Versatile, Environmentally-friendly, and Comfortable Railway Systems

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OVERVIEW: As people have become more aware of global warming and other environmental threats, the importance of railways as an environmentally-friendly mode of transportation has increased. Besides these environmental challenges, Japan is also faced with a worrisome demographic dilemma of a declining birthrate coupled with a growing elderly population. The development of more environmentally-friendly technologies is certainly a high priority. At the same time, rail systems must be continually enhanced and upgraded in ways that make trains the transportation mode of choice for a large segment of the population, so the role and contribution of railway systems in society continue to grow. If more people ride trains even as the current demographic trends continue to play out, that will effectively reduce the energy consumption associated with transportation. This calls for constant enhancement of safer and more stable transportation through ongoing technological development, as well as efforts to improve the quality of train travel — making services smoother and more comfortable, providing timely information services, and so on.

VERSATILE RAILWAY SYSTEMS

BEGINNING in 1920 with the development of steam locomotives, Hitachi's transportation system operations expanded into diverse transportation related areas and now involve extensive research and development as a comprehensive system integrator. As society evolves, the technologies required by railway systems also undergo change, and here we will

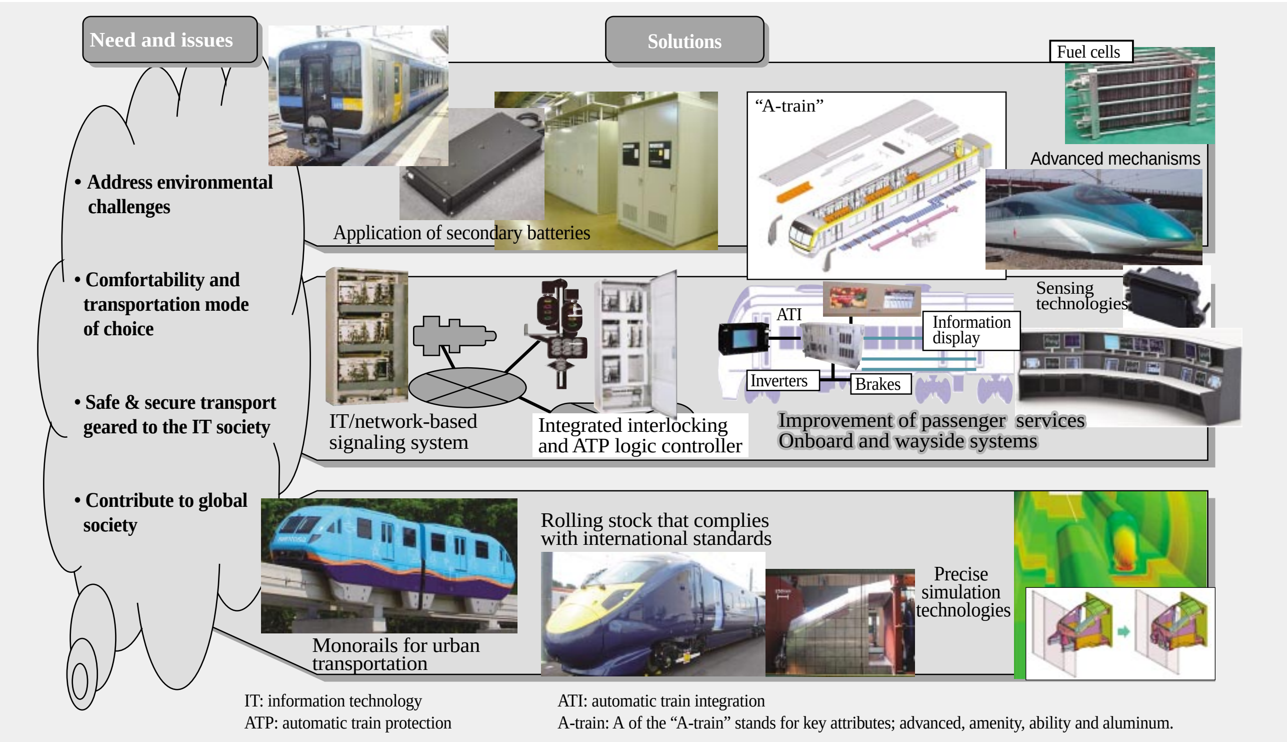

Fig. 1—Hitachi's Total Solution System Addresses Diverse Needs.
Committed to making the railway the transportation mode of choice for a large segment of the population, Hitachi is a leader in the development of environmentally benign, safe, and comfortable railway systems.

