Special feature article

Towards Realization of a Next Generation Commuter Train System

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At the Research and Development Center of JR East Group, through research and development towards the formation of the new railway system to be known as "e@train", development of the "AC Train (Advanced Commuter Train)" has been in progress. The Series E993 prototype train was manufactured as a concrete development model for verification purposes and verification through actual operations towards putting this type of train into practical use began from February 2002. This paper will explain the background to the development of the AC Train and the evaluation using the Series E993 prototype train.

● Keyword : Commuting, suburban train, articulated structure, synchronous direct drive motor, information technology, barrier free facilities

1 Introduction

The "New Frontier 21" initiative, which is the medium term business concept of the JR East Group that targets not only enhancing the safety and accuracy of rail transport, but also providing new services that satisfy the diversified needs of customers at a low cost. Moreover, the concept calls for the incorporation of advanced technology with particular emphasis on information technology (IT) and research and development into the formation of the new railway system "e@train" that will provide services on demand towards creating the "world's top railway service" both in name and in fact. In this endeavor, the development of the "AC Train" is a concrete initiative towards realizing the "e@train" concept in the Tokyo metropolitan area.

The Research and Development Center JR East Group has undertaken verification and evaluation of operations using an actual Series E993 prototype train from February 2002 towards the development of the AC Train that targets further technical breakthroughs and is appropriate as a commuter and suburban train for the beginning of the 21st century.

Fig.1: Formation of the "e@train"

2 Background to the Development

2.1 Objective of the Development of the AC Train

Number of passengers making use of the JR East Group services in the Tokyo metropolitan area amounts to 14 million daily with about 1.25 million people riding the trains in a single hour during the morning rush hour. The railway network in the Tokyo metropolitan area extends radially in six directions from the Yamanote line in the central part and about 8,200 trains run in this network. This transportation system is supported by approximately 8,000 commuter and suburban railway cars. Ever since its establishment, JR has been involved in the development of new types of railway cars and in 1993, development of the Series 209 type commuter train was completed and this train was adopted in the Keihin Tohoku Line. In order to reduce the life cycle cost of the Series 209 type train significantly, development was undertaken with the objective of reducing manufacturing cost, achieving lighter weight, and realizing maintenance free operations, and as a result, consumption of electric power and maintenance cost have been cut in half compared to the trains used in the past.

Moreover, in 1998 the Series 209-950 type train that became the prototype for the Series E231 type train was completed. The mass produced Series E231 type train has the performance required of both commuter and suburban trains and has driven the use of intelligent train systems as the train is particularly characterized by the incorporation of the Train Information Management System (TIMS) that utilizes data transmission technology.

When considering the form of the next generation of commuter and suburban trains that will shoulder the mass transit needs of the metropolis of Tokyo in the future, achieving a breakthrough merely basing development on the current structure and system of the trains will be difficult in order to satisfy future needs and significant system change will be required. Moreover, in order to satisfy the increasingly diversified and advanced needs of passengers, it is important to provide new transportation services utilizing advanced technology such as IT. In order to achieve this, we decided to initiate development of the AC Train as a next generation commuter and suburban train system that is appropriate for the new century.

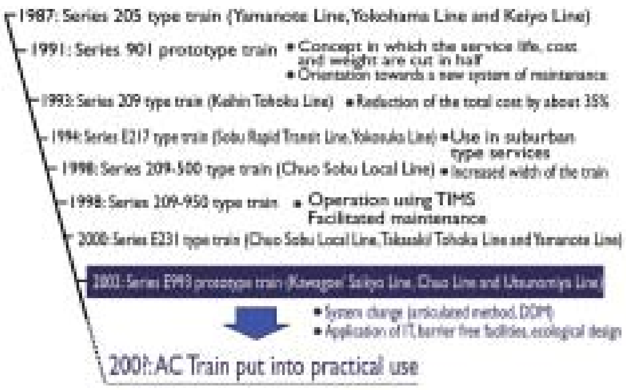

Fig.2: Background to the Development of Commuter and Suburban Trains

2.2 Concept in the Development of the AC Train

The elements that commuter transportation in the future will be required to satisfy are the "enhancement of passenger services" including the provision of information services and comfortable space, "enhancement of the stability of transportation" and continued provision of these at a low fare. Moreover, a decision was made to review the trains of the past from the perspective of fundamental structure and to initiate a significant "system change". At the same time, through "utilizing IT in railway trains actively" as key technology of the age, it will be possible to make further progress in such matters as the on-train "provision of information services", "enhancement of the stability of transportation" (enhancement of the reliability of trains and achieving timely recovery of operations in the event of failure) and "cost reduction".

