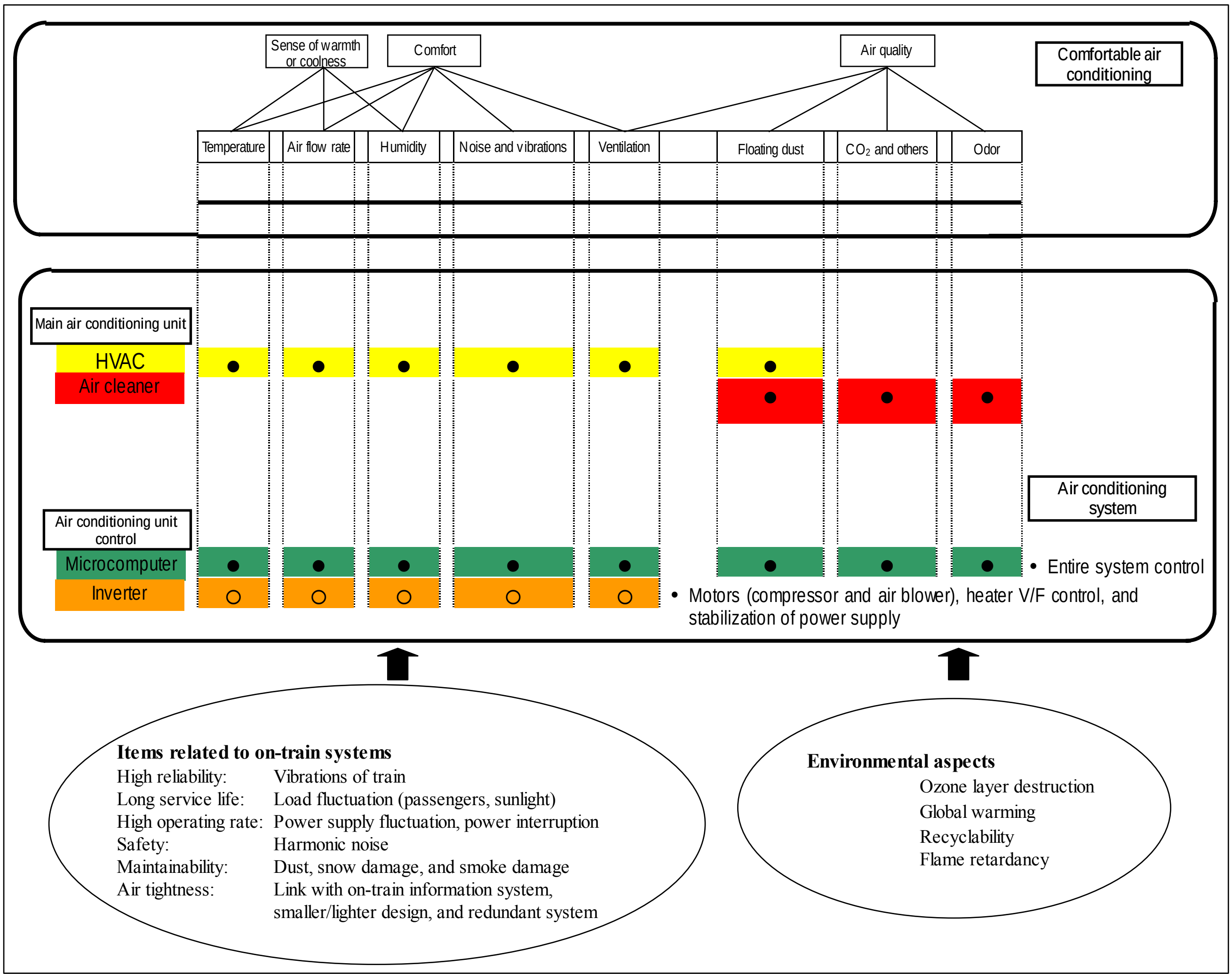
Summary

To make passengers more comfortable during the summer months in Japan, air conditioning systems for railway cars began to be introduced more than 50 years ago, starting in panoramic cars, dining cars, and limited special-class cars of express trains.

Recently much more diversified levels of comfort have been required of air conditioning systems: not only control of temperature and humidity in passenger compartments but also control of the quality of air and quick response to changes in load resulting from the movement of passengers getting on or off the train. Today air conditioning systems are installed on almost all trains including Shinkansen bullet trains, express trains, suburban trains, commuter trains, new transportation systems, monorail cars, and streetcars. They play a key role as a means of improving Customer's Satisfaction (CS).

On the other hand, air conditioning systems that use chlorofluorocarbon as the refrigerant, have attracted criticism for contributing to the destruction of the ozone layer and global warming.
This paper introduces Mitsubishi Electric's air conditioning technologies such as refrigerant circuit technology, air conditioning control technology to improve the level of comfort, and maintenance and failure diagnosis technology, together with the technological advancements of air conditioning systems installed on train cars in the past and future prospects of the systems and related technologies.

Trends of air conditioning systems installed on trains in foreign projects such as those of New York's subway trains, which Mitsubishi Electric has delivered since 1999, are also introduced in this paper.



* *Air-Conditioning & Refrigeration Systems Works*

1. Changes in Air Conditioning Systems Installed on Trains

1.1 Refrigerant circuit technology

Compressors, which are hearts of refrigerant circuits, were of open reciprocating type in 1950. They were developed into compressors of semi-hermetic reciprocating type, and then further improved around 1970 to be those of fully-hermetic reciprocating type, which have been used to the present. The fully-hermetic reciprocating type has remarkably contributed to making the compressors for air conditioning systems installed on trains smaller and lighter. Furthermore, as rotary types replaced the reciprocating types, the compressors became more efficient and produced less vibration. Mitsubishi Electric presently employs reciprocating type, rotary type, and scroll type; the mainstream is the scroll type, with many models rapidly modified into the scroll type. Due to structural advantages, scroll type compressors feature low-pressure pulsation, low noise, high reliability, high efficiency, and many other advantageous characteristics; use of them in air conditioning application is likely to continue for sometime.

