THE HSST MAGLEV TRAIN - DEVELOPMENT, TECHNOLOGY AND PROSPECT

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SUMMARY

The High Speed Surface Transport (HSST) is a magnetically levitated and linear motor propelled vehicle for mass transit. It has superior environmental adaptability over traditional wheeled vehicles. It was first developed by Japan Air Lines in 1975 as the HSST-01 and the following development efforts have resulted in the latest version of HSST-100L. The Ministry of Transport in Japan made an announcement in 1993 that the HSST poses no technical problems concerning its commercial use. It is now awaiting practical operation.

INTRODUCTION

To prepare for the 21st century, an innovative system designed from a totally unique perspective is necessary. The High Speed Surface Transport (HSST) had adopted magnetic suspension technology and realized a contactless and frictionless transportation system. Floating in the air, suspended and propelled by magnetic force, it is expected to bring us unique merits in our society. Its magnetic suspension system is a combination of normal conducting electromagnets and mild steel anchor rails. Its control is similar to that in other normal conducting magnetic suspension systems.

HISTORY OF DEVELOPMENT

Starting with Small Test Vehicles

The HSST's development was started by Japan Air Lines (JAL) in 1972. At that time, the opening of New Tokyo International Airport (Narita) was planned, and research and development of a high speed railroad was started for the access transit system to connect the 60km distance between the airport and downtown Tokyo.

At first, we conducted some experiments with small model units. In 1975, the first test vehicle called HSST-01 (a two-seater car, Photo 1) was constructed in JAL's aircraft maintenance factory. As shown in Fig. 1, it was made of aluminum alloy with a 1 ton gross weight. It has, on the lower part of the body, two lines (left and right) of electromagnets for levitation and one Linear Induction Motor (LIM) at the body center. A run test was performed on the test track constructed at Higashi-Ogishima in Kawasaki City. After various verification tests, it succeeded in running at a speed of over 300km/h (unmanned condition) in 1978.

During this period, a new vehicle, the HSST-02 (Photo 2), was built for the purpose of a riding experience open to the public. As shown in Fig. 2, it had 8 passenger seats and the gross weight was 2 tons. It was used for both technical tests and public relation purposes. The HSST-02 vehicle had a secondary suspension system to improve passenger's ride quality. This vehicle provided maglev experiences to many guests which were mainly leading persons in various areas, including the King and Queen of Sweden.

Major test items were completed in 1980 giving many useful results. We decided to terminate the tests in Higashi-Ogishima and the test site was closed in March 1981.

Aiming at Mass Transportation

The next stage was a larger vehicle which had the capability of mass transportation. The design and manufacturing of the HSST-03 (Photo 3) vehicle used a Module concept which was considered for use in future commercial vehicles. As shown in Fig. 3, the main feature of the Module concept was to build up units called "Modules" combining the functions of both levitation and propulsion. The HSST-03 was equipped with six modules. With more modules, the vehicle can enlarge its capacity, and with less modules, it can diminish the capacity. The HSST-03 was built as a test vehicle. However, its design was also targeted to provide the potential for commercial operations.

The HSST-03 was completed in 1984, and various run tests were conducted using the track constructed at the site of International Exposition in Tsukuba City. Then, it became part of the '85 Tsukuba Science Expo (March to September of 1985) and it was operated for demonstrations in which it provided the maglev ride experiences to 600,000 passengers including the Japanese Emperor and Prime Minister. In the next year, the HSST-03 was also operated for demonstrations at the '86 Transport Expo in Vancouver, Canada, and it was further demonstrated in Aoi Fair (local exposition) in Okazaki, Japan, in 1987. Through the demonstrative operations open to the public during three consecutive expositions, the HSST-03 carried 1.5 million passengers with total running distance of 24,000 km.

