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Développement du matériel grande vitesse coréen HSR350x.

HS

# Development of Korean High Speed Rolling Stock HSR 350x

## Entwicklung des Koreanischen Hochgeschwindigkeitszuges HSR350x

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### Abstract

Korea introduced a new rail service based on the French TGV called the Korea Train eXpress (KTX) which was launched on April 1<sup>st</sup>, 2004, this year to open up the high-speed railway era. That is called an inland transportation revolution. In addition, in September of last year, the Korean High Speed Rolling Stock 350 eXperimental (HSR350x), that was independently developed through a national Research & Development project titled 'Development of High Speed Railway Technology', surpassed 300 km/h on the test track of the Seoul-Busan high speed line. The development of the HSR350x will be classified as the best technological achievement in the Korean railway history.

The HSR350x was designed and manufactured by Korean engineers in six years from conceptual design to on-line test. It has been working toward the commercialization by operating on the Honam high speed line and performing the pilot operation for the review of appropriateness with the infra facilities. Therefore, Korea has secured the design technology of high speed railway, the development of core components and the manufacturing technology of train sets with its own technologies on top of the construction, management and maintenance technology of a high speed railway that was secured through the construction of the Seoul-Busan high speed line. This is a remarkable achievement that has led Korea to be one of the best countries in the world with high speed railway technology.

In this article, a summarized form of introduction is given for the development details of the major core equipments and the features of the HSR350x developed through a national R&D project titled 'Development of High Speed Railway Technology'.

### Zusammenfassung

Korea hat nach Einführung des französischen TGV am 1. April dieses Jahres den Korea Train eXpress (KTX) gestartet und damit sein Zeitalter der Hochgeschwindigkeitseisenbahn eröffnet, bezeichnet als „inland transportation revolution“. Zudem überschritt im September des vergangenen Jahres der Koreanische Hochgeschwindigkeitszug 350 eXperimental (HSR350x), der unabhängig davon in einem nationalen Forschungs- und Entwicklungsprojekt mit dem Titel 'Development of High Speed Railway Technology' entwickelt worden ist, auf der Teststrecke der Hochgeschwindigkeitslinie Seoul-Busan die Geschwindigkeit von 300 km/h. Die Entwicklung des HSR350x wird als höchste technologische Errungenschaft der Koreanischen Eisenbahngeschichte gewertet.

Sechs Jahre lang wurde der HSR350x von einheimischen Ingenieuren vom Konzeptentwurf bis zum Test auf der Strecke entworfen und gebaut. Auf der Honam Hochgeschwindigkeitslinie wurde der Zug mit Zielrichtung kommerzieller Betrieb eingesetzt, ebenso im Pilotbetrieb zur Feststellung der Verträglichkeit mit den Infrastrukturanlagen. Dazu hat Korea sich den technologischen Entwurf einer Hochgeschwindigkeitseisenbahn, die Entwicklung der Hauptkomponenten und die Fertigungstechnik für die Triebzüge unter Nutzung der eigenen Technologien gesichert, und zwar ergänzend zu Bau-, Betriebs- und Instandhaltungstechnologien, die vom Bau der Hochgeschwindigkeitsstrecke Seoul-Busan übernommen worden waren. Diese beachtliche Errungenschaft brachte Korea einen Platz in der Reihe der führenden Länder der Welt mit Hochgeschwindigkeits-Bahntechnik. Der Beitrag gibt eine Übersicht zu den Details der Entwicklung des HSR350x und seiner Hauptkomponenten.

**1. National R&D Project 'Development of High Speed Railway Technology'**

The project „Development of High Speed Railway Technology“ began in the early 1990s under the strong policy of the government whose target is to raise the level of railway technology in Korea up to the top level of the world through the introduction of the KTX. At that time the

level of Korean railway technology was lower than that of the advanced countries. Under leadership of the Ministry of Construction and Transportation, and with the cooperation of the Ministry of Commerce, Industry and Energy and the Ministry of Science and Technology, a project of Development of High Speed Railway Technology was undertaken for 6 years from 1996 to 2002. This R&D program is to realize the next generation of Korean high speed rolling stock in the

2000s while developing an independent design, engineering and manufacturing competence of 350 km/h level of high speed railway. The purpose of this project was to make Korea's own high speed railway as shown in *Table 1* through a reproduction of the technology of the KTX.

This nationwide R&D project was lead by KITECH (Korea Institute of Industrial Technology) and KRRI (Korea Railroad Research Institute) and includes ten

**Table 1: Comparison of core technology of KTX and HSR350x**

Item		KTX	HSR 350x	Remarks
operating speed		300 km/h	350 km/h	-
carbody material of passenger car		mild steel	aluminium extrusion profile	weight reduction : 15 %
traction motor		synchronous motor	induction motor	maintenance cost reduction : 30 %
propulsion system	control type	PFC + phase control converter + current inverter (VVVF-PWM control)	PWM control converter + voltage inverter (VVVF-vector control)	up-to-date control algorism
	electric device	GTO	IGCT	high capacity/high electric power device
brake system	type	regenerative, rheostatic, axle disk, tread	regenerative, rheostatic, eddy-current, axle disk, wheel disk, tread	independent development of eddy-current brake
	control	BP control	PWM control	improve the response characteristic
	blending	electric/pneumatic blending in power bogie	total blending in formation	total blending control algorism
air ventilation	pressurization equipment	none	independent development	improve the riding comfort in tunnel
communication network		tornad network	TCN network	UIC, IEC standard specification
driving control		analog control	digital control	up-to-date technology

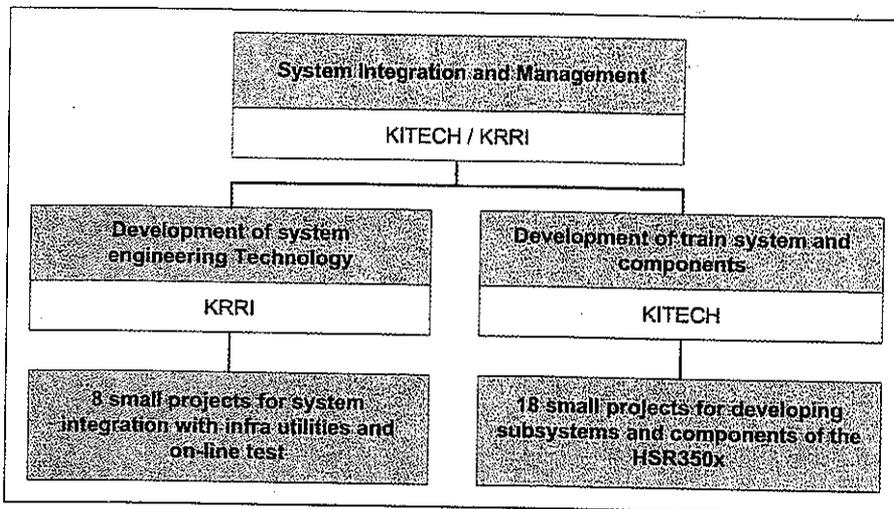


Figure 1: Organization of the national R&D program „Development of High Speed Railway Technology“