On-train air conditioning units, especially ceiling-mounted air conditioning units, are required to be small in height and horizontal units are preferred. Under the circumstances, Mitsubishi Electric has put horizontal rotary compressors and horizontal scroll compressors into practical use since 1985 and 1989 respectively.

Important technological issues related to refrigerant circuits are measures against forming and liquid compression of refrigerator oil upon start-up due to unavailability of power supply to the crank case heater for the prevention of condensation of refrigerant to the compressor due to the difference in heat capacity during a long downtime (power-off of pantograph or the like). In other words, refrigerant circuit design must take into consideration (1) minimization of the amount of refrigerant fed, (2) optimization of accumulator, (3) prevention of the movement of refrigerant during downtime, and (4) prevention of transfer of refrigerator oil in the compressor.

In addition to the points mentioned above, the design process of refrigerant circuit is required to take into consideration ease of maintenance service, which is closely related to LCC (Life Cycle Cost) reduction, including the workability of cleaning and filter replacement for the prevention of reduced cooling or heating power due to contamination of heat exchangers from dust and dirt inside and outside the rolling stock as well as consideration of the requirement for periodic replacement of the bearings in the sliding parts.

Refrigerant as heat-carrying medium in the refrigerant circuit is required (1) to be free from toxicity, (2) to be nonflammable, (3) to be high in heat-carrying efficiency, and (4) to be a stable substance. CFC (chlorofluorocarbon) R12 or HCFC (hydrofluorocarbon) R22 has been used as a refrigerant satisfying the requirements listed above. However, since the chlorine atom contained in such a refrigerant destroys the ozone layer and increases harmful UV or the like in the air, the use of such materials has been regulated in compliance with the Vienna Convention for the Protection of the Ozone Layer in 1985 and the Montreal Protocol on Ozone-Depleting Substances in 1987. Actually, HCFC (R22) was excluded from the regulated substances in the Montreal Protocol and has been used as the main refrigerant of air conditioning systems on rolling stock since its ozone destruction coefficient is considered low due to the hydrogen atom it contains compared to CFC (R12). However, the convention of contracting parties to the Copenhagen Conference in 1992 accepted the proposal for stricter control of the chlorofluorocarbon and determined to ban new production of the HCFC from 1996, reducing it step-by-step. Then, in 1995, at the conference of the contracting parties to Vienna Convention, ban of production of the HCFC from 2020 was determined ahead of the original plan. It must be noted that R22 was banned from production, however, the use itself has not yet been prohibited; air conditioning equipment produced in the past is still permitted to use R22 as refrigerant.

1.2 Air conditioning control technology

Needs for air conditioning of rolling stock are diversified; for example, Shinkansen bullet trains and long-distance express trains demand for fine air conditioning control patterns for passengers' comfort over a long traveling time, while commuter trains need air conditioning control systems that respond quickly to changing heat load caused by door opening/closing operation as well as passengers getting on and off the trains. This chapter introduces such recent technologies as (1) through-the-year full automatic control, (2) air conditioning control using fuzzy inference, (3) object-oriented control program, etc.

Fig. 1 shows the air conditioning control relationship diagram. Optimum control is implemented by using types of information obtained from rolling stock as shown in the figure.

(1) Through-the-year full auto control

This technique controls cooling, ventilation, heating, and the like automatically for increased labor saving and provision of comfortable space on the train. The control system employs a calendar function that takes inside and outside temperatures, passengers' clothing patterns for seasons into consideration and realizes optimum air conditioning including intermediate seasons between summer and winter.

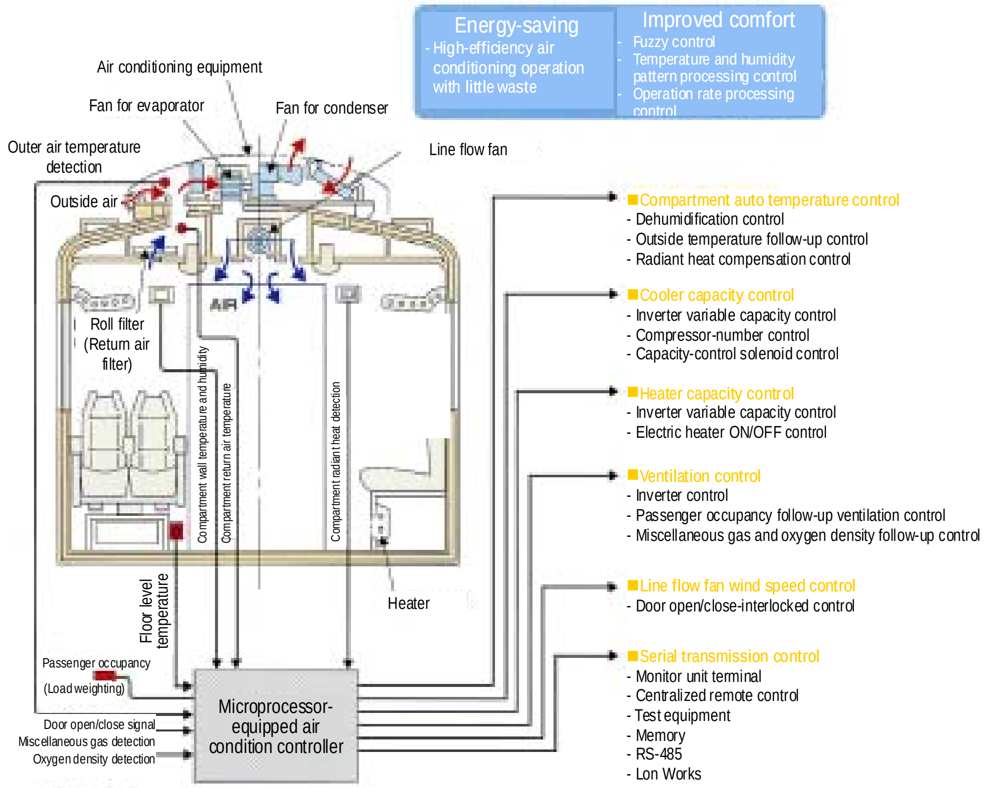
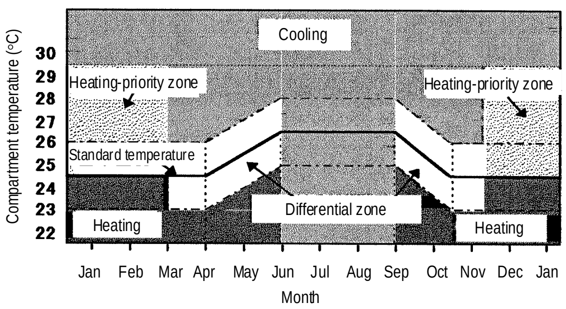
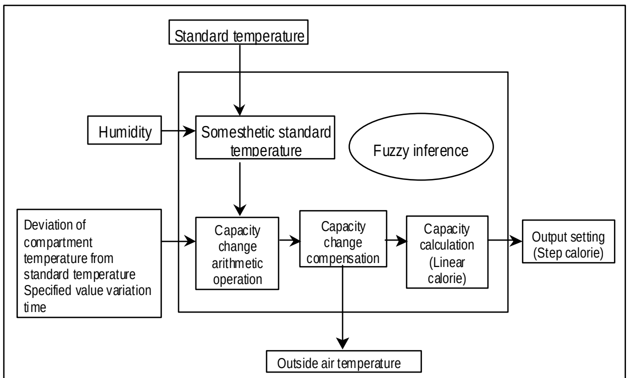