Moreover, consideration of barrier free facilities and ecological design are indispensable issues today.

The concept for the development of the AC Train that defines "the issues relevant to the train of the future" with consideration given to these matters consists of the following five pillars.

(1) Reduction of total cost through system change
- Introduction of the articulated system
- Innovation of the structure of the train
- Introduction of the direct drive motor (DDM)

(2) Enhancement of the stability of transportation
- Enhancement of the reliability of trains
- Timely recovery from impaired operation
- Enhancement of the safety of passengers
- Autonomous system decentralization of train control

(3) Enhancement of passenger services
- Provision of information services on the trains utilizing IT
- Provision of comfortable transportation space (mitigation of congestion, etc.)

(4) Barrier free facilities
- Slopes for wheelchairs, steps for wheelchairs
- Universal design

(5) Ecological design
- Energy saving
- Zero emission

Fig.3: Concepts Targeted by the AC Train

3 Overview of the Development Technology

3.1 System Change

In the development of the AC Train, a fundamental review was made of the basic structure of the train and in order to achieve cost reduction through system change, technical development was undertaken founded on the perspective of innovation of the train structure and of the components. This technology was applied to the Series E993 prototype train and the train was evaluated from an overall perspective.

3.1.1 Innovation of the Train Structure

(1) Introduction of the Articulated System

While there are not many examples of the use of articulated train cars in Japan, the use of such a system in the case of commuter trains is increasing in the countries of Europe in recent years. With the articulated train, it is possible to reduce the number of trucks and of drive axles per train configuration thus enabling reduction of the overall number of parts and a reduction of cost. Moreover, the structure is effective in alleviating congestion through increased width of the train and use of the corridor connection as standing space. In the Series E993 prototype train, development work was undertaken with respect to the body suspension system (two point air spring suspension type and four point air spring suspension type) and the corridor connection and for each type of suspension, ride comfort, and ride stability at low speeds and sharp curves were verified from a variety of perspectives.

Fig.4: External Appearance of the Articulated Part

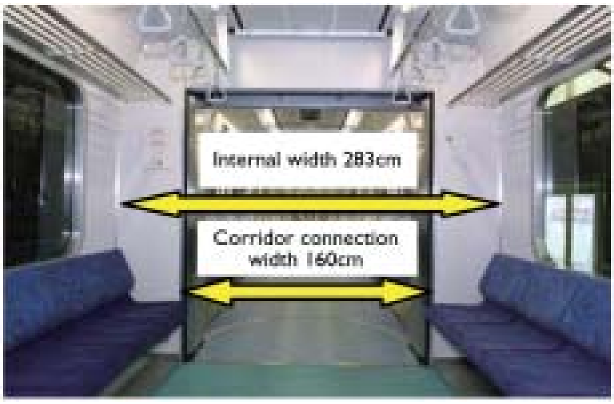

Fig.5: Larger Compartment Space through the Use of the Articulated System

(2) Innovation of the Structure of the Train

As stainless steel has the merits of being able to achieve lighter weight, enabling omission of coating of the external plates, and being relatively inexpensive, the material has come into wide use in recent years as a structural material for commuter and suburban trains in Japan. On the other hand, aluminum is used as the principle material for Shinkansen trains and express trains in which the main priority is reduction of weight. And in recent years, the double skin construction method has been developed enabling efficient manufacture of trains with highly precise finish work.

For the Series E993 prototype train, development work was also undertaken with respect to the double skin construction method using stainless steel that is characterized by the fact that the material allows the frame to be omitted, thus reducing the number of parts and the internal finish work to be simplified by using the inner skin as the interior material. In order to compare this double skin construction method using an aluminum alloy with other methods of construction, trains constructed using the single skin method using stainless steel were also included in the train configuration.