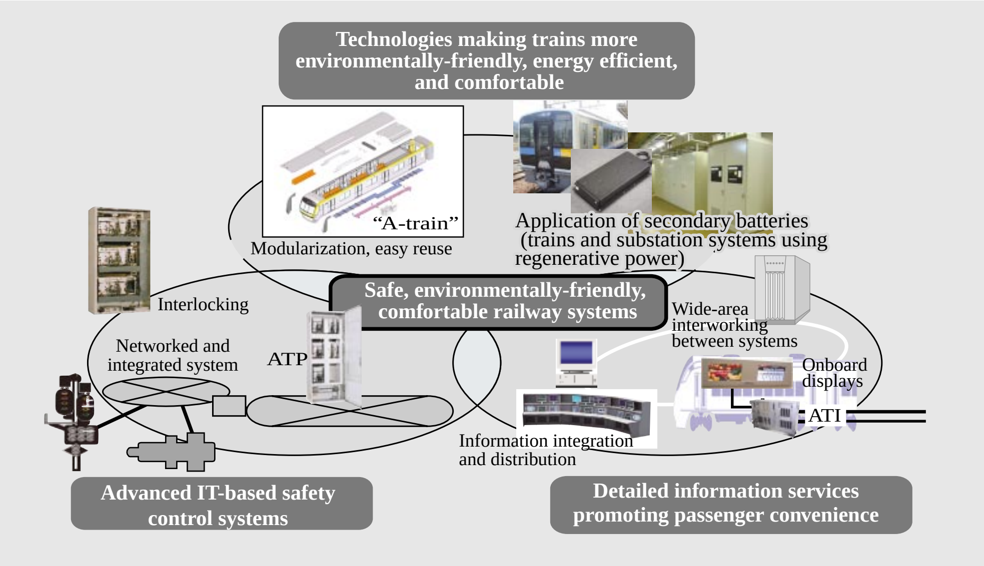

Fig. 2—Development of Basic Solutions for Next-generation Rail Systems.
Hitachi redoubles efforts to address environmental challenges and attract more people to rail transport.

highlight some of Hitachi's recent solutions shown in Fig. 1 that have made railway systems more versatile.

(1) Car bodies and substation systems

Provisioning of very high quality coach interiors based on the A-train concept — the "A" stands for *advanced*, *amenity*, *ability* and *aluminum*. Development of energy saving drive technologies using secondary batteries in onboard equipment and wayside substations, highly efficient inverters, and other systems.

(2) Signaling systems

Development of ATP (automatic train protection) systems enabling trains to operate and run autonomously using advanced IT (information technology), and interlocking systems that are based on a network technology while sharply reducing the cabling needed to connect controllers, points, and signals.

(3) Passenger and transportation control systems

Providing timely information and integrating systems to improve passenger convenience (see Fig. 2).

Through these initiatives, we are doing our best to realize a railway system that continues to attract more people and is also environmentally benign. The technologies cultivated through these developments are also closely geared to the needs of the world at large and we will also contribute to improvement of world wide railway systems.

REDUCTION OF ENVIRONMENTAL IMPACT

Environmentally-friendly Railways

Since the depletion of fossil fuels and need to combat global warming have now become a clear global imperative, we must reduce our energy consumption and carbon emissions — not just to operate and run systems, but throughout the entire product cycle from manufacture and maintenance to eventual decommissioning. Environmental concerns have motivated many railway technology projects to suppress noise along high-speed and dense rail lines, to improve interior comfort of coaches, and to save energy. Specifically, these demands have led to the development of better aerodynamic designs, low-noise cooling solutions, achieving lighter trains without sacrificing structural strength, developing more efficient drive systems, and many other initiatives.