Fig. 1 Air Conditioning Control Relationship Diagram



<<Full-automatic air conditioning mode selection>>



<< Fuzzy inference flow >>

(2) Air conditioning control using fuzzy inference

This technique controls air conditioning equipment in accordance with the air conditioning capacity determined based on fuzzy arithmetic operation. By fuzzy arithmetic, the air conditioning capacity actually required at the moment is calculated (linear calorie). The air conditioning equipment operates under the operation conditions (step calorie) that provide the capacity closest to the calculated cooling capacity. Practically, the refrigerant circuit, components, inverters, and the like are actuated in accordance with the instructions based on the arithmetic above and sensors that work under accurate somesthetic conditions are used for highly responsive compartment environment control.

(3) Object-oriented control program

As the types of on-train air conditioning units on the market increased in number, the control programs used for air conditioning units also increased and become much more diversified, requiring greater time for completion of the programs. Mitsubishi Electric employs an object development technique for programming such software and has also constructed object-oriented development environment for C language for the development of embedded software. In addition, Mitsubishi Electric has formed coding regulations so that object-oriented programming of increased simplicity and reliability can be made in C language. Mitsubishi Electric has also developed macros to support programming in accordance with the coding protocol. Furthermore, Mitsubishi Electric has developed a tool to produce C-language program codes from design models in UML (Unified Modeling Language) for improved workability. As a result, complete object-oriented development from analysis and design to implementation has become possible.

2. Air Conditioning Systems Installed on Trains in Foreign Projects

Air conditioning systems installed on the rolling stock in Europe and America, in particular, lag about 30 years behind the current level in Japan. Although railways systems were first developed in Europe, air conditioning systems on the rolling stock are not as advanced as those in Japan due to the comparatively cool dry weather in Europe. European railway companies have been using large, heavy air conditioning equipment with open-type compressors or semi-hermetic compressors, with periodical overhauling and servicing. With the inroads of Japanese manufacturers into the markets, lead by Mitsubishi Electric Corporation, fully-hermetic compressor systems have been gradually accepted, though they remain far from mainstream.

Mitsubishi Electric has supplied 1500 air conditioning units for New Generation Cars (R142Apj and R143Pj) used in New York's subways since 1999. The improved comfort in the trains has won a good reputation among Manhattan commuters. In the air conditioning systems of New York's subways, two units of the model that employs fully-hermetic horizontal scroll compressor, inverter with a built-in air conditioning unit, and 32-bit microprocessor control system, which are state-of-the-art units also in Japan, are installed per subway car. The units are of thin embedded type installed in the ceiling, which are very different from the conventional units in the U.S. of split type consisting of an inside unit (evaporator and blower unit) installed from the inside of the car and an outside unit (condenser and compressor unit) located under the floor. Mitsubishi Electric's units are packaged into integrated units, easy to install and detach to and from the rooftop position, and are maintenance free, all of which are innovative features in the North American market. The New York City authority reacted skeptically in the initial stage of the business negotiation. But now that they fully recognize the advanced features of the system, Mitsubishi Electric has received orders for R160Pj (for a total of 1700 subway cars).

As for foreign markets, the levels of the technology prevailing in the markets are lower than those available in Japan. The specifications applicable to the foreign market can be selected from technical menus designed for the Japanese market. Along with initiative and strong endeavor, Mitsubishi Electric is in a strong position to lead foreign markets

For foreign projects, including the New York subway project discussed above, Mitsubishi Electric have received orders for a total of seven separate projects: GM-made locomotives in North America, Wuhan LRT in China, Manila LRT in the Philippines, Athens LRT in Greece, and OSCar in Australia.

3. Conclusion

More than 100,000 units of Mitsubishi Electric's on-train air conditioning systems have been shipped in and out of the country since 1950 when the company started production of the systems. These air conditioning systems have provided users with amenity space in rolling stock and contributed to improving customer satisfaction. In Japan, its air conditioning systems have maintained the highest market share at about 65%; the systems are installed on rolling stock throughout Japan, from Shinkansen bullet trains to streetcars. As the need for even more comfort grows, Mitsubishi Electric is ready to accumulate the related technologies to meet such market needs and continue to lead the industry.

