Automated People Mover for Airports

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Recently, as the size of each airport has grown a track transportation system inside the airport for passengers has become indispensable. Under such circumstance, Mitsubishi Heavy Industries, Ltd. (MHI) have received an order for APM system, which is a completely automated rubber tired vehicle, to be installed at the new airport in Hong Kong. The core of the APM vehicle system is designed based on the vehicles of the domestic (Japanese) new transportation system. In order to apply the system to the airports, we had various issues to solve including automatic train control system improvement of safety functions, stopping accuracy and so on. In this report, we explain outline of the work we did during design and manufacture stages. We have tested the completed APM vehicle on our test track. As a result of the test, we confirmed that the vehicle had come up to the target level.

1. Introduction

Recently, construction of airport hubs and the expansion of the existing airports have become popular in the world, mainly in Southeast Asian countries. As the size of each airport has grown, the movement of passengers inside and in the areas surrounding airports tend to increase, and the distance that passengers must move across also tends to be longer. Therefore, new transportation systems, has become indispensable in such large-sized airports.

MHI has received an order for an Automated People Mover System (APM system) for the new Hong Kong airport as the first transportation system for use at an airport. Construction of the entire system has been completed and the system is currently undergoing final adjustment in preparation for the opening of the airport in July 1998. This report presents on overview of the Automated People Mover Vehicle (hereinafter referred to as APM vehicle) which serves as the core of the APM system (**Fig. 1**).

2. Outline of APM system

The APM system for the new Hong Kong airport connects the airport terminal building and the remote gates. It is used inside the airport for passengers. This APM system, as shown in **Table 1**, consists of several sub-systems such as an operation control system, signaling system, communication system, automatic operation system, power distribution system, track, station equipment and maintenance equipment. This contract is the first phase of new airport project which consists of an about 700 m long double track between two stations in an underground tunnel of the entire length. Transportation capacity of the system is a maximum of 5 270 Passengers Per Hour Per Direction (PPHPD).

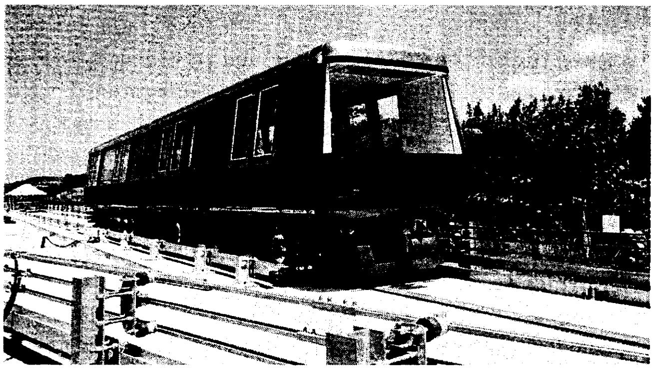

Fig. 1 Vehicle on MHI test track
The APM vehicle under completely automated operation on MHI test track is shown here.

The operation of the vehicles consists of a completely automated operation using an Automatic Train Control (ATC) system. The ATC system consists of an Automatic Train Protection system (ATP), Automatic Train Operation system (ATO) and Automatic Train Supervision system (ATS). The ATP system employs an on-board signal aspect system, a check-in/check-out system, and controls the route through a Solid State Interlocking (SSI) system. The ATO has a programmed station stop function using an on-board arithmetic system. Further, a station ATO system for cooperative control of vehicle doors and platform doors as well as an ATO data transmission system between vehicle and on-land equipment are installed as part of the APM system. The ATS system has the functions of supervising and implementing the operational

Table 1 Sub-system of APM system

Sub-system	Main component	Function
Vehicle	Vehicle	Transport unit
Operation control system	Operation control unit	Operation and control of entire system
Signalling system	ATP/TD unit	Signal and safety function
Communication system	ATO transmission unit, LCX transmission unit	Communication between ground and train
Automatic operation system	On-board ATP/ATO unit, Station ATO unit	Automatic train operation
Power distribution system	Transformer, electric overhead line	Supplying power to system and vehicle
Guideway	Running surface, guide rail, switch	Running track of vehicle
Station equipment	Platform door	Securing safety of passengers
Maintenance equipment	Maintenance equipment	Maintenance equipment of vehicle