Environmentally-friendly Trains

For the Shinkansen, Hitachi has developed new technologies for suppressing increased noise caused by high-speed running for two test trains in collaborations with East Japan Railway Company (JR East) shown in Fig. 3: E954 and E955. The two trains

Fig. 3—East Japan Railway Company's E954 Shinkansen Test Train on the Left, and Tokyo Metro's 10000 Series Commuter Train on the Right.
The Shinkansen train was designed to suppress noise when running at high speed, and the commuter train was designed to facilitate material sorting and recycling when decommissioned.

Fig. 4—JR East's Kiha E200 Series Diesel Railcars.
The Li-ion battery assisted hybrid drive system was developed in collaboration with JR East.

Fig. 5—Regenerative Energy Absorbing Equipment Using Batteries.
Installed in substations along the wayside, the regenerative energy absorbing equipment using batteries stabilizes supply voltages and improve regenerative efficiencies.

are being used to evaluate technologies of suppressing micro-pressure waves in tunnels, cooling for controllers to utilize air flow caused by running wind, and improving sound insulation quality to suppress interior noise.

And for commuter trains such as the 10000 series cars of the Tokyo Metro Co., Ltd. shown on the right in Fig. 3, we have taken the original A-train concept even further by specifying a common type of aluminum alloy for pillars, beams, and other key structural elements in addition to the double-skin body structure, which facilitates sorting and recycling when cars are eventually decommissioned.

Systems Employing Secondary Batteries

Electrified railways have a benign impact on the environment compared with other modes of mass land transport. Especially with the recent emergence of inverter control systems that use regenerative electric power, train drive systems have become remarkably energy efficient.

Leveraging inverter technology developed for electric railways, Hitachi has developed a practical hybrid drive system using rechargeable lithium-ion batteries that greatly reduces the impact of diesel rail cars on the environment. Begun as a collaborative research project with JR East in 2001, this system achieves a greatly reduced impact on the environment (in terms of both operation and maintenance of trains) through efficient use of regenerative electric power, more efficient operation of the engine, and application of an electric drive system, and as illustrated in Fig. 4, was put into commercial service in July 2007.

We have also achieved stabler and easier maintenance operation of electric trains by installing secondary battery systems onboard that enable trains to continue running even during power outages and continue to generate energy when loads are light.

Fig. 5 shows a regenerative energy absorbing system using batteries in a substation that was developed by Hitachi. The system stores the regenerative electric power generated by a train group, then supplies the energy later during peak periods. Implementation of the system will stabilize supply voltages, improve regenerative efficiency, stabilize brake performance, and conserve energy.

SIMPLER INTELLIGENT SIGNALING SYSTEMS

Network-based Signal Control Systems

Conventional railway signaling systems employ a large number of cables connecting interlocking machine in equipment rooms with wayside signals, and deploying and maintaining these cables was extremely burdensome. We have now come up with a much simpler solution by leveraging general-purpose network technology and replacing a lot of signal cables between interlocks and wayside equipment with a few

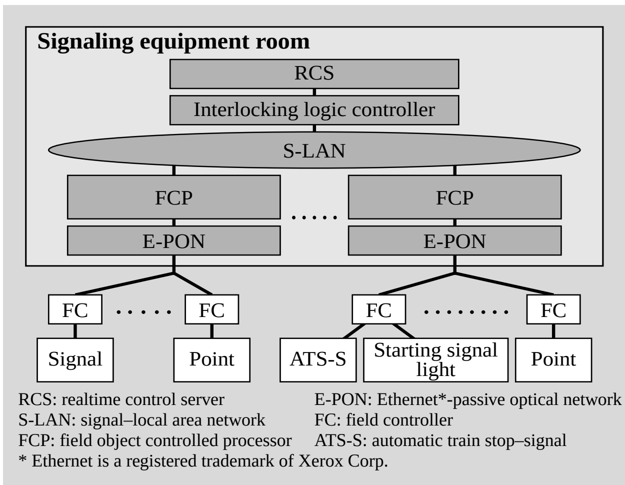

Fig. 6—Network Signaling System.
Deployment and maintenance of signaling systems have been greatly streamlined by adopting general-purpose networking and simpler technologies.