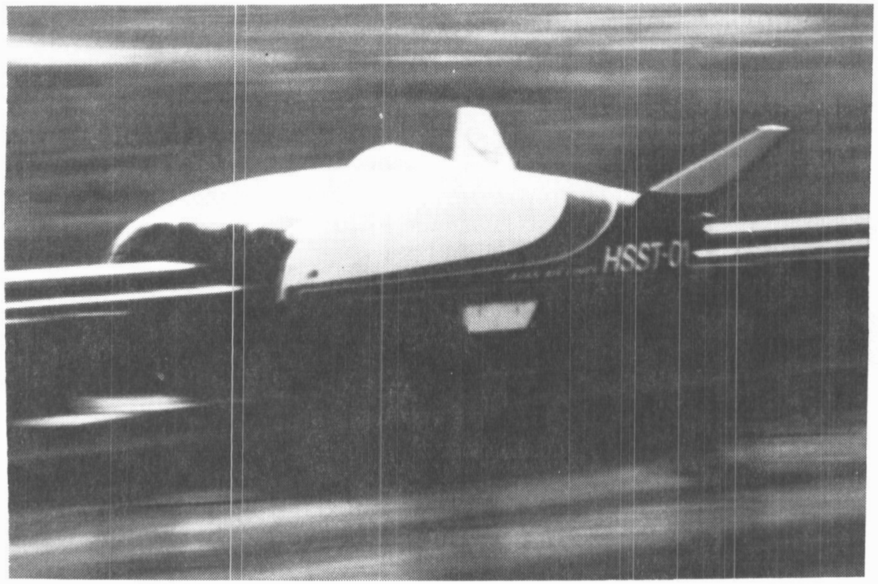

Photo.1 HSST-01 in Ogishima Test Center

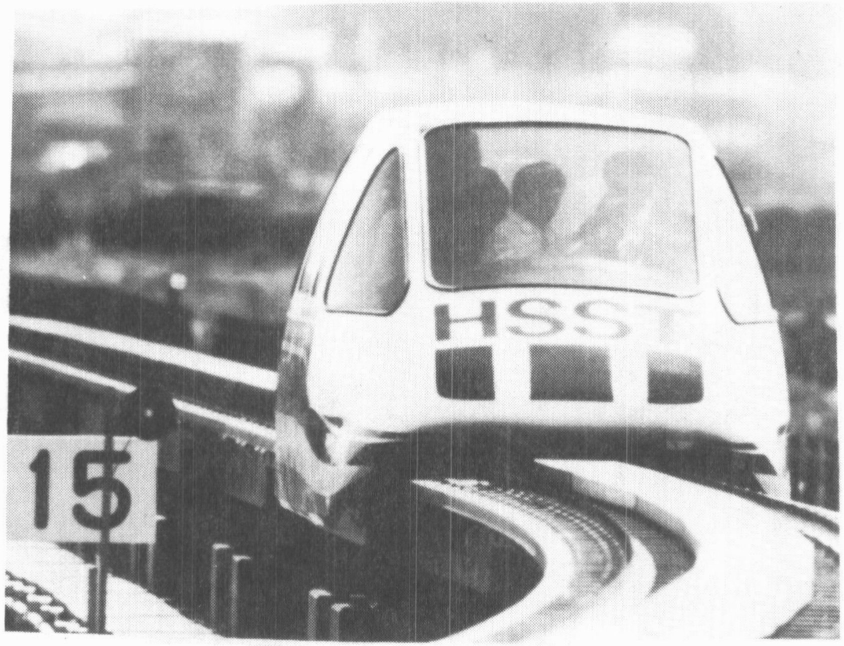

Photo.2 HSST-02 in Ogishima Test Center

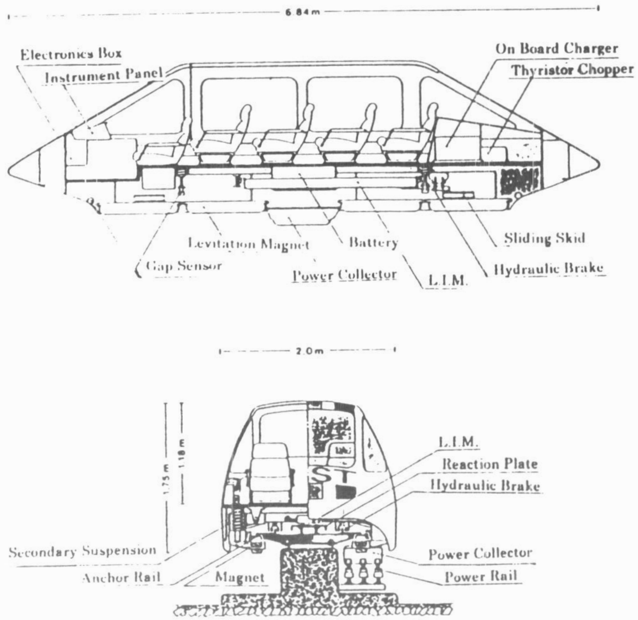

Fig.2 HSST-02 System

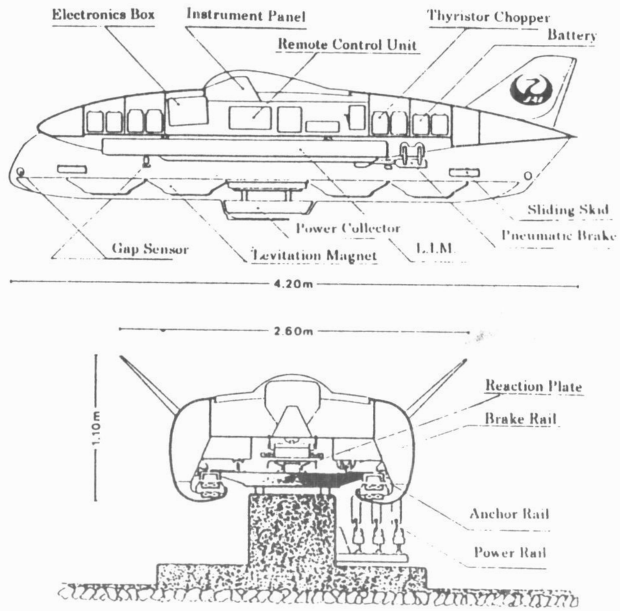

Fig.1 HSST-01 System

Photo.3 HSST-03 in Vancouver Expo '86

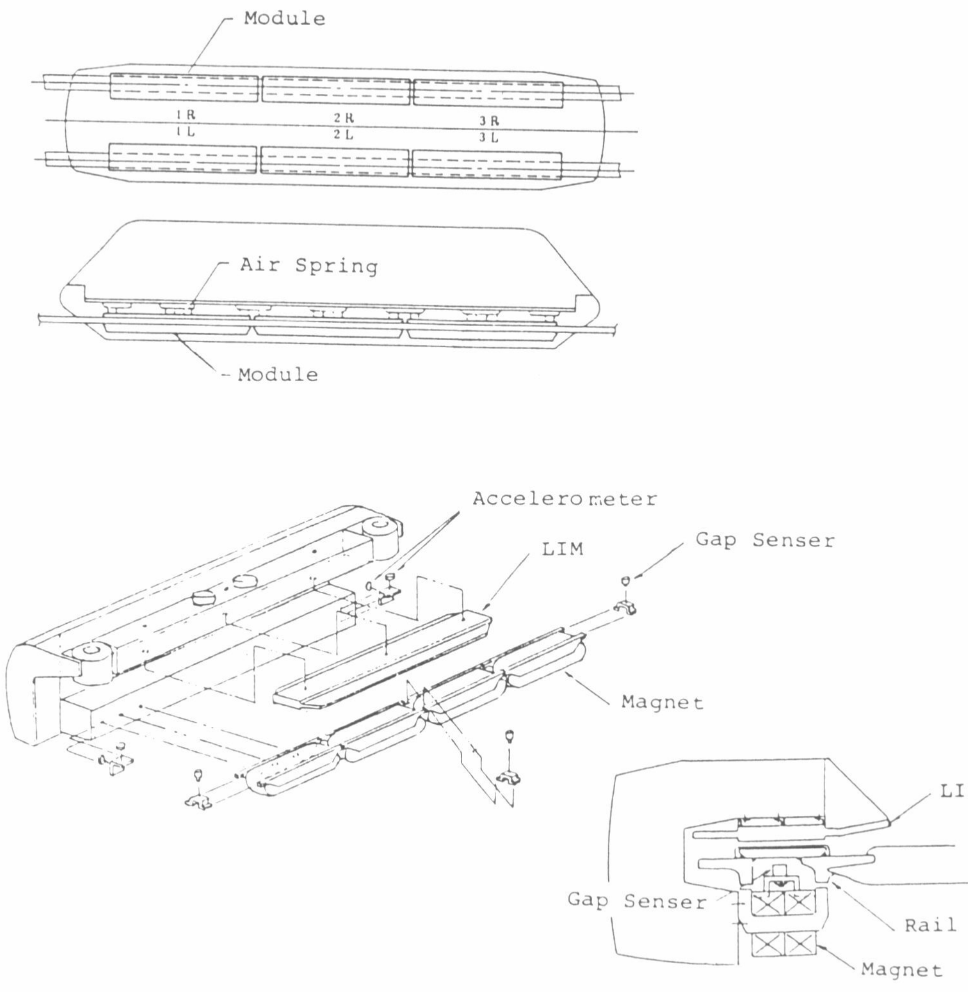

Fig.3 Module System in HSST-03

Establishing a New Corporation for HSST

In 1985, just after the closing of the '85 Tsukuba Science Expo, a small company named HSST Corporation was founded to promote HSST's development and sales, and it inherited all of the HSST businesses from JAL. In this new company, the design of the HSST-04 (Photo 4) vehicle was started. It was a 70-seat single car similar to the monorail system in exterior shape, and had the potential to be operated for commercial operations. Therefore, the design improvements added on HSST-04 over HSST-03 were those such as the adoption of the on-board type propulsion power source (ground side type for HSST-03), the elevated guideway structure (spread footing track for HSST-03), etc. The HSST-04 joined a local exposition held in Kumagaya City, Saitama Prefecture in 1988, and it carried 240,000 passengers during its two-month term.

In 1989, the HSST-05 (Photo 5) was designed and built with a concept similar to the HSST-04. It was fundamentally based on the same technology as HSST-04 except that HSST-05 was a two-car train and was much closer to a commercial train for daily operations. In the same year HSST-05 joined the '89 Yokohama Expo. It is worth noting that HSST operations during the '89 Yokohama Expo were performed as scheduled public transportation with a railroad business license issued by the Ministry of Transport of Japan. The HSST-05, a two-car train with 158 seats, carried 1.26 million passengers during a 191-day term. Both the HSST-04 and HSST-05 were prototype vehicles which belonged to the HSST-200 type with potential to cruise long distances at 200km/hour speed.