Note: ATP/TD Automatic Train Protection/Train Detection

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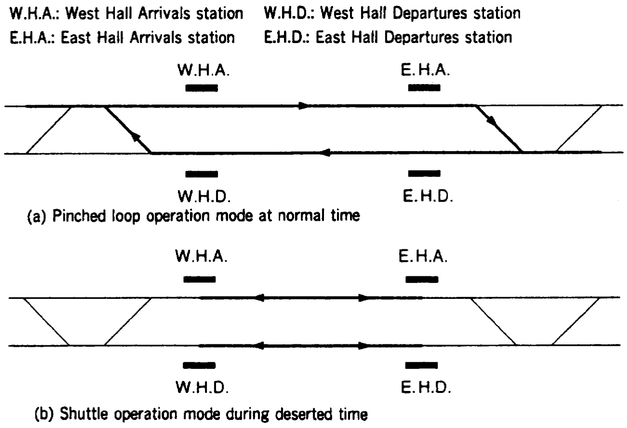

Fig. 2 System operation mode
Basic operation mode of the APM system is shown.

Table 2 Specifications of APM vehicle

Item	Specification
Vehicle formation	Two-cars fixed formation
Passenger capacity (person)	76 (inclusive of 5 seats)/car×2 cars
Tare weight (tf)	11.8/vehicle
Vehicle dimensions (mm)	9 850 long×2 700 wide×3 510 high/car
Guidance system	Side guide 2-shaft, 4-wheel steering system
Electric system	3-phase, A.C. 600V, 50 Hz
Gauge (mm)	Tred 1 700, guide rail span 2 800
Vehicle performance	Maximum speed: 70 km/h Acceleration: 3.5 km/(h·s) Deceleration Maximum service: 3.6 km/(h·s) Emergency: 5.4 km/(h·s)
Control system	Thyristor leonard phase shift control (with load compensating device and regenerative brakes)
Brake system	Electric command electro-pneumatic straight air brake system (with safety brake and parking brake)

command of the system, monitoring and recording of system operations and is installed in the airport operation control center. The command console consists of a touch-screen type CRT operation system and is designed to control the operation by one operator except in the case of an emergency.

As airports are operated 24 hours a day, the APM system must also be operated for 24 hours. In order to meet such variations in demand, two main types of operating modes have been adopted. Four trains are used on the tracks and loop operation is performed during peak times [**Fig. 2**(a)] and, while shuttle operation using two train formations to meet demand have been implemented at the times when the airport is comparatively deserted such as at mid-night [refer to Fig. 2(b)]. Furthermore, five operation modes other than the above are set to deal with maintenance and failure of the sub-systems such as vehicles, power system and tracks. Completely automated operation of the ATC system is possible in these operation modes. The operation modes including the number of train formations are designed to be automatically changed through CRT operation in the central operation command room. This system is designed to achieve a high rate of operation [Fault Tree Analysis (FTA) result 99.9 %] as an APM system by flexibly setting and selecting the operation modes and improving reliability of the sub-systems.

3. Development of APM vehicle

3.1 Overview of APM vehicle

APM vehicles have been improved and altered in design to adapt to the special needs of passenger transport inside the airport based on the rubber tired vehicle of the new transportation systems so far delivered in Japan. **Fig. 3** shows the vehicle formation and **Table 2** summarizes the main specifications of the vehicle.

The vehicle formation consists of a fixed formation of two cars and can be formed up to three vehicles for completely automated operation. The sizes of the vehicle are enlarged based on the vehicles of the new transportation system used in Japan taking into consideration the increase in transportation volume of the system and improvement in the degree of comfort in the vehicles. Passenger capacity per vehicle formation has been increased to 152 persons.

The vehicle body consists of a welded structure of aluminum alloy in order to reduce weight. The bogie is a steering bogie with side guiding equipment consisting of a driving bogie a trailing bogie. A set of the driving bogie and trailing bogie is equipped on each vehicle. Type tests of the vehicle and continuous running for 800 km under completely automated operation of the vehicle were performed during which time its performance and reliability were confirmed.