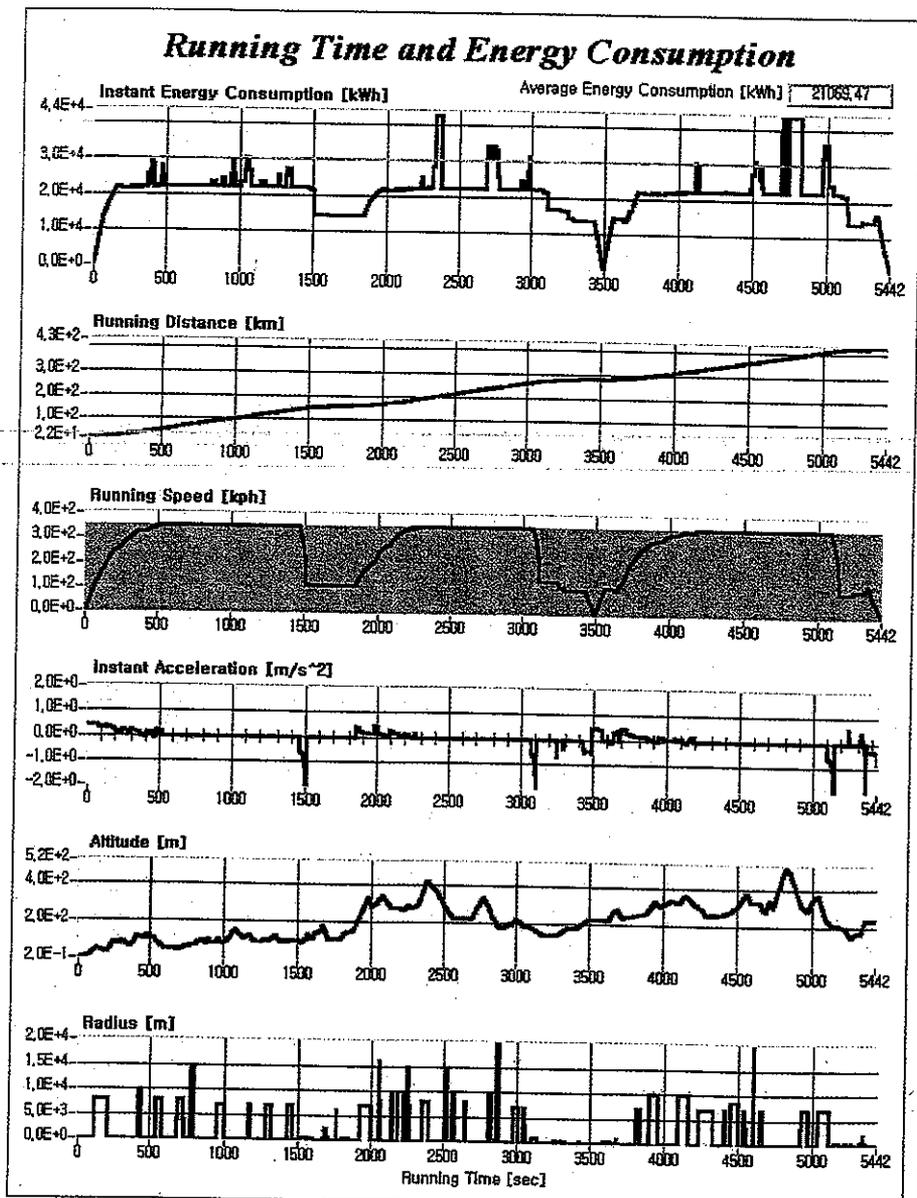


Figure 2a: Example of conceptual design analysis: trip time simulation

government chartered research institutes, 35 enterprises and 16 universities, which were organized, cooperated and collaborated (fig. 1). In particular, KITECH was fully in charge of development of the train system and its components with Rotem Co. Ltd., Hyundai Heavy Industry, LG Industrial Systems, Yujin Machinery Ltd. and others. About 1000 specialized researchers annually participated in this project and a total of 182 million dollars was invested.

## 2. Train System Engineering for Development of the HSR350x

KITECH secured its independent train system engineering technology and managed the train development from the conceptual design to the test of the HSR350x.

The development process of the HSR350x consisted of the process of analysis of requirements, design, production, testing/evaluation and optimization, and the design process of the train was divided into conceptual design, preliminary system design and detail design.

The review of operational requirements for the train system was the first step prior to the design of the train development and included the design specification which was the list of major requirements and was drafted and reviewed in the conceptual design step (table 2). The major requirement categories for review consisted of operational condition, functional condition, design standard, environmental condition, size and specification. The design specification, the list of requirements, was drafted through the analysis of these categories. In the process of reviewing such requirements, testing/evaluation result related to the previous train already developed, issues and improvement requirements discovered in train operation and others were appropriately reflected, and during the development process of the HSR350x, the analytical review and trade-off analysis on factors of speed improvement, efficiency enhancement, increase in transportation, shortening of travel time, reduction of maintenance



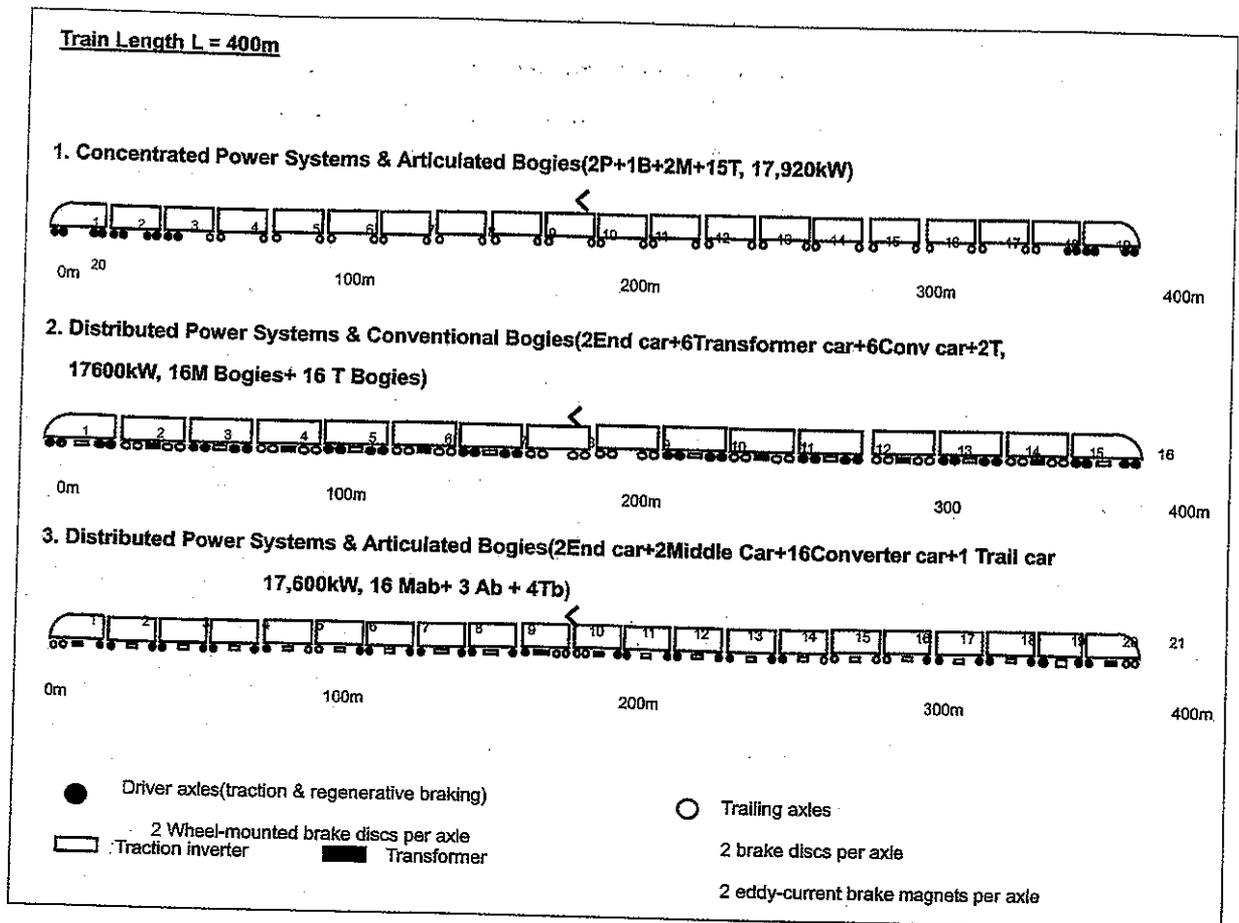


Figure 3: Evaluation procedure of train system configuration (length 400 m)

system design, noise prognosis and dynamic simulation.

Figure 4 shows a sample of supplementary

design that was made by these reviews.

The strength analysis result of carbody end structure (top) shows the strength

concentrated area and initial bending shape (left) was changed to straight shape (right) to reduce the stress level.



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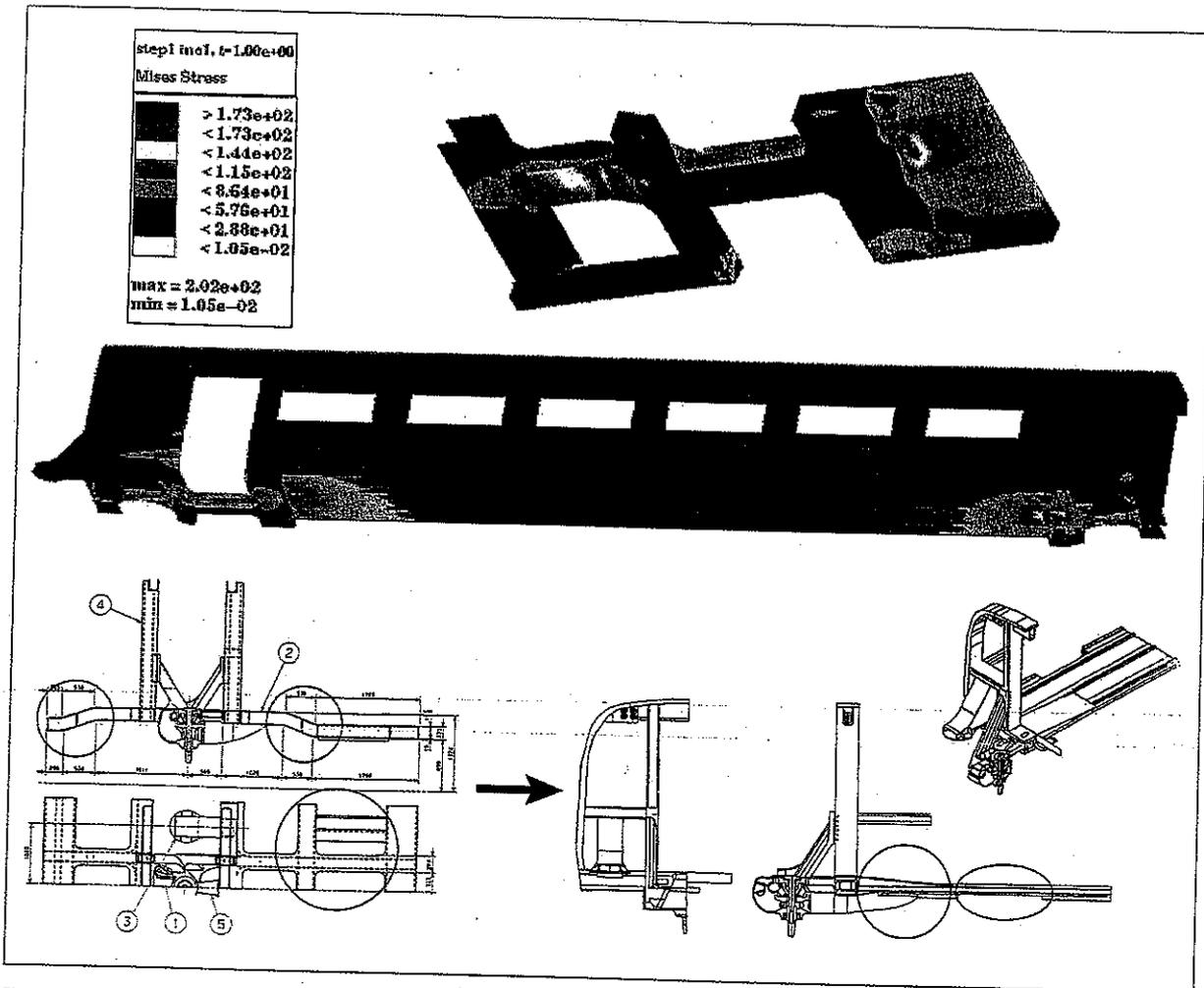


Figure 4: Example of reviewed/improved train design (car body end structure): before modification (left), after modification (right) and strength analysis result (top)

Also, a special specification and regulation was secured for the detail design stage.