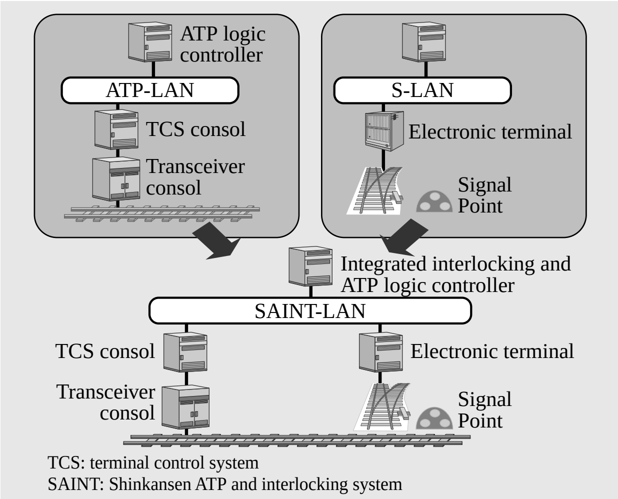

Fig. 7—Integrated Signaling System "SAINT."
SAINT is a signaling system developed by integrating a computerized interlocking system and an ATP system.

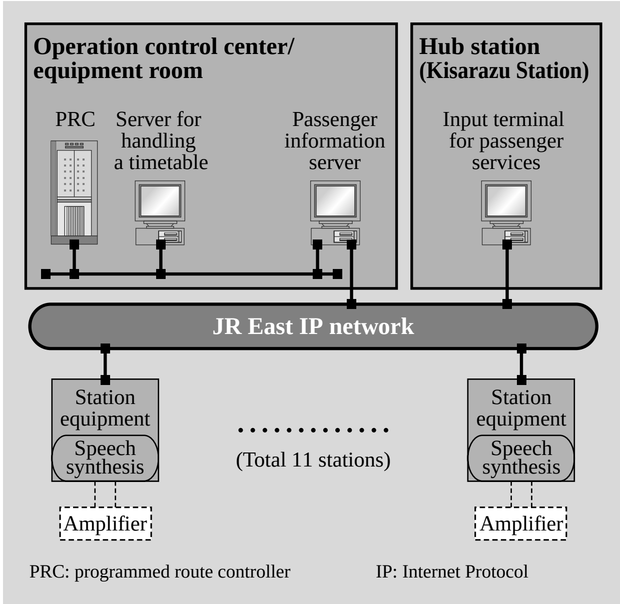

Fig. 8—Passenger Information System (System Deployed on JR East Uchibo Line).
Using speech synthesis technology to broadcast passenger information that is input in the form of text data, the system provides a far more flexible automatic audio system for broadcasting passenger information in train stations.

optical cables. More specifically, we have developed a compact FC (field controller) that easily fits into the control boxes of field equipment and a new communication protocol to send signaling information from the central control logic to FCs, thus permitting the changeover from copper to optical cable. Fig. 6 shows a schematic overview of the network signaling system.

Integrated Signaling System *"SAINT"*

Fig. 7 shows a schematic overview of SAINT (Shinkansen ATP and interlocking system), a signaling system developed by integrating a computerized interlocking system and an ATP system that were originally implemented as separate standalone systems. Developed specifically for the Shinkansen, the integrated SAINT signaling system is far simpler, has a smaller footprint, is more cost-effective than previous systems, and is now deployed on the Tohoku and Joetsu Shinkansen lines.

The history of SAINT signaling system began with the development of digital ATP featuring a fail-safe software technology and digital transmission. This was then combined with an advanced computerized interlocking system that was developed along the same lines with similar technologies as the ATP system.