3.2 On-board ATC system

Fig.4 shows the block diagram of the on-board ATC system.

3.2.1 Automatic operation system

The automatic operation system consists of the following equipment based on the new transportation systems used in Japan.

(1) ATO unit (onboard)

The target operation speed of the system is set based on ATP signal given from ATP receiver, and the function of

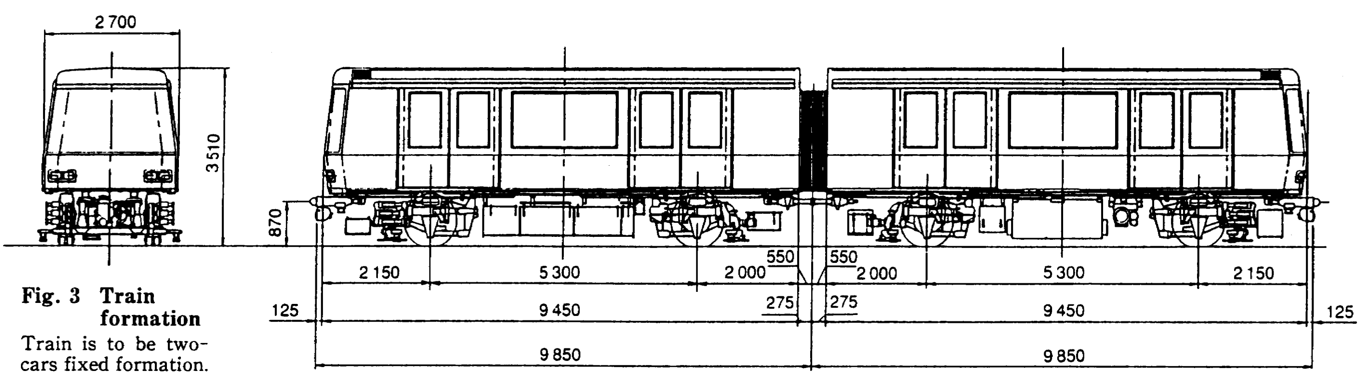

Fig. 3 Train formation
Train is to be two-cars fixed formation.