In order to structure the high speed railway design integration system that

was made up with the integration of the passenger car (motorized trailer and trailer), continuous revising and supplementing were performed until the high speed railway train was manufactured

and released. This included, the unit space of the passenger car and its internal parts and the outside image of the operation room, took into consideration the continuous change in the detailed image that occurred with various issues under the development process, from the early stage of the design of high speed railway to the train production stage. The verification and improvement for prototype train design integration was largely divided into two fields of the train's external shape integration design (fig. 5) and the indoor image integration design.

In order to analyze the detailed design of the HSR350x and secure the system integration, the detailed specifications and drawings were carefully checked and analyzed by using computer simulation and through technical meetings for confirming interface characteristic between

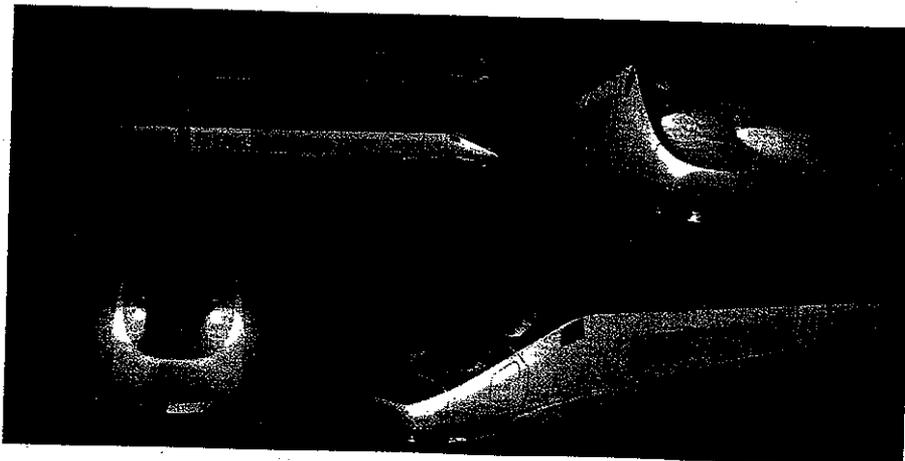


Figure 5: Example of outside shape design development of HSR350x

subsystems and/or components. Major areas were grouped into two, mechanical and electrical parts. Several continuous technical reviews and adjustments rendered the optimized detail design of the HSR 350x. Figure 6 shows the result of detail design of each car.

The train manufacturing stage was the stage when the train and the components were produced/assembled on the basis of the design drawings drafted through the earlier design process. The manufacturing and assembly were performed by dividing the stage into carbody shell, decorative design, bogie and heavy electric field. In the case of the carbody in general, it may be divided into the manufacturing process that the carbody was manufactured through welding and the assembly processing to install and assemble various components on the manufactured carbody. Figure 7 shows the welding process of carbody manufacturing.

The test stage was the process to assess whether the objective of the developed HSR350x was achieved. The most important point was to compare and verify the target functions and performances of the developed items with the actual test results. Therefore, in the train development, defining the target functions and performances is the most important part in the test evaluation field which clarifies whether a setting of the basic specification objective has to be done in advance. In developing the HSR350x, various test operations (fig. 8) were performed including

- the test of component unit that tested and assessed the performance of each component,
- in plant test that verifies the performance of all subsystems on the HSR350x and the train system at a speed less than 60 km/h and
- the comprehensive pilot operation including the acceleration test with the target of 350 km/h.

Therefore, the number of passenger cars is only five including the motorized trailer.

### 3. Features of HSR350x

The HSR350x was successful in securing the one notch higher technology. The

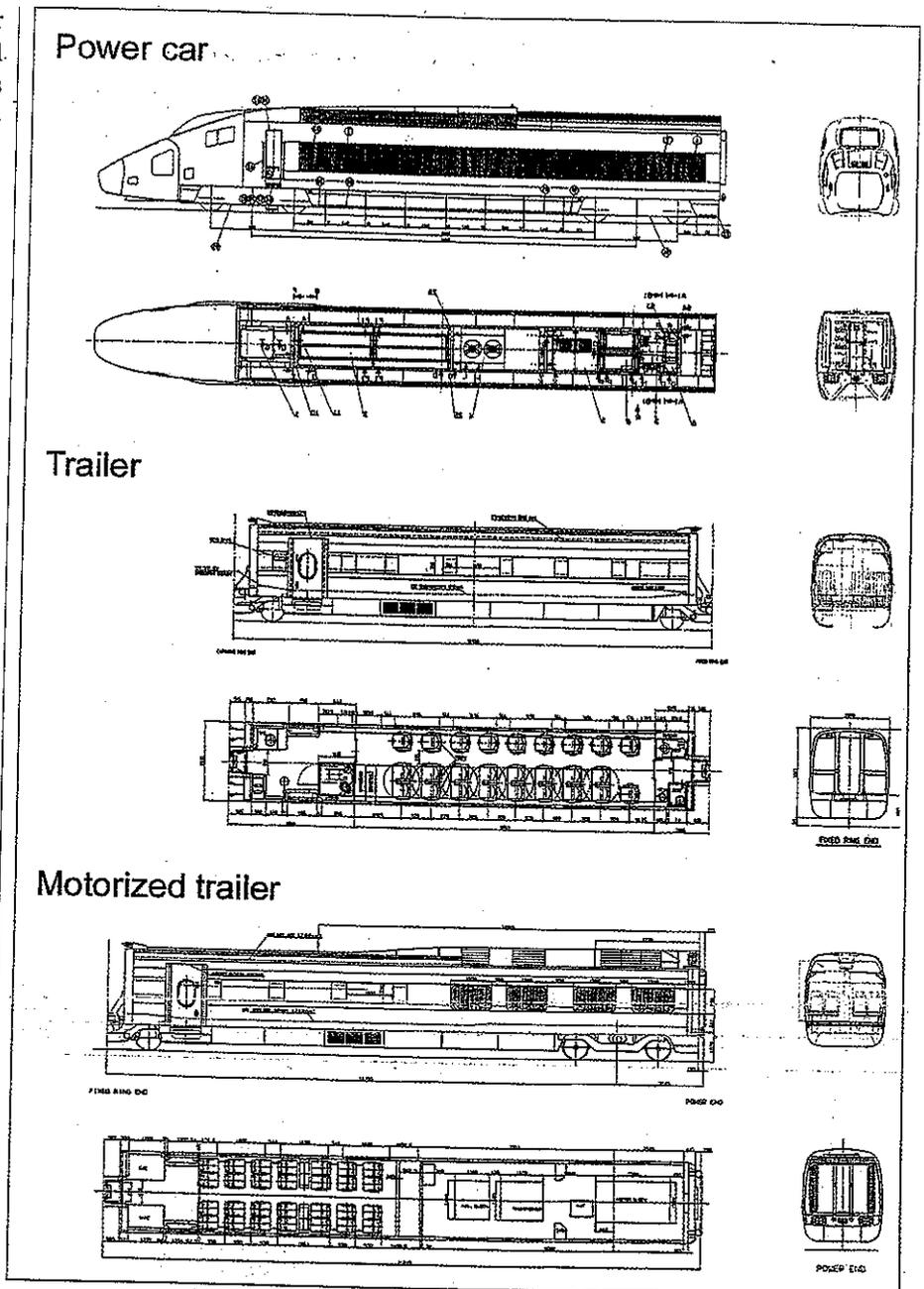


Figure 6: Drawings of each car

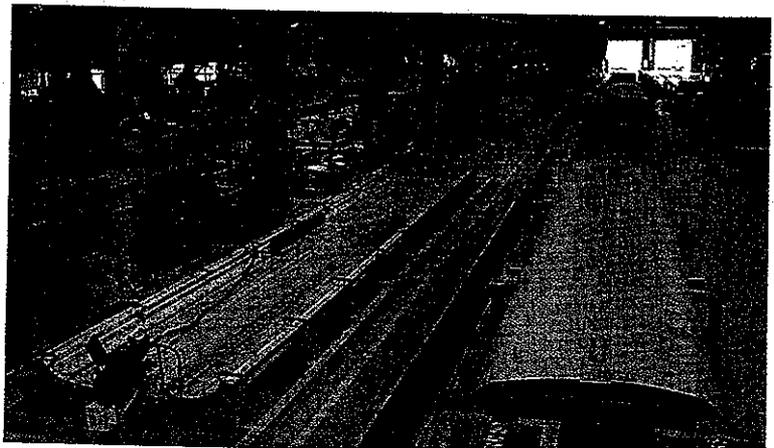


Figure 7: Manufacturing field of a trailer car



Figure 8: Strength test of car body

Korea high speed rolling stock was designed to comply with the domestic environment while maintaining compatibility with the KTX. In addition, it applied the cutting edge technology to equip itself with the futuristic high-speed railway system that would be very adaptable anywhere in the world. It was designed entirely by a Korea technology team with the rate of domestic production reaching 92 % ranging from the major core technology to the design.