CONTROL AND INFORMATION SYSTEM SUPPORTING RIDER COMFORT

Promoting Sharing of Information

Hitachi has decades of experience in developing both kinds of transportation control systems (centralized as well as autonomous decentralized systems) tailored to the needs of railway operating companies, and contributing to safer, more stable transportation. A major emphasis in recent years has been to eliminate redundant functions in multiple subsystems by organically integrating those systems, and improving reliability and maintainability through centralized management of various data. In addition, we have developed information services for timely provisioning of traffic information. For example, we have developed a far more flexible automatic audio system for broadcasting passenger information in train stations using speech synthesis technology to broadcast passenger information that is input in the form of text data (see Fig. 8).

Seamless Integration between Ground and Onboard Systems

Along with the recent rapid development of ubiquitous computer and networking technologies, we have suddenly seen the emergence of a greatly increased need for passengers to be able to individually access the information they need when they need it. Addressing these needs requires integration of mobile communications and other very recent technologies

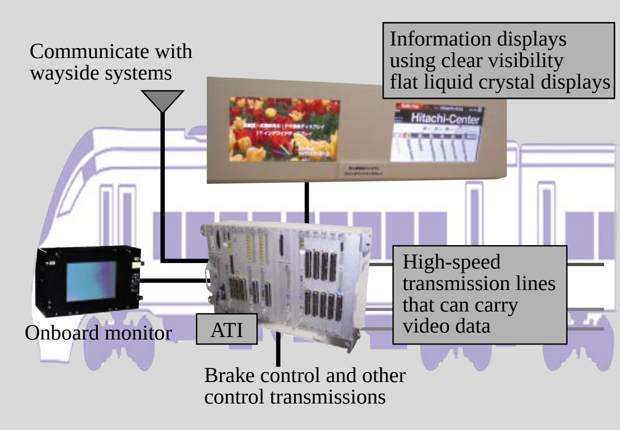

Fig. 9—ATI System.
In addition to improved onboard control, we are also seeking to provide enhanced passenger services.

with railway information control systems; services that provide information to cell phones, PDAs (personal digital assistants), and other kinds of personal terminals; and appropriate deployment of flat-screen monitors that have seen such remarkable market penetration and other kinds of information displays. Hitachi has developed a range of products designed to improve passenger services (see Fig. 9) that have already seen commercial deployment including systems to deliver content onboard trains over digital wireless links, and deliver and display content on trains using Hitachi's ATI (autonomous train integration) system.

Hitachi is committed to ongoing development in this area to further upgrade the functions and capabilities of these systems.

Transportation Systems to Meet Global Needs

As societies have become increasingly globalized, the contribution of Japan's advanced railway systems to the rest of the world is quite significant. As the leading manufacturer of straddle type monorail systems, Hitachi has constructed many of these systems throughout Japan. Based on this impressive record, Hitachi was chosen to build the Sentosa Express monorail system, the primary transportation link to Sentosa Island in Singapore. Key features of the monorail are its more compact, lighter weight cars connected by an articulated structure, and the streamlined signaling system that greatly simplifies the required wayside equipment. Fig. 10 shows a photograph of the Sentosa Express monorail, that has been running smoothly since it was first put into service in January 2007.

Fig. 10—Sentosa Express Monorail.
Providing the primary transportation link to Sentosa Island in Singapore, the monorail has been running smoothly since it was put into service in January 2007.

Fig. 11—Class 395 Series High-speed Railcars for the Channel Tunnel Rail Link in the UK Train.
The lightweight high-speed car bodies developed under the "A-train" concept are in full compliance with the UK's rolling stock standards.

Another recent international order came from England for Class 395 series cars that will serve commuters on the high-speed channel tunnel rail link, and a prototype six-car train was delivered to the UK in August 2007. Numerous advanced technologies developed and proven domestically in Japan are now being applied in Europe. The cars shipped to the UK satisfy collisional properties, material strength specifications, and a host of other conditions in addition to the strong, lightweight, high-speed car bodies developed under the A-train concept. Pictured in Fig. 11, the high-speed Class 395 cars have been developed using computer simulation and other advanced technologies researched and developed by Hitachi.