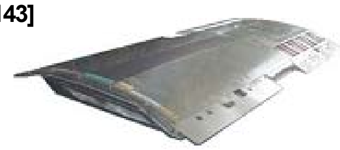
<Air conditioning system for New York's subways>

(Rolling stock and unit)

Rolling stock	R142A	R143
Unit model	EU72	EU73
Capacity	20.3kW	26.75kW

[R142A]

[R143]



Current Status and Future Prospects of Train Operation Information Control System and Train Depot Management System

Authors: *Hidetoshi Honma* * and *Toshishige Nagao* *

Three objectives in the improvement of train depot operation are: (1) Data integration between systems, (2) Preventive maintenance using data, and (3) Field-work support through automation of inspection and measurement. This paper introduces four core systems to realize the three objectives above: (a) Remote Monitoring System, (b) Train Maintenance Management System, (c) Depot Management System, and (d) Maintenance Work Modernization System (note: we will abbreviate the collective term of Inspection and Management Equipment and Facilitates for Maintenance Work Modernization like this).

1. Present Status of Train Depot

At train depots, periodical train maintenance operations are conducted to maintain the specified performance and functions of trains for safe, efficient, and comfortable train operation. From 1990, elimination of dangerous, hard, and dirty tasks from inspection work fields, enhancement of working efficiency, reduction of general costs in depot operation have been the focus of attention as key issues related to train depots. Mitsubishi Electric has worked hard and aggressively to solve these problems.

The first one of our solutions for problems related to fieldwork is the use of test equipment for such onboard equipment, including electric motor, controller, ATC, and the like. Mitsubishi Electric has delivered a large number of test units since 1980s and successfully merchandized test units that are compatible with most onboard equipment.

The second solution is the use of a group of devices that automate measurement and inspection work under the floor or on the rooftop of rolling stock by making use of sensing technology: laser, ultrasonic wave, and image processing. For example, equipment for pantograph contact wear measurement, wheel profile measurement, and axle-flaw detection have been introduced to train depots where rolling stock inspection is conducted, with the result that fieldwork efficiency has been remarkably improved.

For labor-intensive work at train depots, Mitsubishi Electric has provided depots with train operation allocation planning system and train depot work planning systems to automate each task and has also introduced train maintenance management systems that control the rolling stock and equipment ledger, train maintenance data, train maintenance plan in the form of a database.

As mentioned above, types of fieldwork have been subjected to improvements by automating them to eliminate dangerous, hard, and dirty tasks and enhance working efficiency, with individual systems employed independently. Since these systems are not open for the data to be utilized commonly, their functions are limited to each systems application range. Based on its considerable experience in this field, Mitsubishi Electric has developed a solution program, for data integration and utilization, on the basis of four types of technologies: (1) Data integration between systems using real-time information transmission technology, (2) Diagnosis and trouble prevention using data mining technology, (3) Automation by using an expert-inference technology for the work currently depending on veterans' skill, (4) Introduction of work support (maintenance work modernization) using inspection and measurement devices based on sensing technologies and fieldwork automation devices.

2. Fieldwork at Train Depot and Proposed Systems

Fig. 1 shows a train depot represented with respect to the fieldwork. The chain double-dashed lines indicate the scope of fieldwork at the train depot; the related resources out of the depot include the trains traveling on the railways and the train operation command and control center. The solid lines frame each fieldwork, while the arrows indicate data flow. Mitsubishi Electric proposes a system to integrate the entire train depot based on four key elements, which include the three systems shown in the figure: Remote Monitoring System (RMS), Train Maintenance Management System (MMS) and Depot Management System (DMS) and an approach of maintenance work modernization. The key functions of the proposed system are (1) A function to obtain train information from trains in operation in real

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time to support recovery from failures, (2) A function to take statistics and analyze the maintenance data or train information, (3) Automation or support of points operation work through the data integration or data sharing between types of fieldwork, and (4) Support for such work as measurement and input in the inspection to maintain rolling stock.

3. Remote Monitoring System (RMS)

The purpose of this system is enabling a train crewman, an operation dispatcher in operational control center (OCC), and a maintenance attendant in train depot to have the common information by obtaining the performance status data and failure data collected by an on-board Train Information Management System (TIMS) through the data transmission between every trains in-operation and on-ground facilities, and