### 3.1 Formation

The Korea high speed rolling stock was designed to enable the two-way operation with the highest speed of 350 km/h on the Seoul-Busan High Speed Railway. In

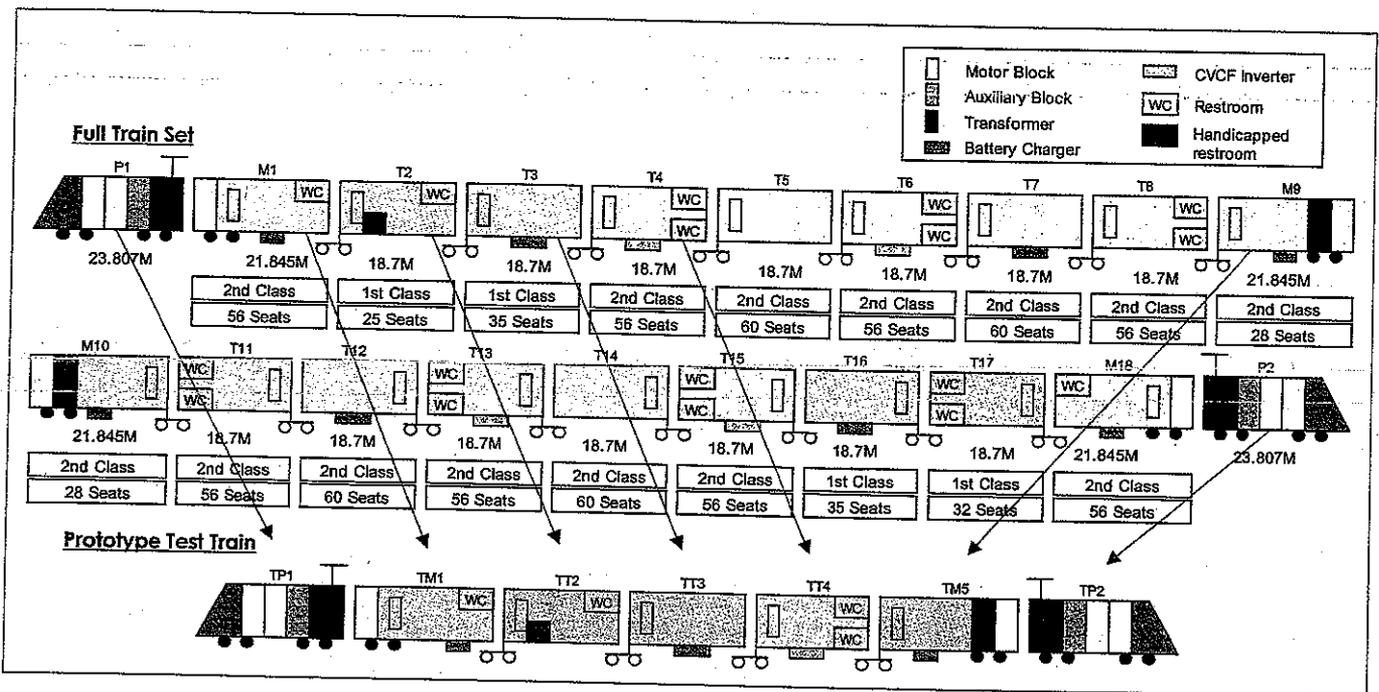


Figure 9: Basic formation drawing of HSR350x

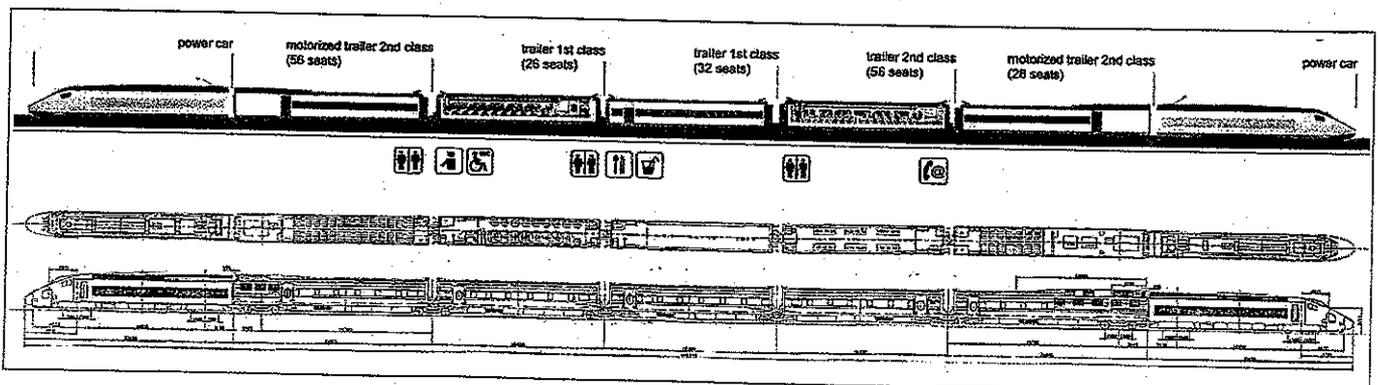


Figure 10: Configuration of HSR350x

addition, the formation was basically divided into 20 cars that would carry the full capacity of 1 000 passengers and 11 cars in a set to transport the full capacity of 500 passengers. Due to the limitation of the platform length of the stations, the set length is 400m or less, as in the case of the KTX.

The prototype train is the train manufactured as a final product of national R&D project 'Development of High Speed Railway Technology' for testing key components and a future commercial train system. It has seven cars with 1 set, the minimum set to assess and verify the performance while displaying the overall features of the Korean high speed rolling stock. The set sequence is composed of power car (TP1) + motorized trailer (TM1) + trailer (TT2, TT3, TT4) + intermediary motorized trailer (TM5) + power car (TP2). *Figure 9* shows the HSR 350x basic configuration from Korea high speed rolling stock, which includes all the key components of this configuration.

In other words, the prototype train is composed of two power cars that are equipped with the operation room to control various functions of the train, the equipment to generate and control the traction power, two cars of the motorized trailer which have no operation room but generate the traction power while used as the trailer units, and three cars of the trailer unit with seats and convenience capacity for guests without the motor device (*fig. 10*).

Here, motorized trailer and trailer 3 (TT3) of the prototype train are available for a conference room and measurement room for test evaluation and test operation of the development train in place of trailer unit facilities (*fig. 11*).

The total number of seats for prototype train is 82 with 26 1<sup>st</sup> class and 56 2<sup>nd</sup> class. In addition, for the trailer unit facilities of the prototype train, there are three restrooms in the TM1, TT2, and TT4, a restroom for handicapped and crew office on the TT2, a network room is on the TT4, and a cafeteria on the TT3. In particular, the prototype train has the advantageous structure in the aspect of running safety by linking soundly in between the trains by using the joint ring

and the joint bogie in the connection of trailer to trailer. The total weight of the HSR350x is 330 tons with an entire length of 145 m. Currently, it is in pilot operation in Seoul-Busan high speed line, and the commercial operation is pending within the near future.

### 3.2 Main Dimensions and Performance of Train

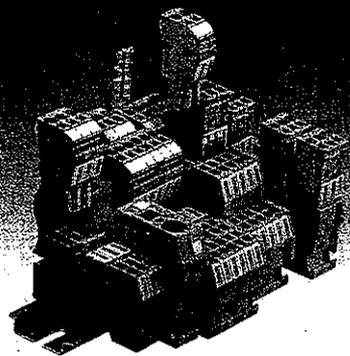
The HSR350x has the size of the outside of trains determined basically to enable the Seoul-Busan High Speed Railway operation, the dimension of the train was modified and improved following the aerodynamic design of the front part (*fig. 12*)

and the change of the items built-in on the inside. In particular, a lot of time and effort were injected in satisfying the axle load limit with the increase of entire weight caused by the performance improvement of the train system during the actual development process.

