Air Suspended and LIM Propulsion Transit System and Next Generation PRT

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Abstract

The air suspended linear induction motor driven Air Linear Mover (ALM) is an Automated People Mover (APM) system that can accommodate complicated guideways.

In 2000, after the practicability evaluation with minute examinations, the system was approved to be suitable for use as a public transportation system.

This paper describes its characteristic technologies and its evaluation test result which had been discussed by the committee.[1]

And at present, one new plan is prepared for putting an advanced LIM Shuttle called “Next Generation PRT” into practical use as a new public transportation system for the next future.

Key Words: air pad, air suspension, linear induction motor (LIM)

1. Overview of the Test Vehicle

The exterior appearance is shown in Figure 1. The most important feature of ALM is that it adopts air suspended system for its suspension. Differing from the steel wheels or the rubber tires of conventional trains (including generally APM system) it has rubber called “Airpad” on the bottom of the vehicle. Its suspending mechanism is that the high speed motor mounted on the vehicle will rotate the blower, which will provide low pressure air to each airpads through the chassis, which is structured with square steel tubes, as it air pipe. Air provided to the airpads is blown down through small holes on the bottom of the airpads, that will make thin airspace between the vehicle and the track surface to lessen the resistance in running. Further, it is designed to need no complicated, costly damping devices such system used by conventional trains, because between the cabin and the chassis are fixed with rubber as a vibration isolator.

The propulsion system of the vehicle is that the LIM's mounted on the bottom of the center of the vehicle will generate propulsion by reacting against the LIM secondary side (Reaction Plate) laid down throughout the track to make the vehicle run.

As regards braking systems, regenerative/generative phase braking is used for service application, and emergency braking
system is accomplished by removing air in the airpads and letting the brake skids closely contact the track surface, which stops the vehicle by its friction. Thus the braking system itself is quite simple but is made active without fail, and it requires no braking system which has complicated mechanism with hydraulic/air compressor needed by the conventional trains.

The major specifications are shown in the Table 1.

### Table 1. Specifications of the test vehicle and test track

<table>
<thead>
<tr>
<th>Test Vehicle</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspension System</td>
<td>Air Suspension</td>
</tr>
<tr>
<td>Guidance System</td>
<td>Side Guidance by Rubber Tire</td>
</tr>
<tr>
<td>Power Distribution</td>
<td>DC750V</td>
</tr>
<tr>
<td>Power Collector</td>
<td>Side Contact, Rigid Conductor Two Lines</td>
</tr>
<tr>
<td>Propulsion System</td>
<td>On-Board Linear Induction Motor Primary</td>
</tr>
<tr>
<td>Switching System</td>
<td>On-Board and Wayside</td>
</tr>
<tr>
<td>Operation System</td>
<td>ATO Unmanned Automatic Operation</td>
</tr>
<tr>
<td>Signaling System</td>
<td>ATP Inductive Loop</td>
</tr>
<tr>
<td>Speed Control</td>
<td>Vector Control and Variable Exciting Current</td>
</tr>
<tr>
<td>Emergency Brake</td>
<td>Skid Brake</td>
</tr>
<tr>
<td>Vehicle Speed</td>
<td>50 km/h (system max. 60km/h)</td>
</tr>
<tr>
<td>Acceleration</td>
<td>0.6~ 1.0 m/s²</td>
</tr>
<tr>
<td>Emergency Deceleration</td>
<td>1.0~2.0 m/s²</td>
</tr>
<tr>
<td>Car Size (mm)</td>
<td>12,800L × 2,900W × 3,600H</td>
</tr>
<tr>
<td>Weight (ton)</td>
<td>Empty: 21.0? Full: 28.3</td>
</tr>
<tr>
<td>Passenger Capacity</td>
<td>122 passengers/vehicle (standing)</td>
</tr>
<tr>
<td>Amenities</td>
<td>Heating, Ventilating and Air Conditioner</td>
</tr>
<tr>
<td></td>
<td>Smoke Detection</td>
</tr>
<tr>
<td></td>
<td>Emergency Intercom (Planned)</td>
</tr>
<tr>
<td></td>
<td>Public Address (Planned)</td>
</tr>
<tr>
<td></td>
<td>Passenger Displays (Planned)</td>
</tr>
<tr>
<td></td>
<td>End and Side Egress (Planned)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Track</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>447 m</td>
</tr>
<tr>
<td>Minimum Horizontal Curve Radius</td>
<td>24 m (system min. 22.9 m)</td>
</tr>
<tr>
<td>Minimum Vertical Curve Radius</td>
<td>900 m (system min. 700m)</td>
</tr>
<tr>
<td>Maximum Grade</td>
<td>6.0 % (system max. 7.5%)</td>
</tr>
</tbody>
</table>