Fig.6: Double Skin Train Body using Stainless Steel

3.1.2 Innovation of Components

(1) Direct Drive Motor (DDM)

In Japan today, the cardan drive induction motor is in wide use in new types of trains. However, development work was undertaken with respect to the direct drive motor (DDM) in order to put such a system into practical use as a drive system to replace the cardan drive system. The DDM used in the Series E993 prototype train is an inner rotor type that is of the permanent magnet type synchronized electric motor in which the rotors of the motor are connected to the wheel axles. With the DDM, gears are not required and since the rotation of the motor decreases, not only does the efficiency of the motor increase but also reduction of the noise in the vicinity of the motor is achieved. Moreover, the system may be made maintenance free by utilizing a fully enclosed structure.

Fig.7: External Appearance of the Propulsion Direct Drive Motor (DDM)

3.2 Utilization of IT

In the development of the AC Train, it was decided to form a system that makes maximum use of IT and for the Series E993 prototype train, on-train information provision services, mutual backup system for equipment, and a train control information system were developed as practical examples of the use of IT and installed on the train.

3.2.1 Advanced Train Information Service System (ATISS)

The Advanced Train Information Service System (ATISS) targets the creation of an environment that can provide diverse information on the train under the concept of "providing passengers with whatever information they want whenever and wherever they want it". The concrete content involves one way mass media information (information on the operation of the train, announcements, news, publicity, etc.) and interactive information using web functions such as Internet communication and e-mail assuming seats on prioritized

Fig.8: LCD for On-train Provision of Information

rapid service trains. Moreover, transmission and reception equipment for wireless communication with trackside systems and an on-train LAN using a server were mounted on the Series E993 prototype trains. On the Series E993 prototype trains, ten 15 inch LCDs and four 18 inch LCDs were installed in order to provide information and in seating space that was configured to express train specifications, web terminals specific to the seats, wireless LAN access points, Ethernet connections, and dedicated electrical outlets were installed.

Fig.9: Web Terminal for Express Train Seats

3.2.2 Enhancement of the Stability of Transportation through the use of IT

(1) Mutual Backup of Equipment

The equipment has been configured so that different equipment with similar functions will provide backup in the event equipment with a high level of impact such as safety equipment, door controller, or brake controller fails.

(2) Self Diagnostic Feature and Emergency Measures System

The train itself has a self diagnostic feature to diagnose failure of equipment and take emergency measures as required in order to enable mitigation of the impact of such failure. With the Series E993 prototype train, the configuration makes electrical inductance unnecessary when one inverter fails by operating two inverters in

Fig.10: Auxiliary Power Source Equipment with Functions for Self Diagnosis and Emergency Measures

parallel with respect to the auxiliary power source equipment. Through this configuration, the location at which the failure in the equipment occurred may be diagnosed and cut out and halving of the load factor may be undertaken automatically.

(3) Transmission of Failure Information and Image Information to the Operation Center

In the event of a problem occurring in the operation, by providing accurate information on the status in the field to the operation center, appropriate decision making and instructions may be provided. For this reason, the Series E993 prototype train is configured to allow information from the train control monitor mounted on the train and information on the train (such as the rail ahead of the train or the status in the passenger cars) captured by the CCD camera mounted on the train to be transmitted to the operation center.

(4) Autonomous System Decentralization of Train Control

In the past, significant contributions have been made to cost reduction through integrating the train control system to the extent possible and concentrating functions. However, in the event failure occurs in important control equipment, the train as a whole will be affected with such a centralized system. For this reason, in the development of the AC Train, the reverse concept was employed and the control system was made autonomous and decentralized so that even in the event failure occurs in one system, the whole system will not become inoperable and this has enabled significant contribution to the stability of transport. While on one hand, this leads to an increase in the volume of equipment required, with the effect of the adoption of the articulated system (that achieves reduction in the volume of equipment required) reduction of total cost is possible. With the Series E993 prototype train, autonomous system decentralization of train control has been attempted by forming a one to one correspondence between the "DDM and control equipment" and "brake control unit (BCU) and train car".