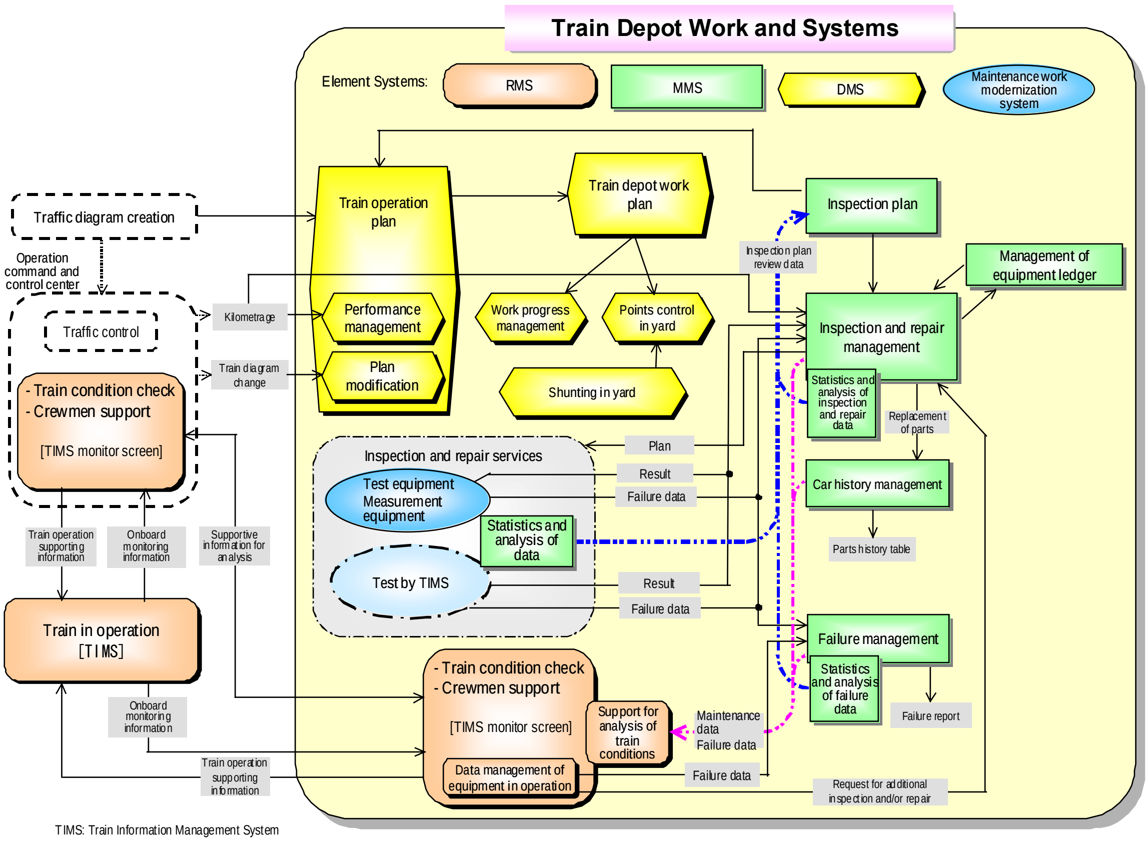


Fig. 1

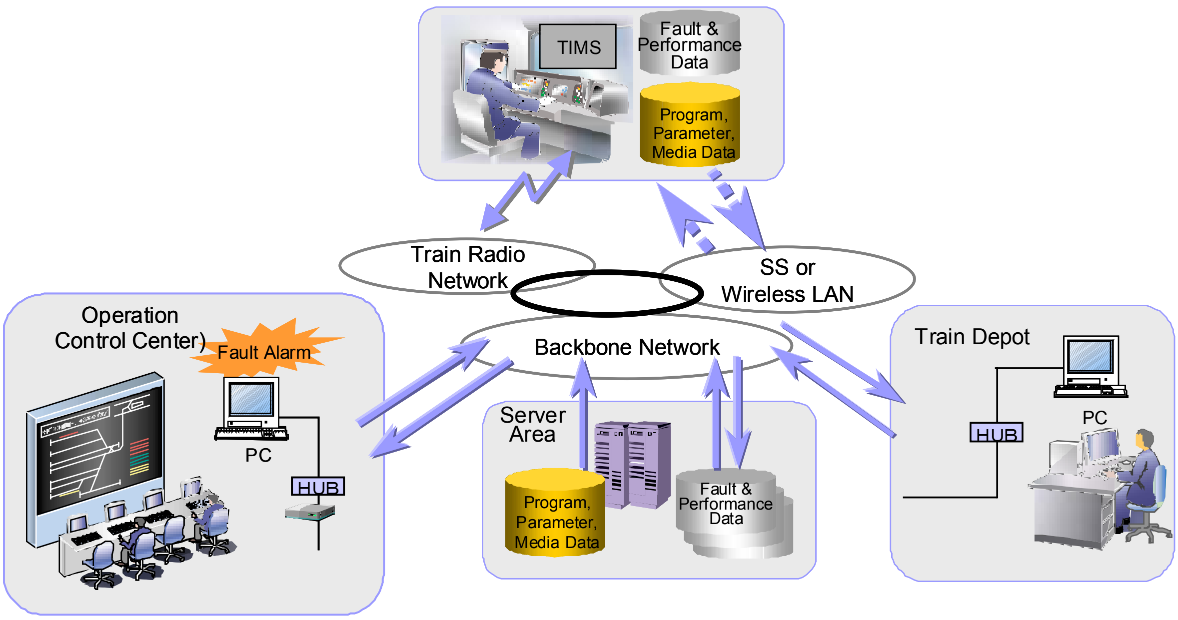


Fig.2

contributing on early prevention of disturbance on an operation schedule and quick recovery from failures. Fig. 2 shows the outline of the system. The following are the main Function of the system.

(1) Operation dispatchers in Operation Control Center (OCC), depot maintenance attendants and train crewmen share the same information monitored by TIMS, the OCC, depot maintenance attendants and train crewmen are also connected through Train Radio Network in case of failure and provide for recovery while communicating with each other.
(2) The ground facilities monitor the operating conditions of trains and equipment in operation to detect abnormal conditions and prevent failures from occurring.
(3) The system has an information linkage with the train maintenance database installed in Server Area and makes the database save data in cases where abnormal operation is detected.
(4) The collection of the performance status data out of a train in operation dynamically enables the inspection intervals to be extended and inspection items to be shortened and will bring cost reduction for maintenance because of its continuous and real-time diagnosis.

As for Functions (3) and (4) above, Mitsubishi Electric are developing the functions to realize preventive maintenance function including automatic diagnosis of train conditions and failure prediction by utilizing new and accumulated data.

With the system completely developed, it will be possible for us to predict the service life or replacement periods of equipment by comparing the TIMS information on the conditions of trains (such as voltage, current, acceleration, travel distance, controlled variable of brake, pressure, temperature, number of switching operations, etc.) with the design standard values or analyzing the correlation between the accumulated values of each item and occurrence of failures in the past. Our future challenges include installation of sensors that detect events closely related to failures such as smell and vibrations, in addition to the standard TIMS installed on trains.

4. Train Maintenance Management System (MMS)

MMS shares maintenance data at depots and factories, including management of ledgers of trains and equipment, management of inspection and repair plans, and management of history ledgers, and controls such data in the form of integrated charts. Maintenance data are automatically collected online from the automated test equipment and measurement equipment as measurement data.