In order to have the lighter weight of the train, structure developments were undertaken through the load optimization design and the development of light materials. In addition, efforts were undertaken to resolve several dynamic issues following the lighter carbody weight including the structural stability of the train, the passenger train unit noise- and

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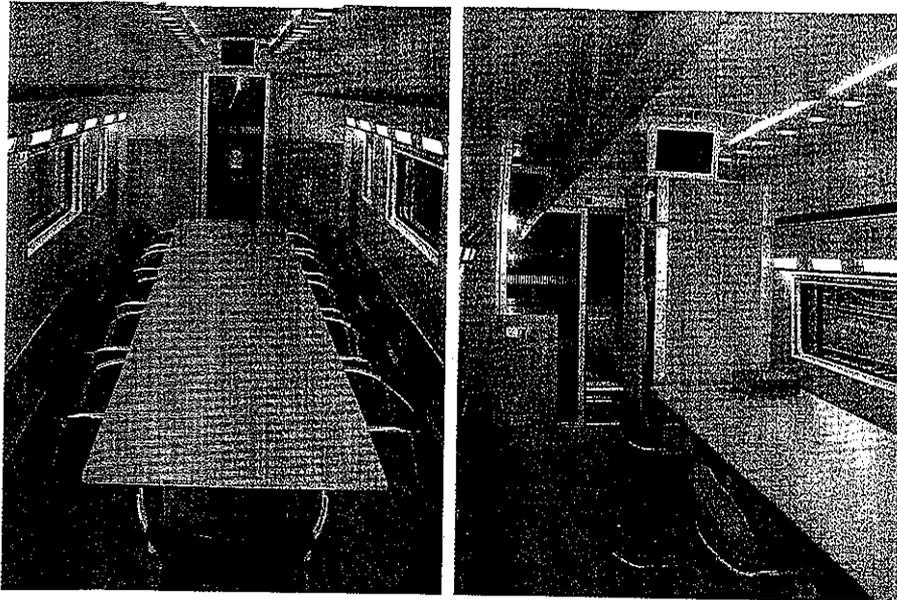


Figure 11: Conference room and measurement room

vibration proof, comfort in riding and others.

Further more, the space composition and interior design of the trailer unit was considered as this makes a direct impact on the pleasant and safe trip of passengers, bring the feature of Korean travel culture as well as the improvement in comfort and convenience of the high speed railway human factor engineering.

The shape of the power car utilized the state-of-the-art aero-dynamic computer interpretation program to reduce the air resistance (fig. 13) and noise problems when running at speeds of 200 km/h or faster, and design and manufacture to maintain the single curve from the nose part of the power car to the roof. The bogie is covered to reduce the air resistance (improvement of about 6.6 % based

on the drag coefficient) which also results in a reduction of noise.

The inside of the power car operation room was designed to minimize the fatigue of the operator and heighten the work efficiency through the ergonomics approach (fig. 14).

By connecting the cutting edge digital technology, the equipment can be simplified to optimize the convenience of operation. In addition, responding to a possible collision, the safety design was applied to protect the passengers. In the front part of the operation room, there is a structure to absorb the energy which is shaped like a beehive. As a result, the safety has improved to completely absorb the impact energy of 6 MJ (fig. 15).

### 3.3 Production of Core Components

This section shows several examples of improved feature and core technology of components for the HSR350x (fig. 16). Unlike the KTX which is manufactured with mild steel, the carbody of the passenger cars of the HSR350x was manufactured with aluminum extruded profile. A weight reduction of 15 % was achieved. For the purpose of aerodynamic noise reduction and resistance, the front shape of the HSR350x was designed by aerodynamic analysis. Through the result of that analysis aerodynamic resistance can be reduced by 27 % compared to the KTX.

The HSR350x is driven by traction motors (fig. 17) which are controlled by motor blocks (i.e. converter and inverter). A motor block unit controls two traction motors. Korea high speed rolling stock is equipped with 1.1 MW level high output induction motors.

The main transformer (fig. 18) is a device to supply all power required on the high-speed train. The capacity has increased approximately 20 % than that of the KTX while the weight has reduced for approximately 15 %.

The motor block (fig. 19) is a device that controls the speed and acceleration of the train by controlling the power supplied to the traction motor. For the 2.5 MW level of device, it applies the most progressive Integrated Gate Commutated Thyristor (IGCT) in the world to improve

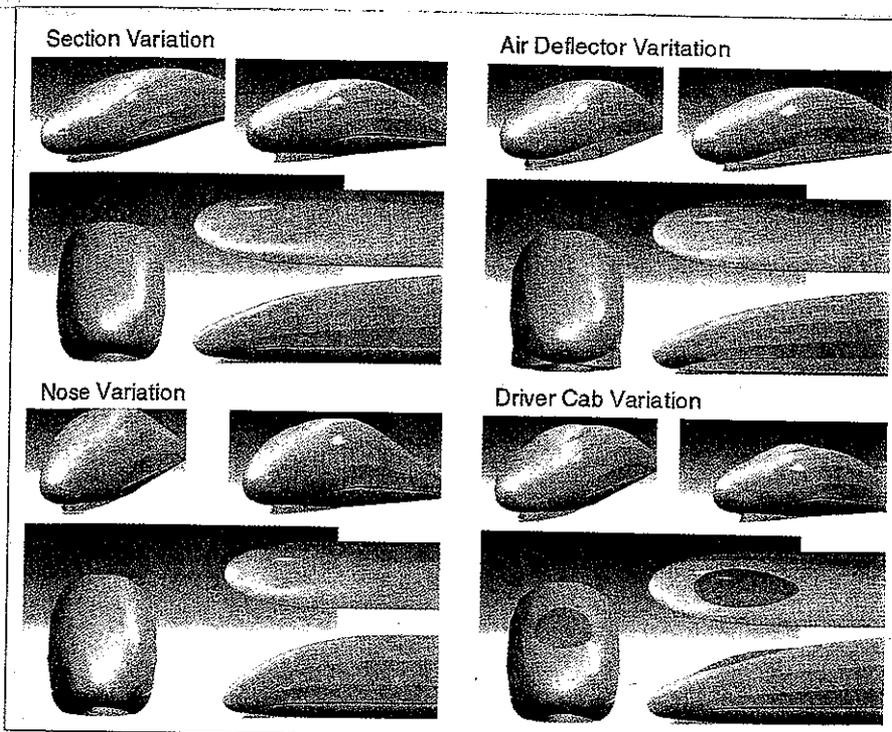


Figure 12: Conceptual modelling of a power car front

the efficiency and control performance. The harmful electro-wave that causes the electric interference has approximately 49 % declined compared to that of the existing railway (based on electric locomotive).

In order to stabilize the high-speed run, the power required for the train has to be supplied continuously. The core component that undertakes such functions is the pantograph (fig. 20) installed on the roof of the power car. The pantograph is one of the core technologies that determines the highest speed of the train and overcame the noise problem that it had through several testing phase, designing and supplementing process and was finally successfully developed with domestic technologies.

The operation of high-speed rolling stock requires computer support for data management and transfer. The computer of the leading unit becomes the master computer and the additional computers in the other units act as slave computers to facilitate accurate motion by delivering the instructions of the operator.

Through the computer monitoring that surveys the operation situation of the equipment (supervisory control unit - SCU), the operator is informed on the condition of the train and can take appropriate action. In addition, in the nerve system that links the computer and equipment, the train communication network (TCN) method is used as the worldwide standard (fig. 21).

In order to secure the stable braking performance within a high speed range, the HSR350x has four sets of eddy current brakes installed on trailer bogies (fig. 22). The eddy current brake is a kind of electric brake thus it has no wear of machinery parts and no contact noise. Another key challenge is the pressurization unit which was fitted in all types of cars in the HSR 350x. Pressurization unit is a kind of automatic pressure controller that is able to reduce the ringing of ears due to the sudden change of pressure in the passenger room when traveling through a tunnel section. It may be a device that is essential for the convenience of the passengers. Figure 23 shows the braking forces blending plan for five kinds of brake in the

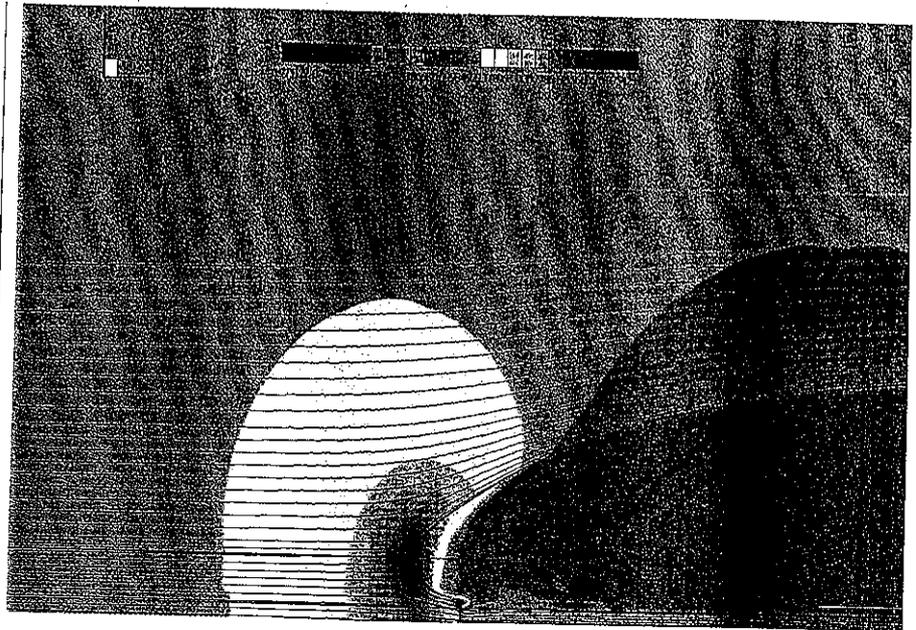


Figure 13: Example of aero-dynamic analysis result of power car front (stream line and pressure contour)

HSR350x. The HSR350x has two kinds of braking condition. In normal braking condition, the braking distance is 5 523 m and in emergency condition the braking distance is 4 800 m. (Table 3)