3. Evaluation Procedure

3.1 Prerequisite for Evaluation

Application of ALM for the following two systems have been examined by the Practicability Evaluation Committee.

A) On-Demand Transportation System
This system is used for a comparatively short distance as an individual transportation system at
the airport or such facilities, operating the nominal speed at 30km/h (maximum 50km/h), the distance between stations of about 600m with total distance of approximately 5.0km.

B) Urban Transportation System
This system is used for an intermediate range of medium-size transportation system for commuters and others, operating the nominal speed at 50km/h (maximum 60km/h), the distance between stations of 1.0km with total distance of around 10km.

In this paper, A) On-Demand Transportation System is going to be described. As for B) Urban Transportation System, it is difficult to evaluate directly for itself because the maximum speed of the vehicle is limited to 50km/h due to the length of test track, which can not accommodate to 60km/h.

So, the feasibility of higher speed operation was evaluated based on the data gained from test results on the track after itemizing all technical issues and evaluation viewpoints on the assumption of higher speed operation.

Also, the basic components such as suspension system and LIM propulsion system are confirmed to perform a full function in the operation of up to 60km/h. On the other hand, strength on vehicle body and each mechanical devices, durability of power collectors, airpads should be verified in the service operation.

Therefore, the results mentioned above shows this system is able to operate as an Urban Transportation System in higher speed operation of up to 60km/h.

3.2 Evaluation Procedure
In order to carry forward the evaluation, at first, the requirement for this system as a public transportation system were collected, and selected those of characteristic technologies which are different from conventional trains. As a next step, test and evaluation items were outlined. Then each test items were categorized correspondingly (actual tests on the track, identification of its performance of each component and simulation) and evaluation was accomplished based on the test results.

3.3 Requirement to meet as a public Transportation System
In order to call this system into a practical use as a public transportation system, study and tests must be completed on safety, reliability, maintainability, passenger safety and rescue measures, amenity, adaptability to environment, utility, economical efficiency, etc. Especially on safety, further verification through study and tests are required for high-speed running, sharp curve running, steep gradient running, vehicle (braking, startup and acceleration, reverse drive protection, startup with overload), track structure, protective devices, power supply and communication system.

Actual vehicle tests were carried out on 57 items concerning technical performance, safety, influence on environment and so on set by the Practicability Evaluation Committee, and 111 evaluation items were examined.

Results showed favorable on almost all items. Most of all, the results of exterior noise is especially excellent when compared with conventional trains. The major test results from the evaluation test are described in the next section.

The actual vehicle test is consisted of 57 items in which include 3 additional items requested by the committee.

These items are listed in Table2 and the complete schedule of the evaluation is shown in Table 3.

### Table 2. Operation Test Items

<table>
<thead>
<tr>
<th>Air Suspension and Guidance Device</th>
<th>Propulsion Device</th>
<th>Guideway and Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Airpad Unit Performance</td>
<td>11. Stress on LIM/ Reaction Plates</td>
<td>20. Stress on Guideway</td>
</tr>
<tr>
<td>5. Sequence on Suspension System Failure</td>
<td>15. LIM Braking Performance</td>
<td>24. Facility Structure / Vehicle Design Clearance</td>
</tr>
<tr>
<td>6. Airpad Failure</td>
<td>16. Sequence upon Service Brake failure</td>
<td></td>
</tr>
</tbody>
</table>
4. Evaluation Test Results

This section describes some typical results in all items of evaluation tests as follows.

4.1 Car Interior Noise

An application of air suspension and linear induction motor propulsion into ALM, It has kept interior noise low under the speed range of 50km/h. The target level of LIM driven subway train is 70 to 76 dB(A).