Similar systems have been operated with a specially designed program on a client-server basis. The current systems employ Web technologies and a template for the database. Display and edit functions using a general-purpose Web browser are provided to the client, allowing the users to view and enter data at any time when connected to the network no matter where they are, thus securing the flexibility of system operation. The system also features an advantageous function that remodels the system by modification procedures performed on the Web server side only. With the server database using a template method, users can easily add or change the types of trains and equipment managed.

Fieldwork has many tasks that require manual data entry. The following methods are provided for supporting data entry work and easy digitization of related information.

(1) Data entry with portable terminals
(2) Recognition of handwritten characters
(3) Voice input system (Actual device application is under development.)

The main purpose of the conventional system was to manage the maintenance data; today it is important to analyze accumulated data for preventive maintenance, including planning the replacement periods of consumable parts, predicting failures, analyzing the causes of failures and taking measures as necessary. Mitsubishi Electric has been developing technologies related to processing, extracting, and analyzing the maintenance data and train monitoring data in the database.

5. Depot Management System (DMS)

This system is an integrated system to manage all types of operations related to train operation in the train depots and consists mainly of rolling stock operation allocation planning system and train depot work planning system; the system includes PRC (programmed route control in depot), Rolling Stock Position in Depot Display function, and work progress management function. This system manages depot work planning and signal control to improved efficiency as listed below.

(1) Saving of the work for scheduling of rolling stock movement in depot with the machine-support
(2) Removal of the signaling operator by PRC to control the route for rolling stock movement inside depot
(3) Quick response to disruptions or changes in main line schedule
(4) Immediate reflection of work progress in the depot-to-depot work schedule
(5) Work saving in communication and confirmation

procedures by work progress monitoring operation

6. Maintenance Work Modernization System

As mentioned above, Mitsubishi Electric has developed and commercialized systems for automatically measuring the conditions in the field where dangerous, hard, and dirty tasks were inevitable and for reducing the workload of maintenance operators. Table 1 shows the examples of such systems developed so far.

Since the latter half of 1990s, Mitsubishi Electric has commercialized automatic measurement systems for underfloor and rooftop equipment using non-contact sensing technology. With the pantograph contact wear measuring system (Fig. 3) and wheel profile measuring system (Fig. 4) in particular, measurement of high accuracy up to ±0.5 mm has been realized, with the result that Mitsubishi Electric have received many orders for the system.

Automatic measurement systems play an important role as a solution to the problem of handing down maintenance techniques to younger generations, due to the aging society and reduction of manpower, because the systems always yield stable measurement results without depending on personal skills. The systems of our recent development include environment-friendly paint peelers in conjunction with train body maintenance.

Train depots vary greatly in scale, configuration, contents of work; Mitsubishi Electric aim to propose and develop optimum systems to meet train depots of the future.

Table 1 Inspection and Measurement Systems and Facilities for Maintenance Modernization

* Under development

Train test	Onboard device testing equipment	Automatic testers for ATC, brakes, propulsion equipment, and drive units
Automatic inspection of underfloor and rooftop systems	Pantograph contact measuring system	The thickness or abnormal wear of pantograph contacts are measured by the ultrasonic method and image processing method.
	Monitoring system for rail car roof-tops	Still pictures of the pantographs and AC devices and the moving images of the entire roof-top condition are recorded.
	Wheel profile measuring system	Dimensions of different sections of a wheel are measured by laser and camera.
	Brake wear measurement unit	Dimensions of the brake shoe and brake lining are measured by a camera and their replacement periods are estimated.
	Wheel flat detection device	Flats on the wheel treads are detected by acoustic sensors and camera images
	Axle flaw auto detector	Flaws in axles are automatically detected by ultrasonic echo analysis.
Train body maintenance	Paint peeler	High-pressure water is used to peel off the paint, instead of solvent which has a higher environmental impact.
	Train body dirt auto detector *	The degree of dirt accumulated on the surface of a train body is judged by the image processing technique for improved efficiency of the following chemical cleaning process.
	Blower for underfloor equipment *	Airblowing of underfloor devices is automatically performed.
Training and education	Simulator for malfunction recovery training	Procedures for countermeasures taken by a railway employee in the event of problems during train operation are outlined on a PC.

Fig. 3

Fig. 4

Emerging Technologies for Train System

Author: *Kiyotoshi Komaya* *

1. Summary

Mitsubishi Electric's scope of R&D for railway system ranges widely from power electronics to information and communications technologies. This paper discusses the state-of-the-art achievements of Mitsubishi Electric's R&D efforts: train wind-cooled dry panel, speed-sensorless vector control system for induction motors, train-ground data transmission technology, and software development technology for Train Integrated Management System (TIMS).

2. Cooling technology for train propulsion control system

The cooling system for IGBT (Insulated Gate Bipolar Transistor)/IPM (Intelligent Power Module) for train propulsion control systems has changed from the conventional forced-air cooling/refrigerant system to dry panel system that utilizes train wind.

Train wind-cooled dry panels have fins that are exposed to the exterior space, with the result that the air once accommodated between the fins leaks out of the fins to conflict with conventional forced-air cooling design. In addition, in order to downsize the cooling system, it is necessary to secure fin design parameters that are compatible with efficient use of train wind. Mitsubishi Electric developed the three-dimensional computer simulation method to calculate the distribution of surface temperatures on a dry panel based fluid dynamics and to design a high-efficiency dry panel that is suitable for the running conditions. Furthermore, Mitsubishi Electric manufactured a wind tunnel that imitates train wind (Fig. 1) for comparison and evaluation of the data with respect to the results of three-dimensional computed fluid dynamics simulation. The wind tunnel has the following characteristics.

(1) The suction wind tunnel is not subjected to the influence of air disturbance caused by the blower.
(2) Stabilized air flow is realized with a sufficient entrance region.
(3) The maximum operating speed of the wind tunnel is about 100 km/h, which is the highest level in the industry.

As shown in Fig. 2, the errors between the simulation results and wind tunnel measurements are within plus or minus 10%, proving a high degree of accuracy.