Through the operations in the above mentioned expos, HSST's high quality in safety and reliability, and its superb compatibility to the environment have been witnesses and confirmed by many people.

Preparation for HSST's Application to Commercial Operations

In 1990, Aichi Prefecture expressed its intention to investigate the adoption of the HSST system to its newly planned line. Accordingly, Aichi Prefecture, Nagoya Railways, and HSST Corporation founded CHSST (Chubu HSST Development Corporation) to conduct verification tests of the HSST system. The first vehicle type to be tested was the HSST-100S (Photo 6) which is an urban type transit system with a gross weight of 15 tons (per car), with a nominal capacity (per car) of 75 passengers (standard) including 24 seated (refer to the drawing). Concurrently, to investigate the HSST's maturity/compatibility for commercial applications, Aichi Prefecture organized a special investigation committee whose members were specialists of the government (Ministry of Transport, Ministry of Construction) and Aichi Prefecture itself, university professors, and engineers of companies concerned including HSST.

CHSST constructed a 1500m long test guideway in Nagoya City for the various running tests. The tests were conducted there from 1991 to 1993, and more than 100 items were investigated covering a wide range of operation modes including the vehicle and guideway. Test results were

Photo.4 HSST-04 in Saitama Expo '88

Photo.5 HSST-05 in Yokohama Expo '89

Photo.6 HSST-100S in CHSST Test Center

Photo.7 HSST-100L in CHSST Test Center

investigated by the committee, and it issued two reports in 1992 and 1993, respectively. The committee judged that the HSST-100 system was technically mature enough for commercial application though small improvements were required for a few items.