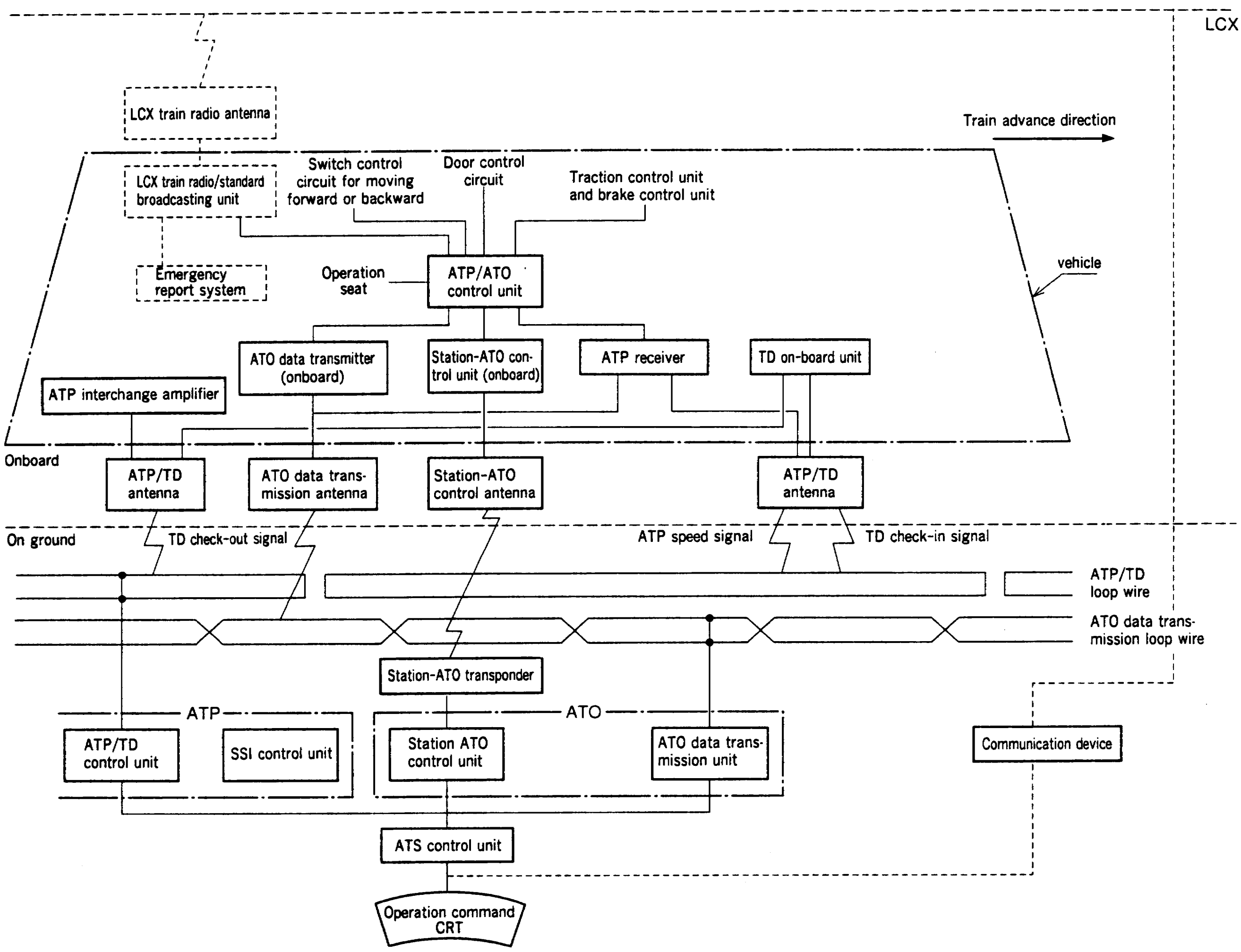

Fig. 4 Block diagram of on-board ATC system
Configuration of on-board ATC system and relation with on-land ATC system are shown.

constant speed operation control and the function of the programmed station stop based on the spot signal received by the station ATO control onboard unit are given to this system. Measures for improving accuracy for programmed station stops were taken as described in Section 3.4.

(2) Station ATO control unit (onboard)

The onboard antenna receives the door control command from the ground unit installed on each station. Further, the function of transmitting train control state signals from onboard at each station is given to the station ATO control unit.

(3) ATO data transmitter (onboard)

The function of the onboard ATO data transmitter is to make contact between the central command station and the train. The central command station transmits the control command to various units in the system, while at the same time the state information such as operation and failure of each unit is transmitted to the central command station from the vehicle.

3.2.2 Safety system

Safety and communication systems are also based on the new transportation systems used in Japan.

(1) ATP system

The ATP system continuously transmits the control speed signal to the inductive loop installed on land which is continuously received and decoded by the onboard antenna. Information such as speed limit and stopping of the train is given to the ATP control system. Further, in the APM vehicle, switching of directions of the vehicle and distinctions for opening the side doors which were previously the functions of the station ATO system, etc. were integrated in the safety function of the ATP system in order to improve safety.

(2) TD system (onboard) (Train Detection: TD)

This system gives information regarding train track position to the ATP system (on ground) and is a continuous transmit-receive type system.

3.2.3 Communication system

The train radio system employs an LCX system, and two emergency speaking devices are installed in each vehicle so that passengers can communicate and speak with the central command station in case of an emergency.