As a result of evaluation of a dry panel designed using three-dimensional computed fluid dynamics simulation in the train wind tunnel, the heat resistance was reduced to a level 0.48 times the conventional level. This achievement was applied to the products delivered to Hong Kong and India; the use of dry panels will rapidly increase in the future.

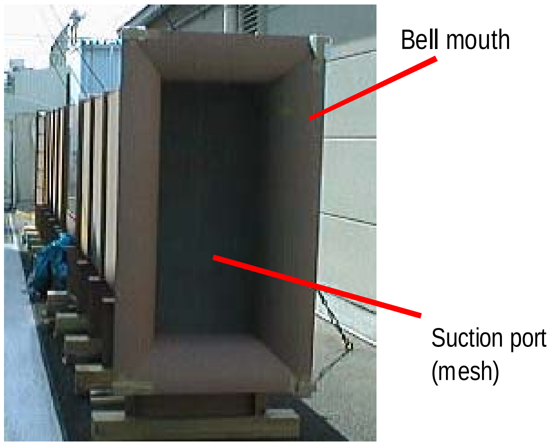


Fig. 1 Appearance of Train Wind Tunnel

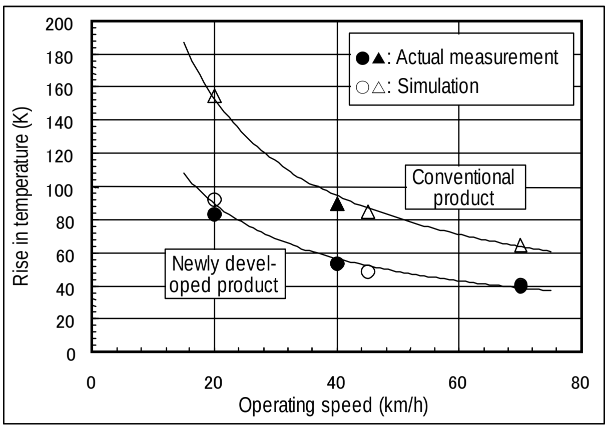


Fig. 2 Comparison between Simulation Results and Actual Measurements of Dry Panel Surface Temperatures

* *Advanced Technology R&D Center*

3. Speed-sensorless vector control system

Mitsubishi Electric developed a speed-sensorless vector control system that estimates train speed from the voltage and current signals of the induction motor. This system, using Mitsubishi Electric's original algorithm based on the modern control theory, realizes the stability of speed estimation in the wide range of train speed and the high responsivity of speed estimation for anti-slip and re-adhesion control. Figure 3 (a) shows the estimation results of train speed conducted with a mini model tester, when increasing the load torque level with keeping the operation speed at a fixed level. The horizontal axis indicates the estimated speeds, while the vertical axis represents the torque levels. In general, speed estimation operation becomes unstable at low-speed and regeneration ranges where the frequency applied to the induction motor becomes zero. However, we propose a new speed estimation method which optimizes the transfer characteristics of speed estimation operation based on modern control theory; the unstable range mentioned above is remarkably reduced compared to the conventional method. Figure 3 (b) shows the responsivity to speed estimation in accordance with the proposed method. This figure shows the estimated speed and the current estimation error, when the actual speed is changed from an electrical angle of 6 Hz to 7 Hz stepwise. The proposed method makes it possible to design the response characteristics quantitatively without depending on trial-and-error steps. This example represents that the estimated speed responds in good agreement with the response design values, 200 (rad/sec).

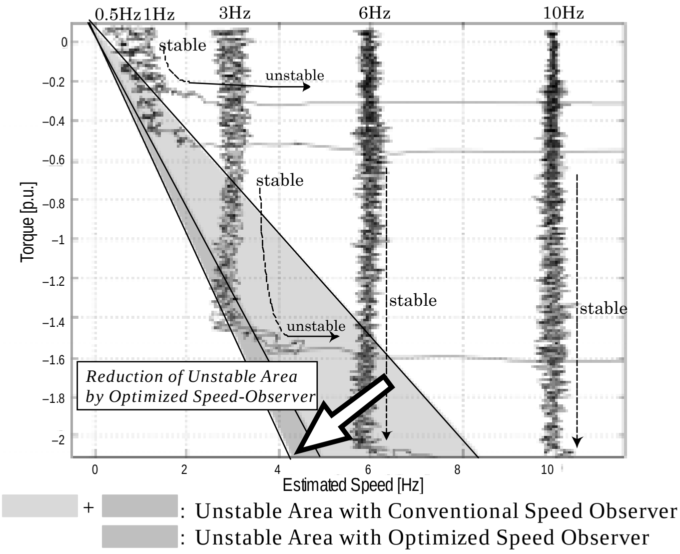
With this method employed, all the speed sensors, which are installed as many as the motors in a train formation, are unnecessary, and it leads to dramatically improve the reliability, maintainability, and customer satisfaction. This method has been applied to many products in actual rolling stock, and they have been used long-term commercial operation without any problems.

4. Train-Ground Data Transmission Technology

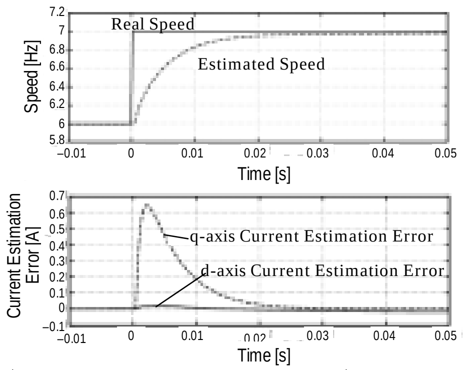
Train-ground data transmission is indispensable for securing safety and maintaining efficient operation of railway system. This chapter discusses high-performance data transmission technology using state-of-the-art transponders.