#### 4. Testing and On-Line Test

The technology to evaluate the performance of the developed train and present

the improvement plan where a supplement is necessary is the core part in train development. Through national R&D project 'Development of High Speed Railway Technology' the independent technology was available for testing, assessing and verifying the performance and for comparing it with other high-speed railways of the world. The reason that the development of the Korea high

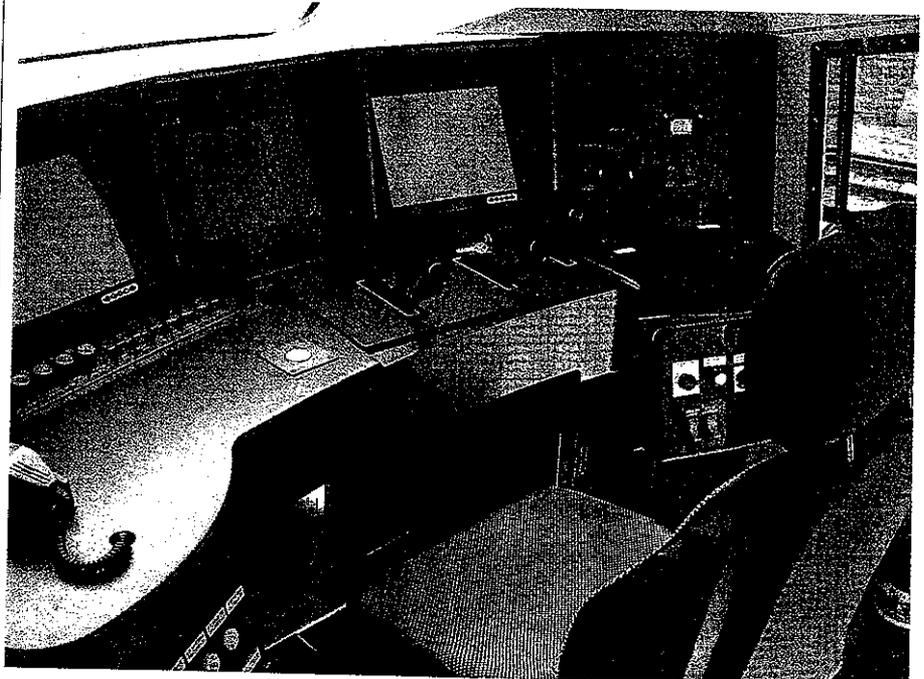


Figure 14: Drivers desk through the ergonomics approach

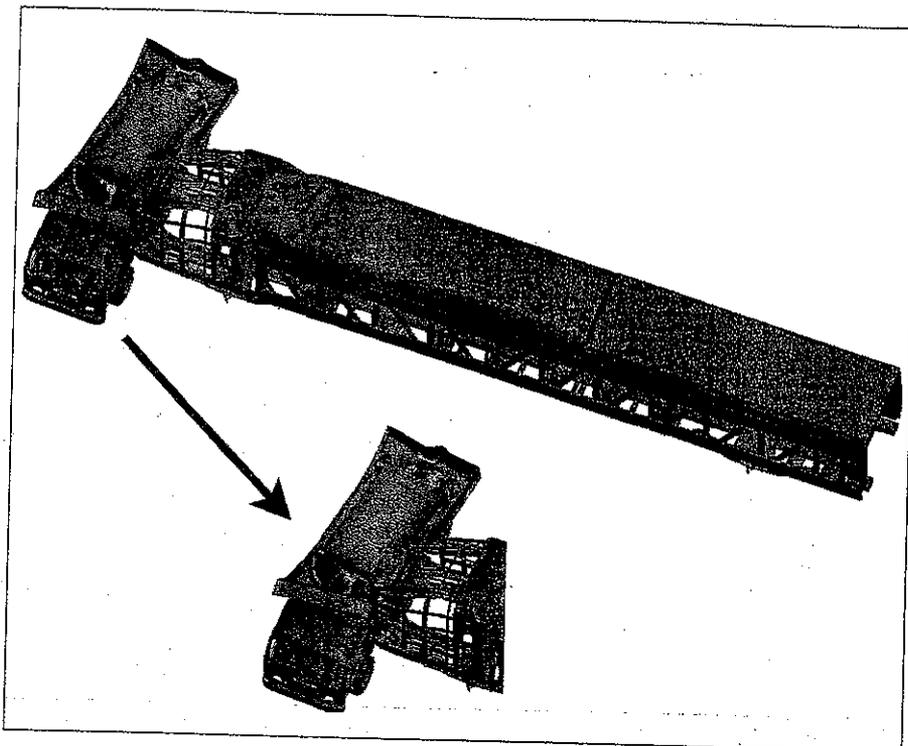


Figure 15: Example of collision analysis result (power car speed at 100 km/h)

speed rolling stock is assessed as remarkable technological development is that it secured the comprehensive system technology from design to interpretation to manufacturing to test evaluation.

During the development process, various core devices were tested in total 4 386 categories including running test, train

structure, and functional motion, within the plant.

The on-line testing began with the pilot operation at the speed of 60 km/h on August 19, 2002, at the Osong Station of Seoul-Busan high speed line in Ganggi-myeon, Chungcheongbuk-do with the assistance of the Korean National Railroad

and the Korea Train Express. With the review of its safety, the speed was gradually increased, and it reached 300 km/h on September 17, 2003. While making a total of 80 test operations for 18 000 km to this point, it traveled at the highest speed of 322 km/h. In the future, with additional test operations for about 100 000 km, it is planned to raise the speed up to 350 km/h.

At the comprehensive testing, the measurements and assessments were made in twelve fields including running performance, stability, vibration feature and comfortable riding in order to verify whether the train could assert various capabilities to the target level.

In order to make the performance analysis and evaluation of the system, the HSR350x has a built-in computer measurement system that was developed with the independent technology (fig. 24). Through this system, the performance during the train running can be collected and analyzed comprehensively. In addition, electric sensors were attached in some 400 places to obtain the motion feature of the train in comprehensive terms.

## 5. Concluding Remarks

The first railroad of Korea was Gyeongin Line between Noryangjin and Jemulpo,

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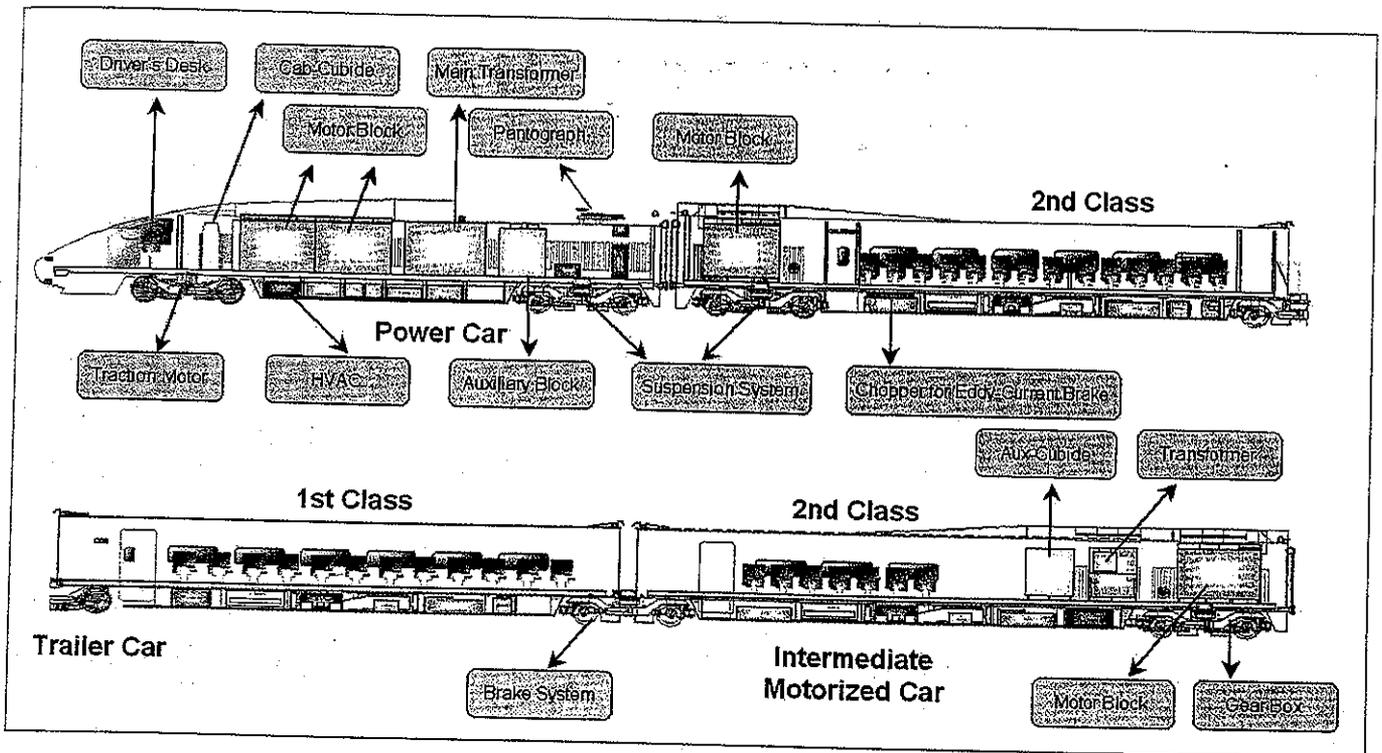
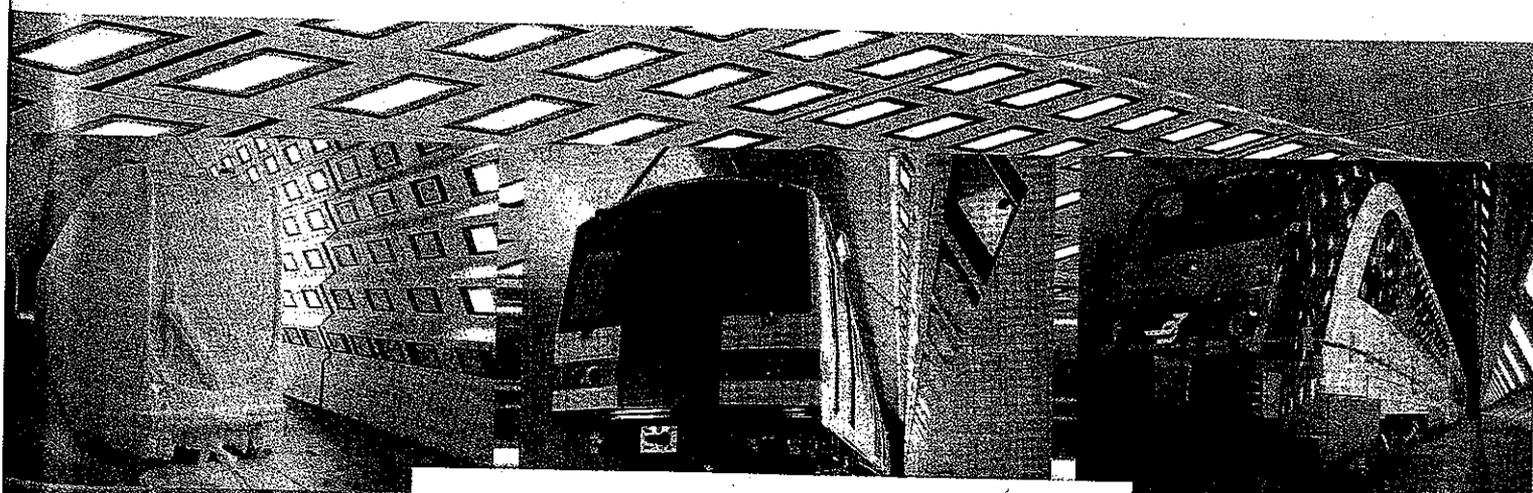