On-ground and onboard connection tests as well as automatic operation running tests were performed on the MHI test track for the above onboard ATC system. It was confirmed that the functions and performance characteristics achieved the expected target values. In addition, the software of the entire ATC system including the on-land system was examined

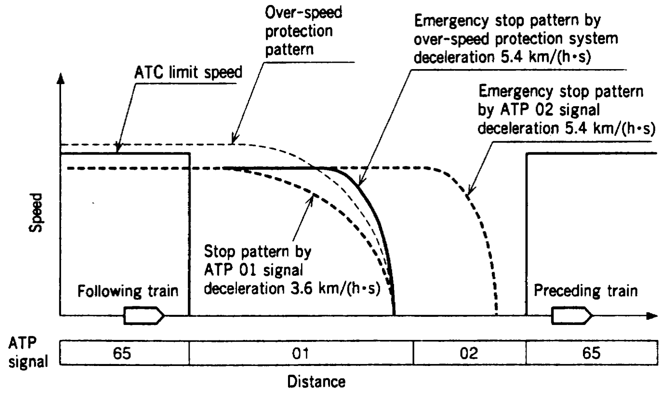

Fig. 5 Conceptual drawing of over-speed protection
An emergency stop is executed at the expected stop position even if the over-speed protection pattern is touched in the ATP 01 signal section. The ATP 02 signal section may possibly be omitted when the over-speed protection system is installed.

by the Railway Technical Research Institute for safety based on IEC 1508 "Functional Safety: safety-related systems (part 1 to 7)" according to which the safety was confirmed.

3.3 Over-speed protection

The ATP system of the safety system on ground was employed as an operation safety system in this APM system. Further, an over-speed protection function was newly added as an on-board-related operation safety system, in order to improve the redundancy of the operation safety system and reduce train operation intervals. **Fig. 5** shows a conceptual drawing of the over-speed protection.

As shown in Fig. 5, the tracks on which the vehicles run is fixedly divided into a constant section (block section) for safety and ATP signals (limiting speed signal and stop signal) are given to each section based on the relative position between trains and restrictions on the tracks such as curvature. The train is automatically operated according to these ATP signals received from the ground. The stop signal (0 signal: 01 or 02) is given to the rear section of the preceding train. The function which decelerates and stops the following train by the ATP brakes [service maximum deceleration 3.6 km/(h·s)] when it enters the 01 signal section, and decelerates and stops the train by the emergency brake [deceleration 5.4 km/(h·s)] when it enters the 02 signal section, is set to the ATP system. Further, when the train exceeds the ATP signal during constant speed running according to the speed signal, the train is decelerated to less than the ATP signal by the service maximum brake. These safety functions are given by the ATP system on the ground. However, the ATP system based on such fixed block establishes the fixed safety intervals which are always required by the brake performance of the train between the preceding train and the following train. As a result, this system hampers high density operation of the trains.

However, in this system the emergency stop pattern was set in the outside of the ATP signal from the ground as shown in Fig. 5. This function is in which after the train enters the ATP 01 signal section, the emergency stop pattern is generated in the onboard control unit and the presence or absence of touch with this pattern is verified by the running distance and speed of the train itself. When presence of such touch is verified, the emergency brake is actuated.

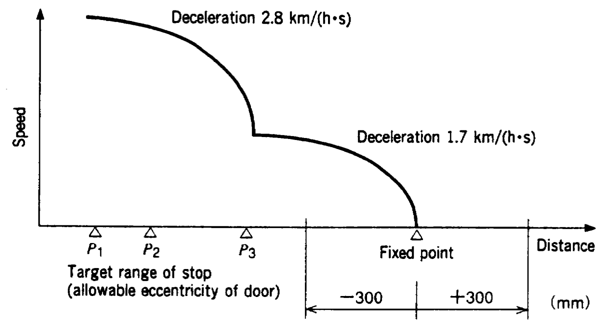

Fig. 6 Train automatic stop control pattern
The typical deceleration and stop pattern of a train which stops at a station is shown here. The train is controlled in such fashion as to be automatically decelerated and stopped according to a two stage pattern.

The emergency stop pattern is set such that the emergency stop pattern is generated in the onboard ATP control unit in the ATP 0 signal section. Even when the train is not decelerated with the specified ATP brake by the 01 signal, the train is stopped by the emergency brake at the specified stop position by the ATP brake. At the same time, the absolute limiting speed line in the ATP limit speed signal section is established above the limiting speed. When the train speed exceeds this line, the function of emergency stop [deceleration 5.4 km(h·s)] is added to the emergency stop pattern. The operation safety system using such onboard control system is called over-speed protection.