4.1 Data transmission technology using transponder

A transponder consists of a reader called a "pick-up coil" installed on the train car and a tag called a "beacon" installed on the railway track. When a train with a pick-up coil passes over a beacon installed between stations, the pick-up coil reads the data stored in the beacon, such as the speed limit in the section, position, curvature of a curve, etc. Beacons installed between stations are not equipped with a power supply unit, the pick-up coil has to not only read data but also supply power to the beacon. Beacons installed in station yards are designed to not only provide data to pick-up coils but also detect the stop positions of trains and interlock with the door control system on the platform. The following are the latest achievements of technologies related to beacons without power supply and beacons with power supply.



(a) Effect of Optimal Observer Design (Mini-model Test)



(b) Speed Estimation Response (Simulation Results)

Fig. 3 Stability and Responsivity of Speed Estimation Method

4.2 Beacons without power supply

Mitsubishi Electric developed a beacon without power supply for the maximum operating speed of 160 km/h and a communication rate of 1 Mbps for accurate data reading when the beacon is used for express trains. The time required for a train running at a speed of 160 km/h over a beacon (an object of about 20 cm per side) is about 5 msec. In consideration of this fact, Mitsubishi Electric developed a low-power consumption beacon that has a high-speed starting up circuit and a transmission circuit based on a backscatter method, so that power supply is accomplished in a short time to activate the circuit of the beacon for data transmission. In the backscatter method, microwaves sent from the pick-up coil are directly reflected or reflected by inverting the phase, depending on the beacon data (0 or 1). Since the transistors are used to build the circuit, only about 1 mA of current is required for operation.

4.3 Beacons with power supply

Since the beacon installed in station yards can be equipped with power supply, Mitsubishi Electric mounted a CPU on the beacons to serve also as a train stop-position detection device. For the detection of train stop-position, multiple coils are equipped in the beacon and signals generated when the beacon coils are activated by the pick-up coil are measured to detect the relative position of the pick-up coil with respect to the beacon coils. The accuracy for stop-position detection obtained with this method is a few centimeters.

4.4 Data transmission test

Mitsubishi Electric developed a trial model having the specifications listed in Table 1 and conducted data transmission tests. The same frame of data, configured 400 bits/frame, is repeatedly transmitted while receiving the power wave. Mitsubishi Electric conducted data transmission tests at a data rate of 1 Mbps with this experimental model. From this test results, it is estimated that about 5200 bits of data at an operation speed of 160 km/h.

Table 1 Main Specifications of Trial Model

Center frequency	260MHz
Output level of carrier	Weak radio wave
First modulation frequency	2.5MHz
Data rate	1Mbps
Distance between reader and tag	20cm
Carrier frequency for electric power	245kHz
Input level of coil for power	0.95W

5. Software Development Technology for TIMS

Information and communication technologies have been applied to various fields of railway system, and Mitsubishi Electric develops a wide spectrum of software products from on board train control system to large-scale rail traffic control system. Under such situation, improved productivity and reliability of software development are increasingly important for our business. This chapter discusses one of our achievements, automatic testing technology for TIMS.

Train Integrated Management System (TIMS) is a system designed to manage various equipments mounted on trains such as motors, brakes, air conditioners, doors, etc. Since TIMS is indispensable for safe and stable operation of trains, high reliability is required.

As the system scale of TIMS is extended, it causes another tough challenge that the number of patterns to be combined in software test increases enormously. Mitsubishi Electric developed an automatic testing system for TIMS (Fig. 4), which performs efficient and comprehensive testing and is effective in realizing high-quality software.

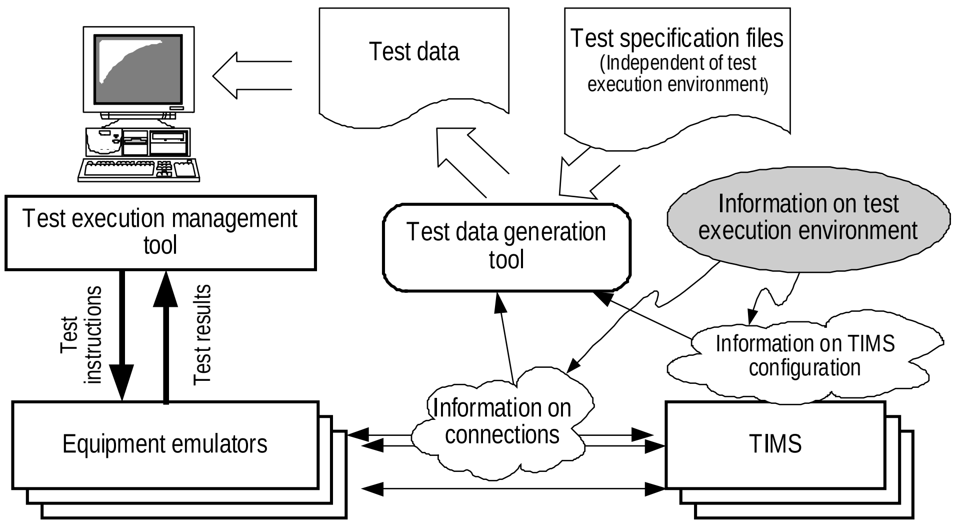


Fig. 4 Automatic Testing System for TIMS

The automatic testing system consists of equipment emulators that emulate various types of equipments managed by TIMS, a test execution management tool that controls the operation of equipment emulators, and the TIMS tested. The test execution management tool completes each test by (1) sending instructions to the equipment emulators for operation according to given test data, (2) obtaining the outputs of TIMS collected via the equipment emulators, and (3) judging test results by comparing the outputs with the expected values described in test data.

Mitsubishi Electric developed a test specifications description method for automatic testing. Using this method, it makes possible to describe test specifications independent of the test execution environment (configuration of TIMS tested and connections between TIMS tested and the equipment emulators). Thus test specifications can be described without regard to details of the test execution environment. Mitsubishi Electric developed the tool to collect information on the test execution environment prior to test execution and to generate test data from collected infromation and test specifications. With this method, the reusability of the test specifications is improved and efficiency in preparing test specifications other than test execution is increased.)

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