In parallel to the above committee, the Ministry of Transport organized another committee, which announced in 1993 that the HSST system was applicable for commercial application without any technical problems. Then the required legal actions were taken through the amendment of the law/regulations concerned for maglev application to commercial operations.

To further speed-up the HSST's development for commercial application, a new company with 12.1 billion yen capital, called "HSST Development Corporation" was founded in January 1993 by the investment of 52 companies including JAL and Nagoya Railways as the top share-holders. After inheriting all HSST businesses from HSST Corporation, it has been promoting the technologies and sales of the HSST system. For the better sales, HSST Development has added a new type vehicle, the HSST-100L (Photo 7) which can meet wider market demands, with a longer car body with more passenger capacity. The HSST-100L prototype vehicle (two-car train) has been operated on the Nagoya test track for the running tests and endurance tests since 1995, and it has provided, through demonstration runs, many visitors with a comfortable maglev ride [1],[2].

The total running distance of the HSST-100S is 61,724km and that of the HSST-100L is 29,306km as of September 10, 1997.

MAGNETIC SUSPENSION IN HSST

Levitation Magnet

The HSST is equipped with "Modules" which have the similar functions of a bogie of conventional rolling stock. Each module is equipped with four electromagnets. One module has 2.5 tons of levitation capability for HSST-100 vehicle. A 15 ton-car can be supported by six modules.

The main component of the module is an assembly of electromagnets. Table 1 shows the specification of each one of four electromagnets of the HSST-100. The HSST uses an electromagnet which is a so-called "U-shaped Magnet" with its core cross section shaped like a "U". Compared with the "Salient Pole Magnet" with a quadrant shaped magnet core cross section, the "U-shaped Magnet" has the following characteristics. Regarding Lift/Weight Ratio, the "U-shaped" is inferior to the "Salient". On the other hand, the "U-shaped" is similar in structure, for the "U-shaped" has the functions of both vertical levitations and lateral guidance. Furthermore, magnetic drag during a high speed run is less with the "U-shaped" than with the "Salient".