KEY TECHNOLOGIES SUPPORTING RAILWAY SYSTEM ADVANCES

Lithium-ion Batteries

(1) Anticipated benefits of battery technology

In relation to efficient energy usage, energy storage

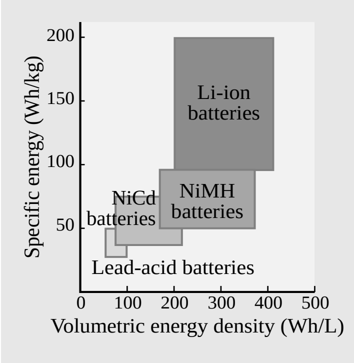

Fig. 12—Comparison of Secondary Battery Characteristics.
The energy density ratio of Li-ion batteries is superior to other kinds of batteries.

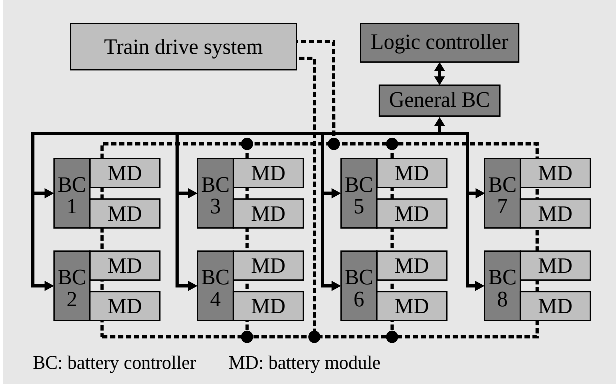

Fig. 13—Hybrid Drive System for Diesel Railcars.
Optimum control of the batteries is achieved using a controller to monitor the battery modules and the hybrid drive system as a whole.

technology is critically important. Amid many energy storage technologies that have been proposed, secondary batteries have significant advantages — few restrictions on size and where they can be located, and energy storage systems based on secondary batteries can be constructed relatively quickly. The widespread adoption of Lithium-ion batteries is thus a near certainty. Of course, that is not to say there is no room to improve existing batteries by extending their service life, reducing costs, and enhancing other characteristics.

(2) Lithium-ion batteries

Today there are four main types of secondary batteries being manufactured in the world: lead-acid batteries, NiCd (nickel-cadmium) batteries, NiMH (nickel-metal hydride) batteries, and Li-ion (lithium-ion) batteries. As one can see from the comparison of energy density (a measure of the storage capacity of batteries) in Fig. 12, Li-ion batteries perform far better than the other types. Note too that Li-ion batteries are still relatively new, so there is still much room for performance gains in the years ahead. Li-ion batteries have excellent properties: they have a very high single-cell voltage of 3-4 which accounts for their high energy density and efficiency, and it is expected that the lifetime of the batteries can be further extended.

(3) Applications of Li-ion batteries

Li-ion batteries have only been commercially available for 15 years, but have already captured the lion's share of the battery market in Japan and are next only to lead-acid batteries on a worldwide basis. This rapid penetration can be attributed to the proliferation of cell phones, personal computers, and other mobile electronic devices. This trend will continue in the years ahead. Applications are certainly not just confined to consumer electronics; Li-ion batteries are already starting to be used in hybrid electric vehicles, electric energy storage systems, and other industrial applications. Hitachi Group has focused on research and development of large-scale lithium-ion batteries since the beginning of the 1990s, has emerged as the global leader in lithium-ion batteries for electric vehicles, hybrid-electric vehicles, and electric scooters and motorbikes, and Hitachi lithium battery products are already being used in some vehicles that are on the market.