Based on the results of actual tests mentioned previously, the noise level of ALM can be expected under 70 dB(A) when the speed increased to 60km/h.

Therefore, the interior noise level was proved to be excellent. (Ref. Figure 3)

4.2 Car Exterior Noise

Exterior noise level is in proportion to the speed. But there is around 10 dB(A) difference between with and without walls structure. The wall is located along the both side of guideway, which has 1.0m in height. In case of "without wall" structure, the noise level is not low compared with other traffic system's external noise. But if the standard guideway system was to be with walls, it is possible to make low noise system compared with other traffic system. (Ref. Figure 4)
4.3 Suspension Performance

Suspension height is in straight proportion as the speed increase. Minimum height at 50km/h is at least 5mm lower than maximum compared with when idling with no load and full load.

There is no contact between the skid brake and track surface, so it is possible to conclude that stable running can be performed. (Ref. Figure 5)

![Figure 5. Air Suspension Height](image)

4.4 Power Consumption (Energy Efficiency)

The measurement result of power consumption is approximately 90 to 100 Wh/t?km at an actual running on the test track at a same operation duty of 1.0km running in 90 seconds reaching maximum speed of 50km/h.

Power consumption was slightly higher when compared with electric railway conventionally operating.

Several factors of higher power consumption are considered and they are described as follows.

First of all, the blower motors have to be kept operating to maintain levitation while the vehicle keeps running all the way and low enough to be efficient of LIM's, and all of LIM's have to be kept operating while the vehicle keeps running at constant speed. (Ref. Figure 6)

![Figure 6. Power Consumption from operation of each transportation system](image)

5 Next Generation PRT

From the progress on the above mentioned items, work has commenced on a study of Next Generation PRT as well as actual installations of ALM as medium size transportation system for a intermediate range.

At present, we are participating in a working group of Urban Transportation System called "MOBICS"[*] and has proposed it as an urban transportation system that will meet public needs and fit into a new generation.

5.1 Objectives of the Development

In areas with a mass transportation volume, railways are used for a transportation system, and buses are used in areas with a less volume. For intermediate areas, there are few transportation systems that are economically feasible.

A Next Generation PRT that can meet social requirement such as low cost, less burden to the environment and barrier free, is strongly needed.

5.2 Outline of Next Generation PRT

The distinct feature of Next Generation PRT is that it is able to address dual mode operation both on an elevated guideways and on a flat track with no vehicle's guide and no power rail. The application of steering units and batteries to propel onto the former system that has made possible to operate the vehicle on the flat track. Moreover, the application of IT (Information Technology) such as On-Demand operation that has improved in utilizing a new transportation system.

The features of this system are listed as follows.

a) Driving Performance
   Available for sharp curve running, steep incline running, elevated guideway and flat crossing track.

b) Transportation Performance
   Available in the vehicle designs corresponding to the demand of transport.
   Available for the independent operation corresponding to a small transportation volume.
   Available for the formal operation corresponding to a great transportation volume.

c) Flexibility Performance
   Available to move vertically, horizontally, diagonally.

[*] Affiliated members; Kyushu University, JR Kyushu, Nippon OTIS
d) User Friendly
   Available to minimize gap between vehicle floor and platform floor.
   Available for low floor vehicle (300mm in height from track surface)
e) Independent Performance
   Available for a flat track (crossing) operation.
   Available for On-Demand operation by unmanned automatic operation.
f) Environmentally Friendly
   No exhaust gas
   Low noise and low vibration.
g) Applicability Performance
   Available for flexible design of system.\[3\]

![Figure 7. Next Generation PRT](image)

![Figure 8. Utilities of Next Generation PRT](image)

6 Prospects for the Future

The outline of ALM's characteristic air suspension system, its performance actually now in operation around the world are presented in this paper. After strict evaluations by the committee mentioned previously, consequently, this system was approved to be suitable for practical use as a public transportation system.

Also introduction of Next Generation PRT is presented, which is under study simultaneously. Work is combined study of air suspension system and linear induction motor propulsion system together with steering unit and batteries to propel.

However, several problems still exist to be solved, not only the development of system itself but also social acceptance of this system, regulations and so on.

Therefore, a further study is necessary to solve these substantial problems.

![Figure 9. PRT Running in Town (Image)](image)

References