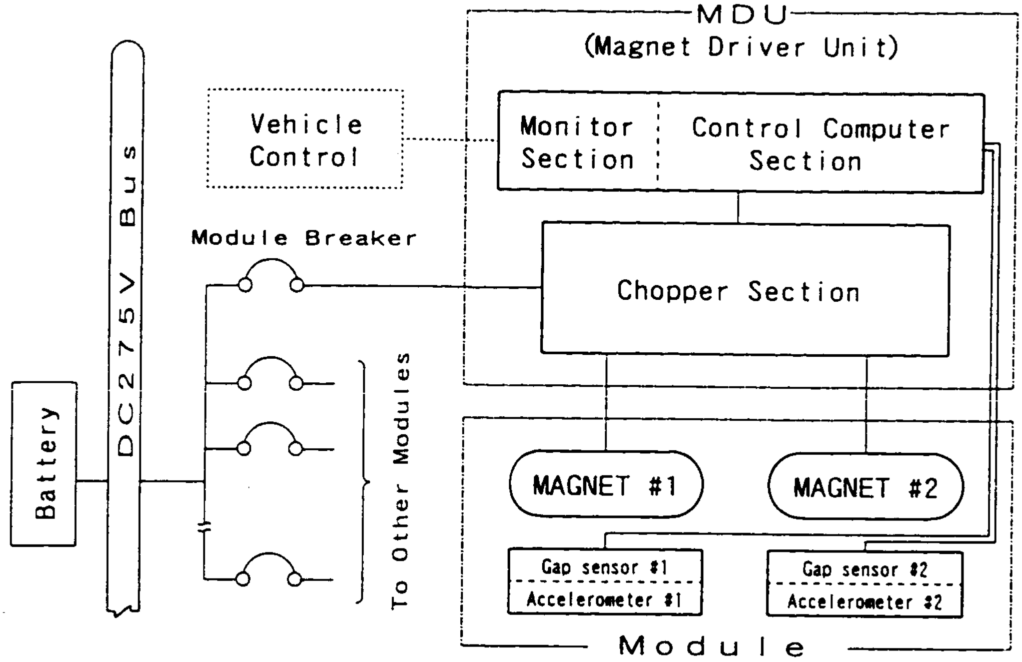

Fig.4 Levitation and Guidance System

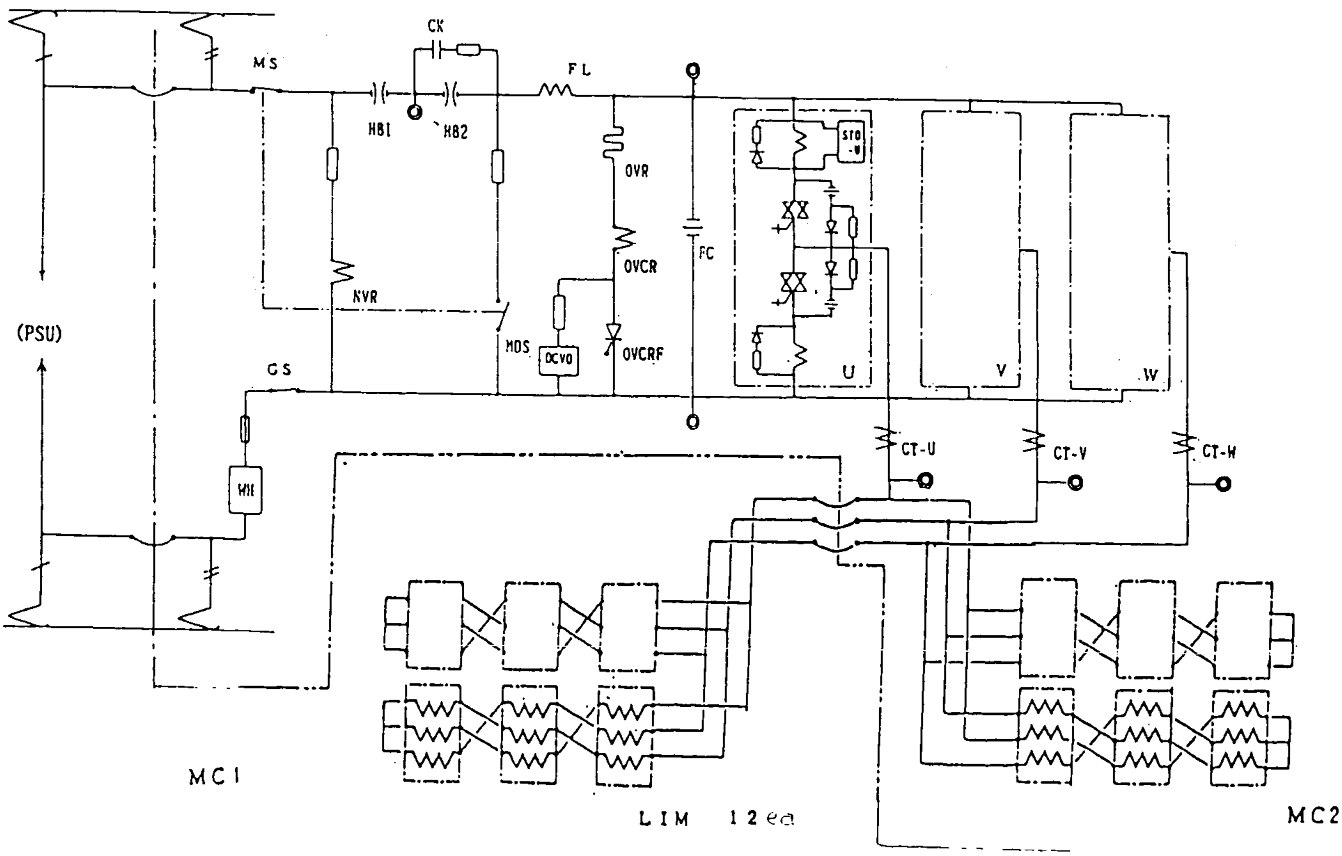

Fig.7 Propulsion System of the HSST-100S

Levitation Control System

Attractive levitation has no natural stability. It requires a feedback control system with sensors. The HSST uses, for this purpose, gap sensors and accelerometers mounted on the surface of the magnet. Fig. 4 shows the block diagram of the levitation system. Sensors detect the movement of magnet and send its signal to the MDU (Magnet Driver Unit). The data is processed in the Control Computer Section and the resulting voltage is sent to the Chopper Section. The Chopper regulates the 275VDC supply voltage in accordance with Pulse Width Modulation (PWM). This regulated power is fed to the magnet coil. The 275VDC supply power is backed up with batteries.

The control system is proportional-integral-derivative (PID). The main signal is the gap between magnet and steel rail. Its proportional element determines magnet position from the rail. The integral element ensures the magnet position accuracy against disturbance such as load change caused by passenger increase/decrease. The differential element has a damping effect to prevent vibration. Accelerometers further ensure damping characteristics of the magnet.

CHSST TEST CENTER AND OPERATION TESTS

Test Center

The Chubu HSST Development Corporation constructed the HSST Test Center in Nagoya in 1991. Fig. 5 shows its profile. The track is approximately 1.5km length, which is sufficient to attain a speed of over 100km/h. It incorporates lateral and vertical curves, 100mR and 700mR respectively, which represent the major allowable mainline curvature for the HSST-100S vehicle. A switching device near the car shed leads a vehicle to a branch line of 25mR horizontal curve which represents the minimum allowable radius in the maintenance yard. Rail gauge is 1.7m.

Test Vehicle HSST-100S

Fig. 6 shows the configuration of the HSST-100S, which was the first vehicle system to be tested in Nagoya. This vehicle has two cars, MC1 and MC2 (Motor Control 1 & 2), with a maximum capacity of 67 passengers per car. The car length of 8.5m was determined chiefly by the minimum curve radius of 25mR. The design speed is 110km/h. The car body is made of aluminum alloy. The gross weight is 15 tons per car.

The levitation system is shown above. Here Fig. 7 shows the propulsion system of the HSST-100S. A car has six modules and each module has one LIM. A total of 12 LIMs are connected in three series and four parallel. Trolley power voltage is 1500VDC which is inverted to VVVF through GTO inverters. Maximum frequency is 90Hz, maximum current 800A. It is incorporated with regenerative braking control and weight adaptive compensation control. This system is backed up by a hydraulic mechanical braking system. Thus the acceleration and deceleration rate is maintained constant as long as the trolley power supply is sufficient [3].