(4) Railway technology and Li-ion batteries

Li-ion batteries can be used to store the regenerative energy during braking by regenerative braking systems, and this energy can then be used by the train when it is stopped or running. The batteries are also expected to find many useful applications in diesel railcars to achieve quieter operation, cleaner emissions, and other beneficial effects.

The desirable properties of batteries for trains are essentially the same as those for hybrid electric automobiles, but railcars need much larger battery capacity to accelerate themselves than automobiles. This requires a monitoring and control system such as shown schematically in Fig. 13 in order to efficiently control a greater number of interconnected lithium batteries. We developed this battery storage and control technology for application to the hybrid drive system in diesel railcars.

(5) Future prospect of battery technology

Lithium-ion batteries are becoming increasingly indispensable, and will become even more reliable and cost-effective as the technology matures and finds more widespread applications. Meanwhile, other new battery technologies are being actively investigated that could exceed the performance of lithium batteries, and we are anticipating battery breakthroughs in the years ahead.

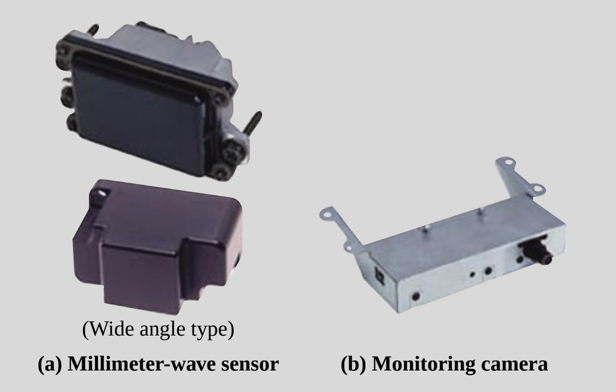

Fig. 14—Millimeter-wave Sensor for Automobiles (a), and Camera for Monitoring (b) .
Integrating sensors with different attributes enable more effective safety control systems.

Sensing Technologies

Automobiles, which have a greater degree-of-freedom than railcars, employ various sensors that support vehicle dynamics control and active safety systems (systems that invoke an action based on sensor signals in order to improve safety). Here we will briefly describe two sensing technologies that use millimeter-wave radar and cameras.

(1) Safety control technologies integrating millimeter-wave radar and cameras

Sensors featuring millimeter-wave radar have recently become commercially viable and are starting to be installed in some vehicles. Leveraging its expertise, Hitachi too has focused efforts on developing millimeter-wave radar systems. The primary functions of millimeter-wave radar are (a) detecting obstacles or other vehicles ahead by observing reflected waves of emitted millimeter-waves from the objects, (b) measuring the distance to the objects ahead based on the time it takes for return signals to be detected by the receiver, and (c) detecting the relative velocity of the objects by measuring the frequency shift of the reflected waves (Doppler shift). Recent radar systems can emit radio waves in various directions or scan in multiple directions in order to detect obstacles or other vehicles. As shown in the photo in Fig. 14, viable camera-based sensors for recognizing obstacles and vehicles ahead have also been developed.

Millimeter-wave radar provides precise distance and speed measurements but poor directional measurements, while cameras yield good directional measurements but poor distance and speed measurements. Since the two technologies have complementary strengths and weaknesses, we can obtain accurate measurements of distance, speed, and direction by combining the two kinds of sensors. Use of these capabilities to detect obstacles in the road or vehicles ahead have already been incorporated in collision avoidance technology for automobiles, and will be able to put to similar use in rail systems.

(2) Speed sensing technology and applications

By measuring the Doppler shift of reflected radio waves from the road surface, the speed of the vehicle can be measured without being affected by tire skidding. This so-called *"ground speed"* will be used in ABS (anti-lock brake system), VSC (vehicle stability control), and other vehicle dynamic control systems. In the activation of ABS and VSC there is considerable slipping and skidding between the tires and road surface, so the result of the conventional method of detecting speed based on tire rotation could be fairly inaccurate. Under these conditions, the true value of millimeter-wave-detected ground speed is clearly revealed.