Figure 16: General layout and location of components

and the service operation began on September 18, 1899. 105 years later, the Korean consortium succeeds in developing a new high speed rolling stock whose maximum speed is 350 km/h. It is a landmark in the history of Korean National Railway especially in the field of Research & Development of a railway.

To this point, the investment on R&D in the railway field had been neglected and the core technology and the engineering human resources were absolutely vulnerable. However, in a short period of 6 years Korean engineers leveled up the core technology of railways to the similar level of the advanced countries by

overcoming the overwhelming technology gap in the high speed railway field where it required complicated technologies in mechanical, electric/electronic, communication and civil engineering fields through the cooperation of the industries, academies, and research.



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Table 3: Main specification of the HSR350x

train configuration		7 cars 1 set
seating capacity		82(1st class 26, 2nd class 56)
maximum speed[km/h]		350
acceleration at starting[km/h/s]		1.2
extra acceleration[km/h/s]		0.218(350km/h)
rated output[kW]		13,200
weight[ton]		330
dimension	length[m]	145
	power car[mm]	22,645x2,814x4,062 (LxWxH)
	motorized trailer [mm]	21,845x2,970x3,694 (LxWxH)
	trailer[mm]	18,700x2,970x3,694 (LxWxH)
body structure		extruded aluminum profile welding structure
bogie type		bolsterless type bogie
motor block		PWM control converter + voltage inverter(VVVF), IGCT device
communication network		TCN (Train Communication Network)
brake system		electric brake : recuperation, rheostatic, eddy current brake mechanical brake : tread, wheel disk, axle disk brake
main circuit system		VVVF (Variable Voltage Variable Frequency) control induction motor, main transformer : 25kV, 8,900kVA
pantograph		single armed type

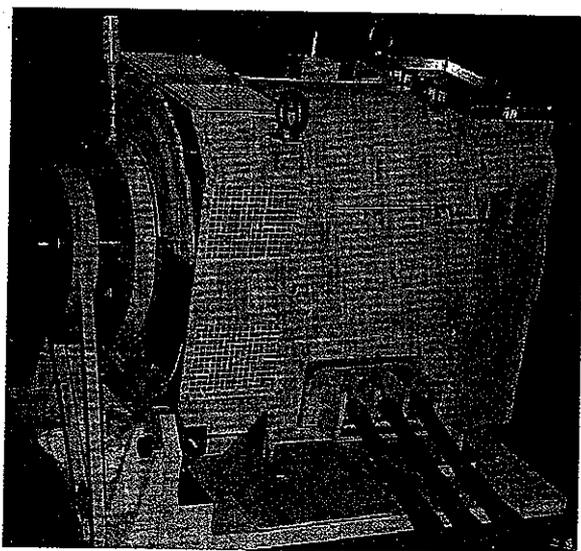


Figure 17: Traction motor

The background of this outstanding outcome was obtained in a short period of time.

First, this R&D program required thorough research planning in advance, a guaranteed stable budget support and development period as well as minimized distortion or shaking of the plan by external disturbances due to different motives of each government agencies or bad economic state.

Second, the three groups of the consortium who developed the HSR350x, private

enterprises, universities and institutes cooperated with each other, and each group had its share in the development. From the beginning, the leading role to manufacture the prototype train and components was given to private enterprises, and the roles of the research institutes or universities were on basic research territory or technological integration/verification fields. Such a project organization to carry out efficient technology development faced invisible interference of some research institutes and universities during the early planning stage, however, leading engineers made concrete decision on the distribution of roles in the R&D project by considering their performance and possibility of

contributing to the technical design and manufacture of the HSR350x (fig. 25). Lastly, the passion and sweats of domestic engineers and researchers should not be left out. The R&D consortium team that participated in designing and manufacturing of train and components completed the ambitious development plan finally, although specialists in Europe were concerned about the difficulty of completing such a project.

The Korea High Speed Prototype Test Train was developed successfully and the commercial operation of the KTX was started and stabilized very rapidly, the railway industry of Korea is expected to have achieved an important turn around and to be equipped with worldwide competitiveness. In addition, it would expect to have the broad propagating effect throughout the domestic railway industry and related industries in anticipation of the railway connection with South-North Korea and the continental railway projects.

The HSR350x will be tested on the high speed line continuously with the aim of verifying the reliability and safety as well as the technological completeness to provide services for passengers Honam high speed line from Seoul to Mokpo in 2007.

The technical review, discussion for deciding operating requirements and basic specification of a commercial train has been made.

(Key index words: Electric trainsets, High Speed Traffic, Testing and Research)

- A 145 -

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Figure 1-3, 5, 9-12, 14, 16, 20, 25, KITECH; Figure 4: KITECH/Rotem Co. Ltd; Figure 6-8, 22, Rotem Co. Ltd; Figure 13: Seoul National University; Figure 15: KIMM (Korea institute of machinery and materials); Figure 17, 19, Rotem Co. Ltd/ Hyundai Heavy Industry; Figure 18, 21, Hyundai Heavy Industry; Figure 23: Yujin Machinery Ltd.; Figure 24: KRRI (Korea Railroad Research Institute)

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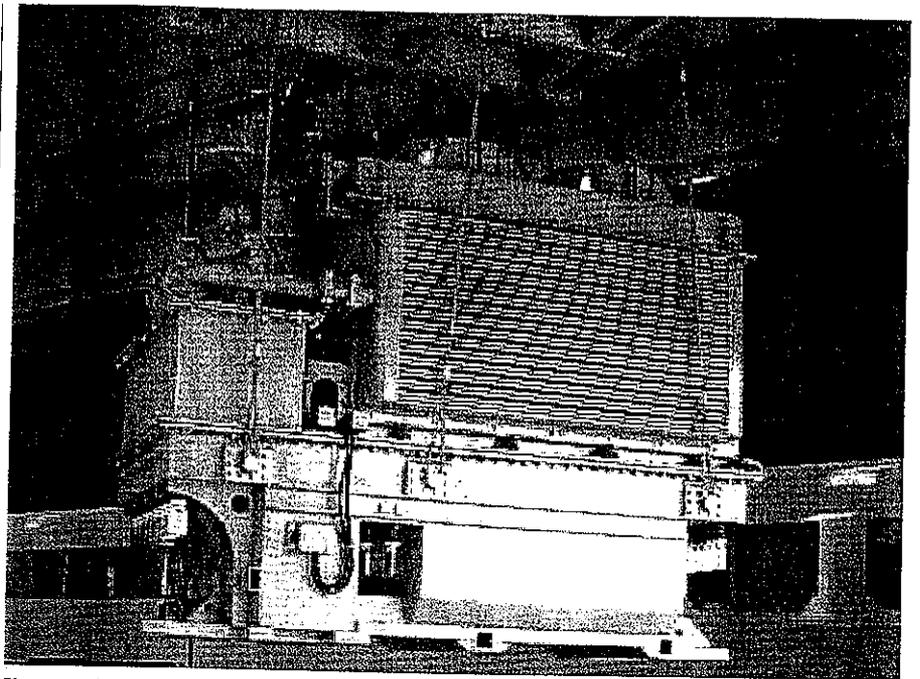