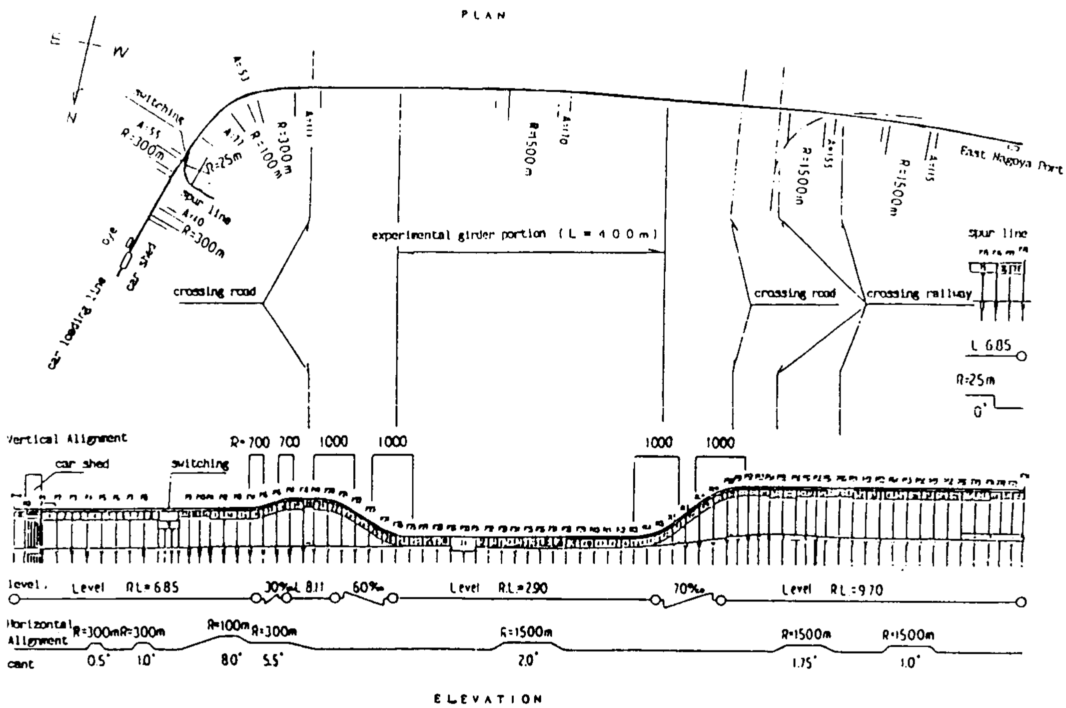

Fig.5 Horizontal Plan and Vertical Elevation of Test Track in Nagoya

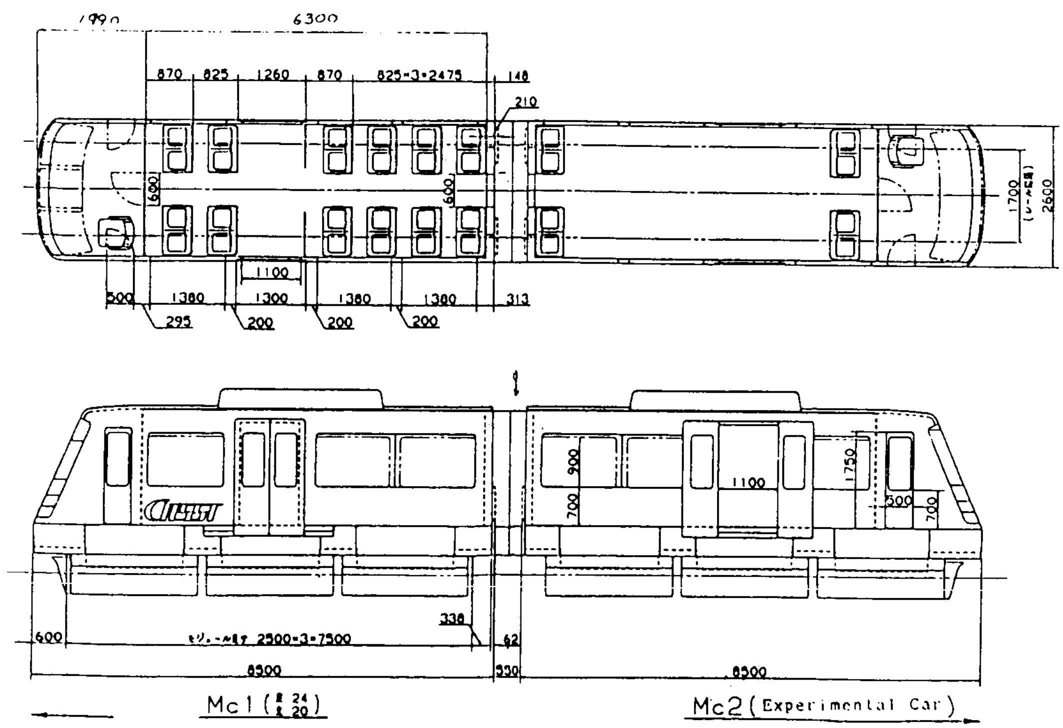

Fig.6 HSST-100S Vehicle

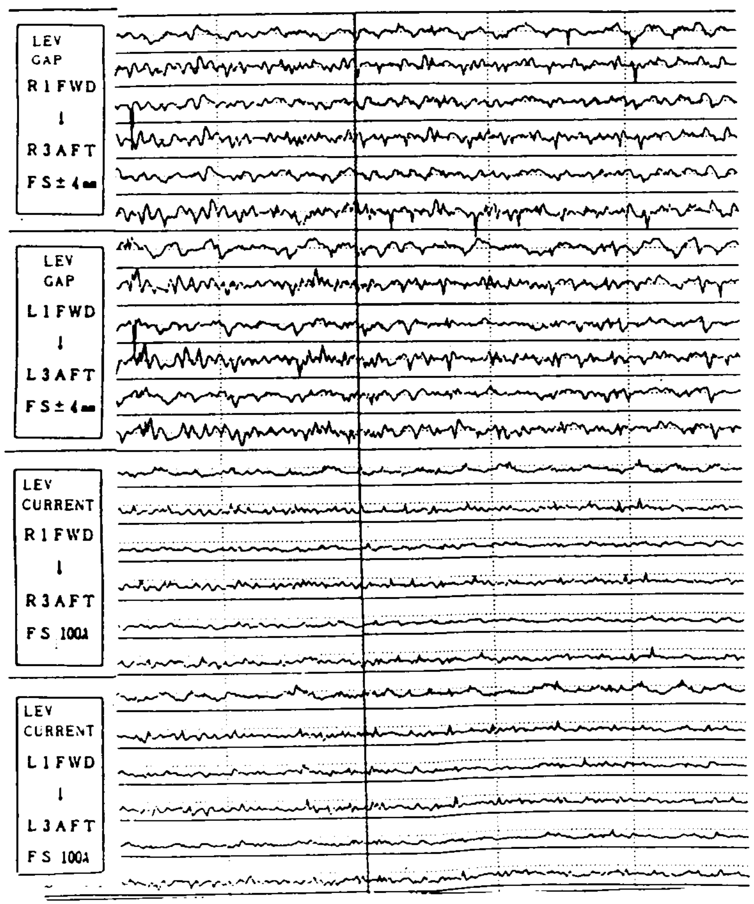

Fig.9 Propulsion and Braking Behavior - 100km/h, Empty Load

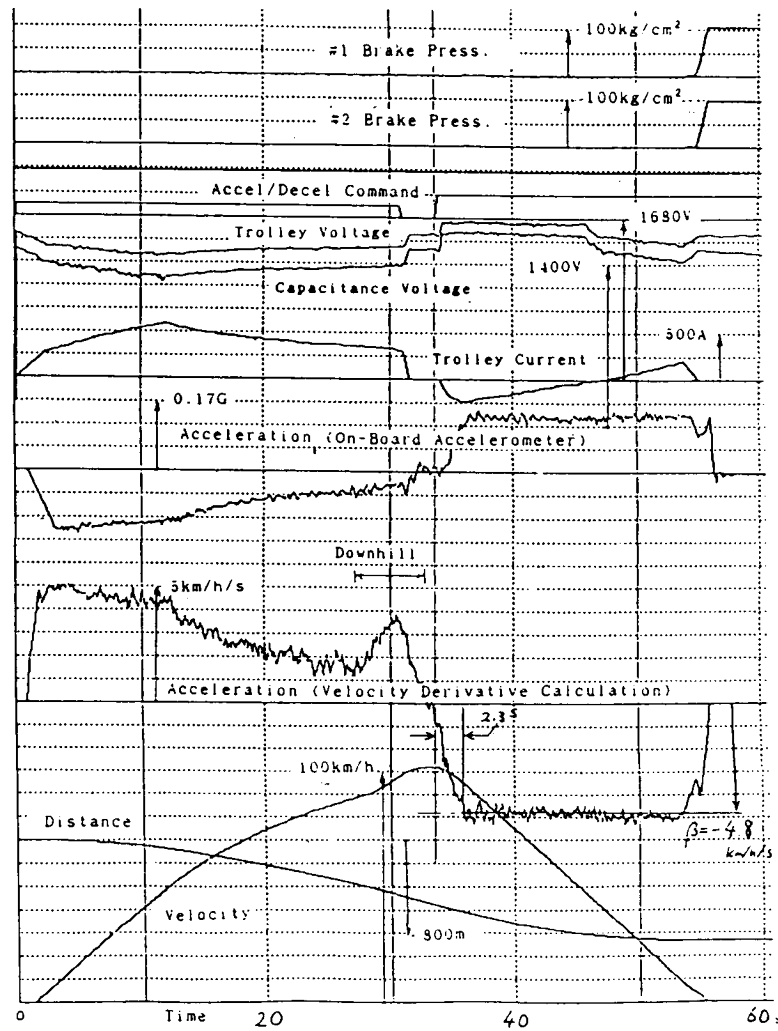

Fig.8 Magnet Gap and Current Fluctuation - 100km/h, Full Load

Operation Test Results - Levitation and Propulsion (Tested in 1992 on HSST-100S)

Fig. 8 shows the test result of a levitation gap fluctuation at 100km/h. Upper half oscillations are the output signal of gap sensors equipped on each module. The center line means a standard gap of 8mm and full scale values are +/- 4mm. The lower half are output signals of the current detector of the chopper. The scale is 0-100A. We can see that magnet gap fluctuation at 100km/h is less than 4mm and the vehicle can run without contact to the rail. The RMS average of the magnet gap proved to be less than 1mm.

Fig. 9 shows propulsion and braking behavior of the vehicle. We can see the general running pattern of the vehicle from this figure. In this case the vehicle started from the west end of the track. Acceleration becomes 5km/h/s at 2 seconds after starting. It begins to decrease at 10 seconds after starting with 50km/h of velocity where trolley current begins to decrease on account of VVVF voltage saturation. The vehicle speed reaches 100km/h at the 500m (35 seconds) point. This location is the bottom of the east downhill because, just prior to the top speed, the on-board accelerometer maintains constant acceleration while the velocity derivative acceleration shows a sharp increase. Braking is engaged just after top speed. Deceleration is maintained at 4.8km/h/s until the car stops at 900m (55 seconds) point. During the braking mode, trolley current flows in a negative direction which means regenerative braking, however it soon comes to a positive direction (power feeding braking) and, at last, zero when the vehicle stops. Hydraulic brake pressure rises at this moment which means the braking function changes from deceleration to parking.