3.2.3 Advanced Train Information Management System (AIMS)

The functions of the monitoring equipment for the trains of the JR East Group have been improved in the past utilizing transmission technology. As a result, with the TIMS that is mounted on the Series E231 type trains, such functions as significant reduction in train lines, automation of inspection prior to departure from the depot, and automation of the overall control of the train configuration have been added and the system has been brushed up to a level that may be rightfully called a "train information management system". With the Series E993 prototype train, the general purpose transmission technology Ethernet that is a global standard has been utilized in the trunk transmission system of the train configuration as a whole, the terminal equipment has been configured in a flexible manner, and initiatives have been taken in order to reduce the cost of the system infrastructure. Moreover, in the branch transmission system of individual cars, the general purpose communication chip LON (Local Operation Network) has been used to reduce the control lines in the compartment significantly and in addition to providing for the function of transmitting images of the status of the train car and the status of the front of the car, the system has the function of transmitting on-train data to the trackside.

Fig.11: Monitoring Equipment in the Motorman's Cab utilizing AIMS (Advanced Train Information Management System)

3.3 Human and Environmental Friendly Train

3.3.1 Barrier-free Facilities

In the future, initiatives having to do with barrier free facilities are indispensable in the railway business and the Series E993 prototype train is equipped with a "wheelchair slope" that stretches from the train to the platform and "wheelchair step" that reduces the gap between the train and the platform interlinked to the opening and closing of the doors to assist passengers using wheelchairs. Moreover, externally mounted doors have been adopted to do away with the door rails and to achieve a flat floor at the entrance to the train. With consideration for passengers with visual or hearing impairment, a system for announcing the opening and closing of doors using audio or display lights has been employed and with respect to the design of the interior, the coloring and form of the hand straps have been based on a universal design.

Fig.12: Wheelchair Step

Fig.13: Wheelchair Slope

3.3.2 Ecological Design

The 21st century is called the century of the environment and the manufacture of trains that are environment friendly is an important requirement. With the Series E993 prototype train, initiatives have been taken to adopt highly efficient DDM and achieving lighter weight towards further enhancement of energy saving. Moreover, as an initiative that addresses the issue of ecology, development has been undertaken towards achieving zero emission (no emission of waste material) through the use of materials and structures that facilitate recycling and sorting particularly with respect to materials for internal finishing.

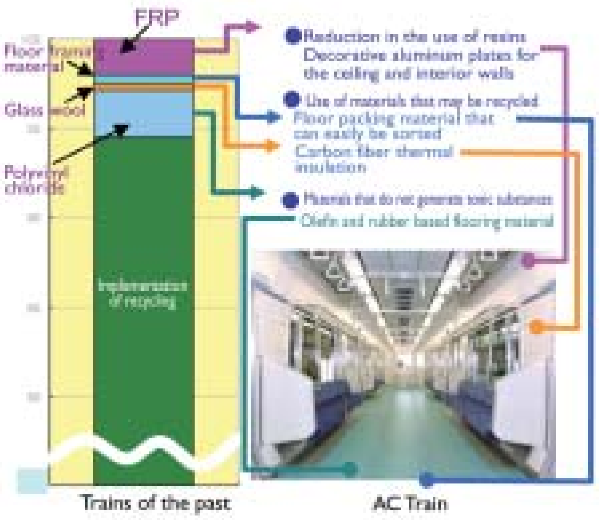

Fig.14: Achieving Zero Emission

4 Evaluation of Development Technology

As the final step in achieving the concept of the development of the AC Train, the developed item configured from the Series E993 prototype train was subjected to test operation for verification purposes from February 2002 using an actual train. Figure 15 shows the steps in the operation test.