(3) Application of sensor technologies to rail systems

Application of these same sensor technologies to railway systems will bring significant benefits: improved safety and security with the ability to detect obstacles on the track and trespassers where they are not supposed to be, the ability to drive at higher safe speed and more accurate automatic train operation systems based on improved detection of speed and position unaffected by slipping and skidding. Various other advances and improvements in sensing and analysis technologies are expected to result in more efficient maintenance operations as well.

Simulation Technologies

The areas in which simulation technologies contribute to product development are expanding thanks to increasing computational power of supercomputers and more sophisticated analysis techniques. Hitachi's railway division is also taking full advantage of the latest advances in simulation technology at the upstream design stage.

(1) Simulation-based analysis

Hitachi has a long R&D history of using simulation technology to analyze the crashworthiness of heavy electric machinery. The company has thus accumulated considerable expertise in simulating strength and deformation characteristics. Hitachi also uses simulation technologies for analyzing EMC (electromagnetic compatibility), cooling characteristics, and fluid dynamics in the design of its products as tools.

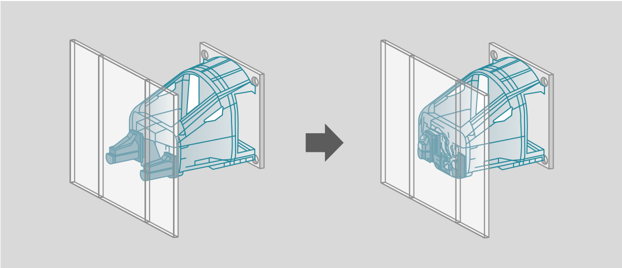

Fig. 15—Crash Analysis Simulation.
Exploiting the company's expertise in crash analysis in the heavy electric equipment field, Hitachi complies with all crash-related standards.

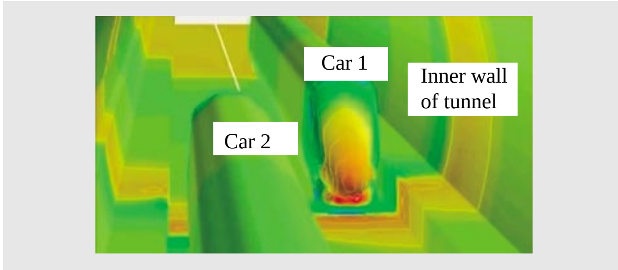

Fig. 16—Compression Wave Simulation when Trains Pass Each Other in a Tunnel.
Utilizing domestic micro-pressure wave simulation techniques, we verified compliance with UK standards.

(2) Applications to railway systems

(a) Crash analysis

Standards are stipulated in Europe (including the UK) regarding the crashworthiness of rolling stock involved in collisions, but many cases are difficult to verify by using actual railcars. Exploiting the company's considerable expertise in crash analysis, we have developed technologies for verifying the safety of rolling stock through simulations using a supercomputer without resorting to actual crash tests to satisfy the crashworthiness requirements. Fig. 15 shows simulated crash analysis results assuming that the lead car is involved in a head-on collision.

(b) Pressure change analysis

Fig. 16 shows a snapshot of simulation results revealing the pressure changes that occur on tunnel and train surfaces when high-speed trains pass each other inside tunnels. These findings were developed based on flow analysis techniques that were domestically used to develop a new aerodynamic nose shape that effectively suppresses noise caused by the micro-pressure wave generated when trains enter a tunnel.

(3) Effective utilization of simulation

Simulation is a powerful tool for analyzing and assessing complex phenomena, and we will apply simulation technologies developed in other areas as well to rail systems to speed up design and development work.

CONCLUSIONS

In pursuit of improved railway systems, we will continue to exploit our expertise in developing advanced key technologies and our role as a comprehensive railway integrator. We also perceive an expectation and hope that Japan's advanced rail systems will be made available on a global basis, and we are certainly committed to fulfilling this need.

Hitachi is thus committed to developing rail systems that are safe, environmentally-friendly, comfortable, and the transportation mode of choice for large numbers of people the world over.

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