FUTURE PROSPECT OF HSST

The HSST's basic feature is contactless running. As a result, it has many advantages over conventional railway systems. Fig. 10 summarizes these features of HSST. Low noise emission, low inner and outer vibration - in short, outstanding adaptability to the environment seems to be the most remarkable feature of the HSST when we consider the latest social conditions.

A magnetic suspension train is being developed also in Germany and Korea. In Japan, the JR group is developing another type of vehicle system with superconducting magnetic suspension. We believe that such a tendency is in accordance with the social needs for better quality in transport [4].

Currently, HSST has some projects of practical operation. Domestic projects are in Oofuna, Nagoya and Hiroshima, etc. Overseas projects are in the U.S.A., Mexico and Brazil, etc. They are under investigation at this time. We hope we will be able to inform you of the first practical application of HSST very soon.

Type	Normal Conducting and Attractive
Core Material	Mild Steel
Pole Width	28 mm
Pole Length	616 mm
Coil Material	Electric Aluminum
Coil Turn	304T
Rated Air Gap	8 mm
Attractive Force	625 kg (per one magnet)
Weight	65 kg (per one magnet)

Table 1　Levitation Magnet of HSST-100

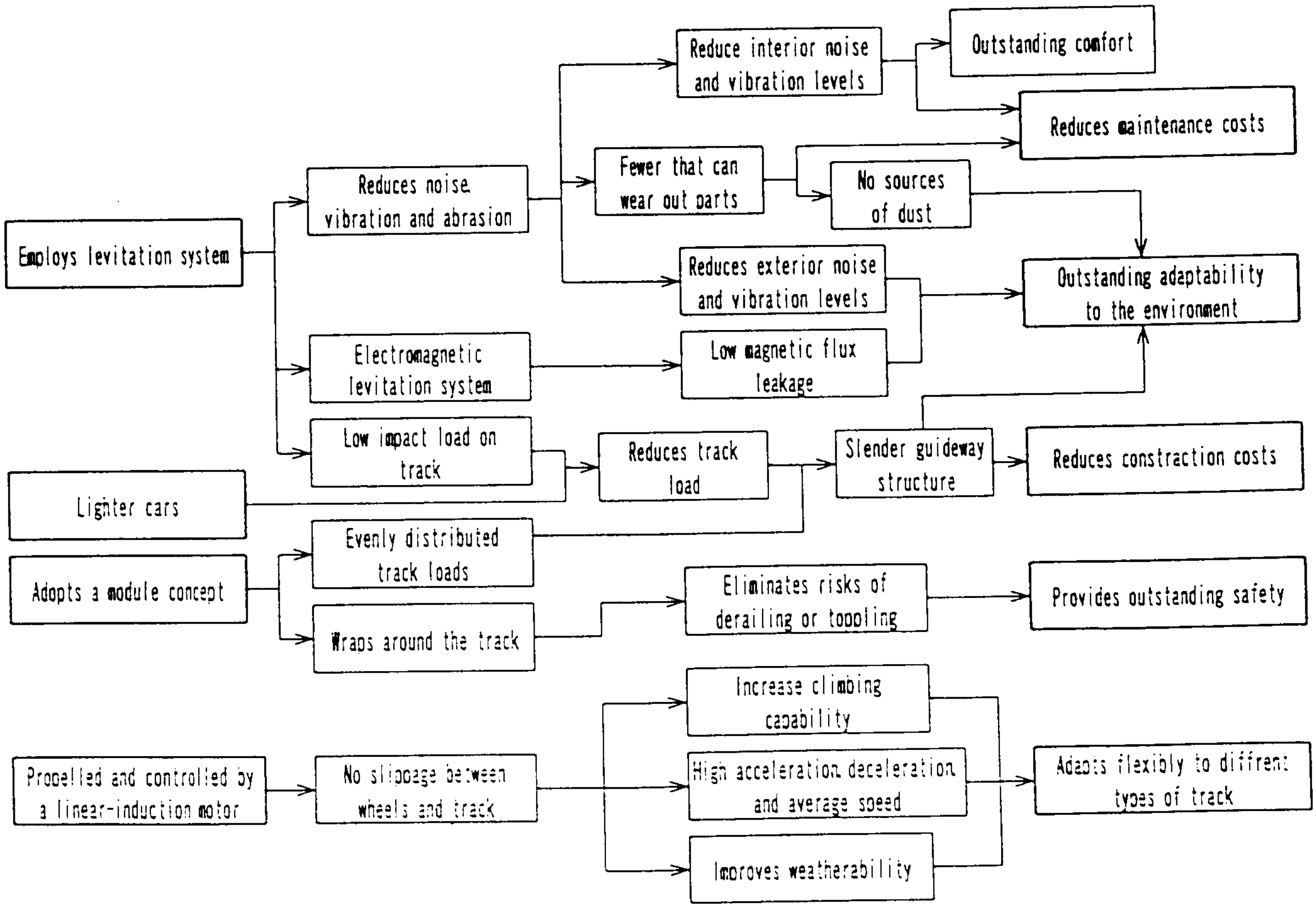

Fig.10　Special Features of the HSST system

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[2] T. Seki, "The Development of HSST-100L", Maglev "95, Bremen

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[4] HSST Development Corporation, Internet Homepage http://www.jalgroup/gr/HSST/index.htm