First, particularly with respect to technology such as the articulated truck and DDM in which significant system change was introduced, the operating stability which is a basic requirement of a railway train was evaluated. Since the targets of the evaluation were structures and equipment that are not found in the trains of the past, the safety of operations was confirmed starting at a speed of 40km/h and gradually speeding up to 120km/h after which the total performance of the train was verified. The DDM was evaluated on steep inclines and the articulated structure was tested on sharp curves. Moreover, tests to evaluate performance such as ride comfort, slip control, and durability of the brake disks were conducted. Tests were also conducted at a speed of 130km/h. In parallel to this, the IT system was evaluated. Moreover, a test run and questionnaire survey were conducted among specialists and people solicited from among the general public in September 2002 in order to have the development theme evaluated from the viewpoint of the passenger.

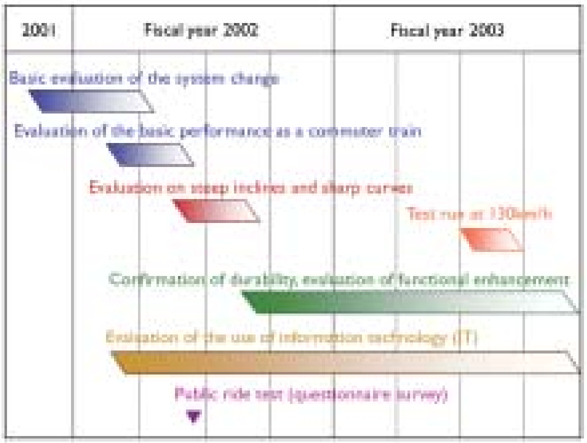

Fig.15: Steps in the Operation Test

4.1 Articulated System

With respect to the articulated system, it was confirmed that costs may be reduced by decreasing the number of trucks and drive axles and that congestion may be mitigated through increasing the compartment space and utilizing the corridor connection as standing space.

With respect to the suspension system, it was found that use of the four point air spring suspension system afforded the same simple structure of the train body as the non-articulated train and that the system is advantageous in terms of cost. Moreover, the loss of wheel load in the spiral at the exit of a curve decreases with this structure thus enhancing performance with respect to derailment when passing through a curve. Furthermore, in the run stability evaluation with loads mounted assuming a difference in the load at the front and back of the car, it was verified that there are no problems with respect to operating safety and offset wheel load in evaluation of operating stability.

With respect to the corridor connection, improvements such as preventing the floor of the articulated part from rising and preventing the lateral panel from becoming misaligned were implemented.

Today, as a new initiative, tests are being carried out to improve ride comfort towards semi-active control targeting greater speed for traditional train systems.

4.2 DDM

In addition to attempting cost reduction by decreasing the number of DDM drive axles, more than 5% energy saving has been achieved through greater efficiency of the motor and a reduction of noise by about 5dB in the train compartment as well as mitigation of shock to the rails have been confirmed. Moreover, it was verified that the system is a superior one that does away with the need to blow air as a result of the use of the fully closed self cooling system, reduces the life cycle cost through reduction of noise and improves friendliness to the environment.

Today, further initiatives are being undertaken aiming towards lighter weight through review of the specifications of the cooling structure.

4.3 Stainless Steel Double Skin Cars

The stainless steel double skin cars that attempt to reduce cost through simplification of the structure of the cars were found to reduce man hours required in manufacturing to a certain extent, but since there is no outlook for mass production as a result of the withdrawal of the panel manufacturer from the business, it has been decided that adoption of such a system will be put on hold for the time being.

4.4 AIMS

Through the use of general purpose transmission technology (Ethernet, LON), further reduction of wiring has been achieved and AIMS that is high speed and highly scalable (with easy connection of equipment) has been formed and together with the use of displays for the instruments in the motorman's cab, the outlook is for a reduction of about 50% of the wiring in the train (compared to the Series E231 type trains).

4.5 Enhancement of the Stability of Transport

It has been found that the impact of equipment failure on transportation may be minimized by configuring the system to be autonomous and decentralized, using mutual backup and undertaking self diagnosis and emergency measures. Moreover, a function for sending failure information displayed at the on-train display and the image of the rails ahead of the train to operation control has been added thus enabling timely support from operation control as well as displaying the images from the on-train camera and door camera on a monitor to grasp the conditions on the train. The results of this development work are being considered for installation on trains that will be manufactured in the future.