Figure 18: Main transformer

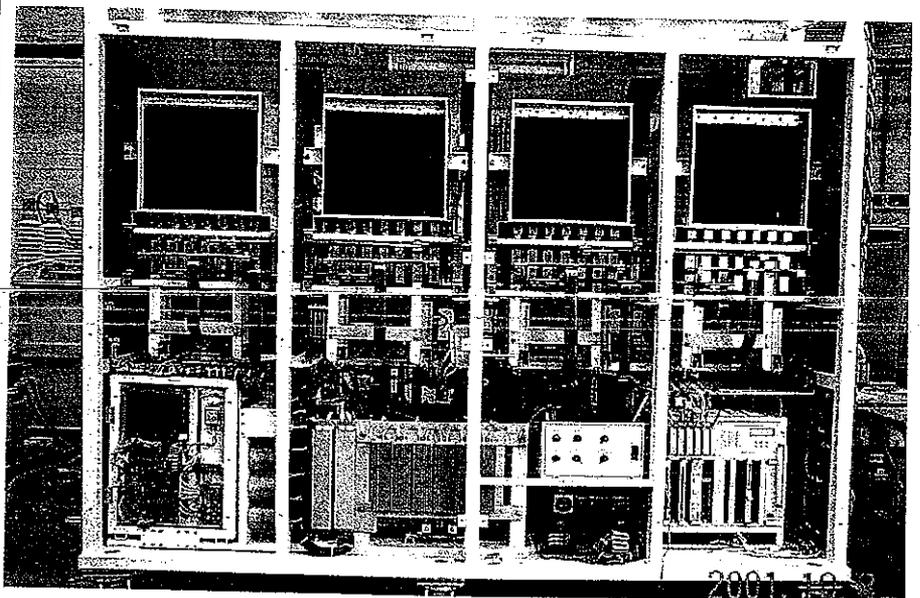


Figure 19: Motor block

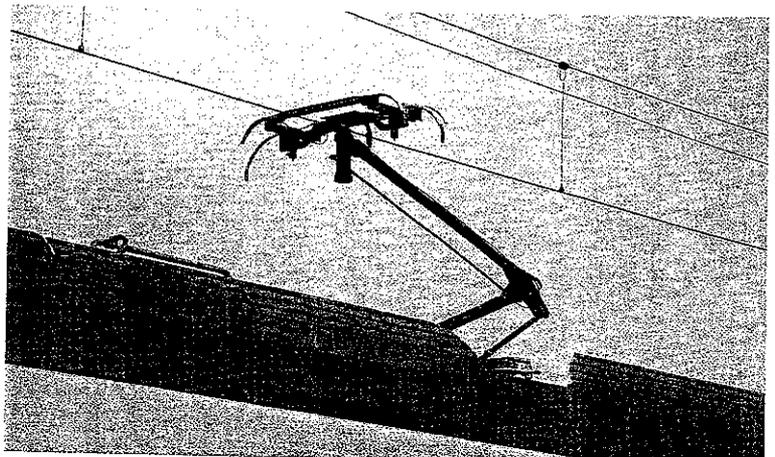


Figure 20: Pantograph

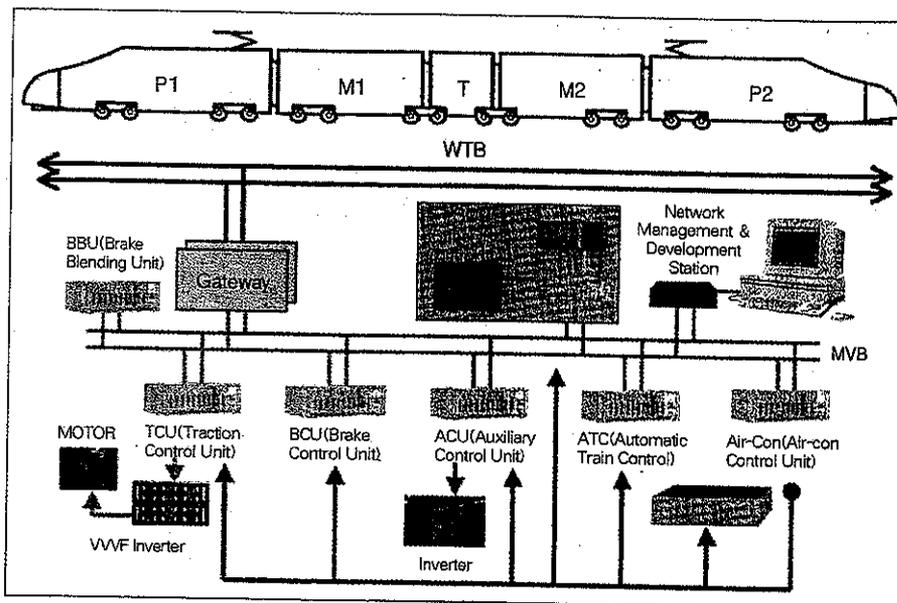


Figure 21: Configuration of the supervisory control unit (SCU) and train communication network (TCN) of HSR 350x

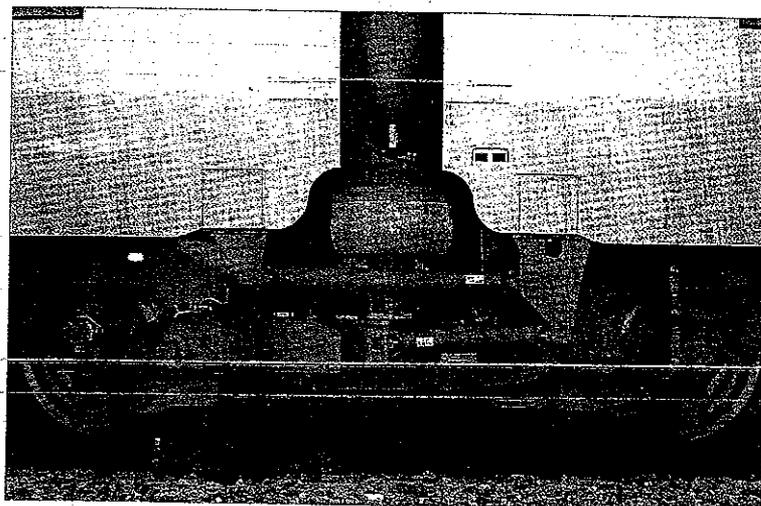


Figure 22: Eddy current brake on the trailer bogie

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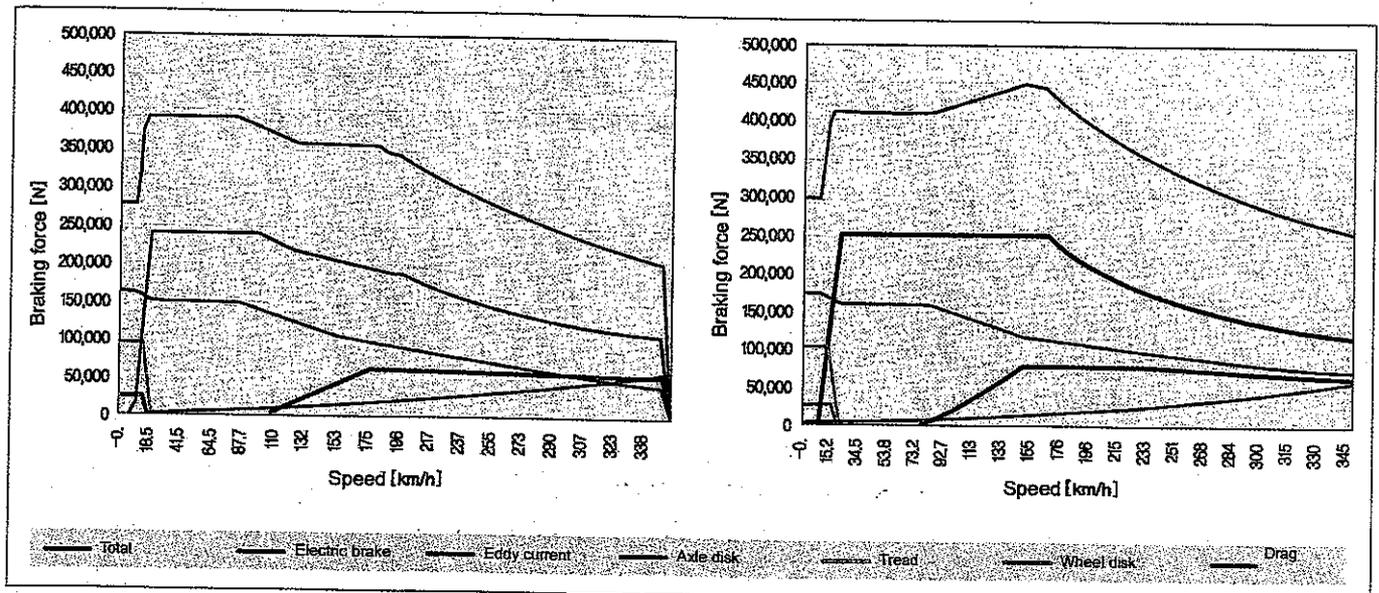


Figure 23: Braking force distribution diagram. Normal braking (Left), emergency braking (right)

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Figure 24: Example of measuring equipment system



Figure 25: Korea high speed prototype test train HSR350x



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