As described above, safe and high-density operation became possible in the completely automated operation through the addition of over-speed protection function to the existing ATP function. The verification test for this function was performed on the MHI test track. From such results, it

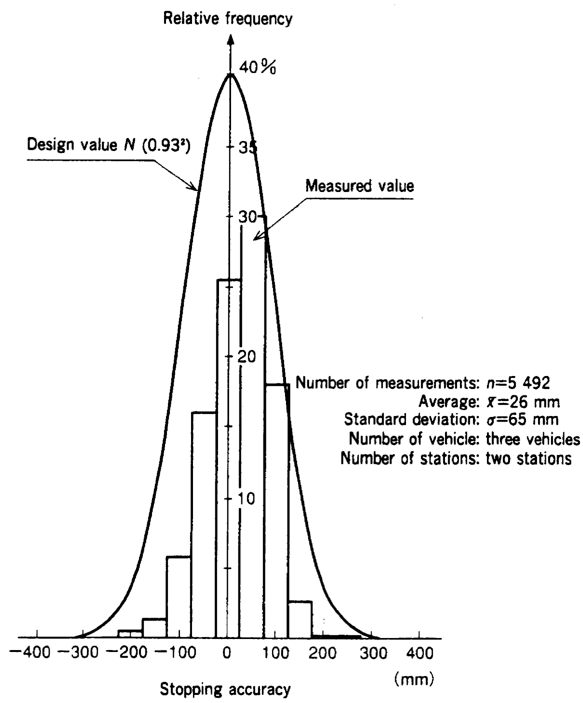

Fig. 7 Result of measuring of stopping position
The results of measurements of stopping accuracy at the MHI company test track is shown by a histogram. From this figure, it can be seen that a good result of 195 mm (=65×3) against the target of 3σ=300 mm was obtained. The solid line shows the design value.

was confirmed that minimum operation intervals of approximately 100 seconds in the APM system for the new Hong Kong airport could be realized.

3.4 Improvement of stopping accuracy

It is a necessary condition that a completely automated train stops accurately at each station. In the APM system for the new Hong Kong airport, the customer's specifications required that a stopping accuracy of 150 mm at σ of a generation probability of 68.3% and 300 mm at 3σ of generation probability of 99.7% from allowable eccentric values between the train access door and the station platform door.

Fig. 6 shows the train automatic stop control pattern at the station. The stop control pattern is generated in the automatic train operation control system between the point P_1 (about 250 m before the stop position) and the expected stop position (the fixed point). The train is decelerated and stopped by the specified stop control pattern based on the speed and running distance detected on the train. On the way, the absolute position between the point P_2 and the fixed point is detected by the transponder in the ATO system of the station to support the stop control.

The factors related to the stopping accuracy for such existing stop controls were analyzed and their degree of contribution was simulated. The stopping accuracy was improved based on the above results as shown in **Table 3**.

Fig. 7 shows the distribution of the stopping accuracy. The solid line shows the simulated results (design values) of the stopping accuracy after improvement, and the histogram shows the measured values of the stopping accuracy on the MHI test track. It can be understood that 300 mm at 3σ of the specified stopping accuracy could be attained by improving of the stopping accuracy shown in Table 3 using the above results.

Table 3 Improvement of stopping accuracy

Factor	Measures
Speed and distance detecting accuracy	Improvement of speed resolution by changing speed sensor output to total wave rectification system
	Determination of accurate distance and speed by adding automatic compensating function of tire diameter
Absolute position detecting accuracy	Exact determination of point position by employing carrier detection system in spot signal input
Brake force controlling accuracy	Smooth brake control just before stop by changeability of brake notch for prevention of rolling

4. Conclusion

The new Hong Kong airport will be opened in July of 1998. At the same time, the first APM system of MHI will start operation. In this report part of the outline of the APM train and its development are introduced. Currently the system is undergoing final adjustment, but every effort is being made to finish the system more completely until commencement of the operation. It is the strong hope of everyone involved in the project that many people will use the system effectively after opening of the new airport and that the expected objective of the APM as a transportation system can be attained.

In conclusion, the authors wish to express their special thanks for the valuable external support which they have had to date, particularly from the companies concerned who supplied the sub-systems.