4.6 Enhancement of Passenger Services

As a result of the adoption of the articulated structure, the width of the compartment has been increased by 80mm compared to the past and it has been confirmed that the corridor connection may be used as standing space, thus increasing the compartment space by 5% compared to the Series E231 type trains.

In terms of enhancement of service functions through ATISS, the vehicle information service system (VIS) that was introduced on the Yamanote Line has been further enhanced enabling the display of a wealth of images and provision of diverse interactive services. Through this, a menu for reviewing future adoption based on the type of train and level of service has been produced.

4.7 Barrier-free Facilities

The slope and step equipment to facilitate embarking and disembarking in a wheelchair was developed through durability tests and confirmation of measures to be taken in the event of system failure. Moreover, initiatives were taken regarding the opening and closing of the sliding doors with consideration given to people with hearing impairment and the effects of the basic functions and effects of the introduction of the various devices were confirmed. These chimes and displays that announce the opening and closing of doors are gradually being put into practical use such as through adoption on the Series E231 type trains of the Tokaido Line.

4.8 Ecological Design

As a result of having taken initiatives for further energy saving through the introduction of DDM and achieving lighter weight rail cars, the outlook is for an energy saving effect of more than 10% compared to the Series E231 type trains. Moreover, through converting to materials that can be recycled (zero industrial waste), the amount of resin used has been reduced and sorting has been facilitated leading to achievement of zero emission. Today, further initiatives are being taken for the recycling of FRP products (reuse of glass fiber and fillers) towards raising the level to one that is appropriate as an ecological train.

4.9 Questionnaire Survey

In order to study the evaluation of the content of the development work and the direction that ought to be taken towards the next generation of commuter trains, a public ride test was undertaken between Tokyo and Musashi Koganei on the Chuo Line and a questionnaire survey was conducted among the participating 143 specialists and 340 people solicited from among the general public.

Opinions among the specialists concentrated on the evaluation of the system change technology and equipment while opinions from the general public concentrated on the evaluation of enhanced services and passenger facilities but in either case, the evaluation of the content of the development was high.

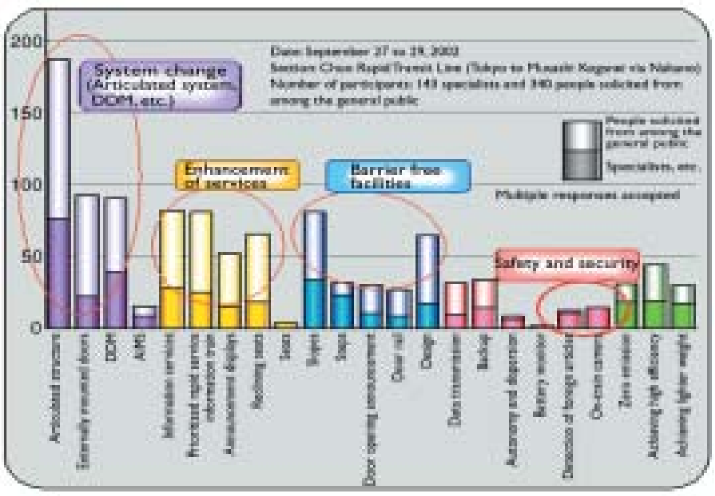

Fig.16: Result of the Questionnaire Survey

5 Conclusion

The Series E993 prototype train was developed incorporating diverse concepts that are required for the next generation of commuter and suburban AC Trains and evaluation of the various functions that were incorporated as the new core concept was completed in fiscal 2003. AC Trains Vision for mass production incorporating the technology evaluated for practical use with the Series E993 prototype train will be positioned as the next generation commuter and suburban train in the Tokyo metropolitan area and is in the preparatory stage towards realization.

We have been committing to the initiative for achieving the concept of the development of the AC Train and have achieved various success. However, this does not mean that a next generation commuter and suburban train system has now been completed. Until passengers ride the trains and actually provide a "true evaluation" of the AC Train as a reliable one, we cannot slacken our future development efforts. In the future, we will identify needs and will study and develop technical trends towards achieving the "e@train" concept.

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