Straddle-type Monorail as a Leading Urban Transport System for the 21st Century

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Overview: The Tama Monorail began partial operations in November 1998 along a phase-1 interval of 5.5 km, and full operation is scheduled to begin in the middle of 1999 with a phase-2 interval of 10.7 km. This monorail system follows in the footsteps of urban monorail systems like Kita-Kyushu Monorail and Osaka Monorail built on subsidies from national and local governments. The Okinawa Monorail system, moreover, is currently under construction and is scheduled to open in 2003 as the fourth urban monorail. Meanwhile, the Maihama Resort Line Monorail is aiming to begin service in 2001 as a general monorail built by private capital. Monorails are (1) economic because of their relatively short construction period and a construction cost one-third that of subway systems, (2) superior in terms of environmental effects having a simple structure that can fit into narrow spaces, (3) a pleasant means of urban transport having a 35-year history of stable operation, and (4) capable of being even more economical and efficient by upgrading to one-man operation. Hitachi, Ltd. is actively involved in the development of monorails with these features as a means of providing medium-scale urban transport for major cities in Japan and abroad. Hitachi’s operations-and-maintenance know-how has been built up over many years of experience and achievements in cooperation with the Tokyo Monorail Company, a member of the Hitachi Group. Hitachi, Ltd. seeks to apply this engineering expertise to finding practical solutions to user needs.

INTRODUCTION

The straddle-type monorail is usually adopted as a medium-scale transport system to supplement general trains and subways in an urban area. In such a system, the following measures are indispensable to raising the efficiency of maintenance and management:

1. Adopt one-man operation to reduce train crew,
2. Establish a no-man station platform and reduce station staff overall,
3. Introduce efficient operation-control and power-control systems appropriate to the scale of the monorail line, and achieve efficient operations by control center staff,
4. Strive for maintenance-free operations to reduce maintenance expenses.

In line with these measures, Hitachi, Ltd. actively pursues the use of up-to-date technology including VVVF (variable voltage, variable frequency) control equipment and autonomous distributed control systems.

In this report, we describe our use of new technology in the Tama Monorail and the development of compact and inexpensive monorails (see Fig. 1).
USE OF NEW TECHNOLOGY IN A STRADDLE-TYPE MONORAIL

One-man Monorail Operation

In the case of urban monorails, one-man operation system as a labor-saving device has been adopted since the Kita-Kyushu Monorail began service in 1985. Moreover, as a means of further improving safety and service for passengers, platform screen doors have been introduced for the Tama Monorail. A comparison of principle specifications and one-man facilities between the various monorail systems is shown in Table 1.

Each monorail system endeavors to reduce the work of the train crew by incorporating automatic drive facilities like ATO (automatic train operation), automatic public-address and display equipment, etc. A monitor on the operations panel also makes it possible for a crew member to monitor the state of devices on the train and to check for system faults.

When applied, one-man operation is achieved by integrating the operations of control center staff, station staff, and the train crew member in conjunction with the platform screen doors, platform CCTV (closed-circuit television) equipment, and other ground-based facilities.

In the event of an emergency, functions are provided to establish communications with the ground through emergency facilities.

ATO system

In one-man operation, whether or not to adopt an ATO system in support of train crew operations is left to the user. The users of the Kita-Kyushu Monorail and Tama Monorail decided to adopt the ATO system.

Due to structural constraints, it is difficult to install ATO ground units for deceleration and stop-pattern generation at the most optimal positions as in a standard railroad. For this reason, transit curve data between all stations are stored in ATO equipment installed on the train. The code for the next station is therefore received through an ATO unit at the current station, the next-interval transit pattern is selected, the distance count (subtraction) from the station of departure begins, and inter-station transit control is performed according to the stored transit pattern.

On approaching the next station, the system has a

<table>
<thead>
<tr>
<th>Table 1. Principal Specifications of Straddle-type Monorails</th>
</tr>
</thead>
<tbody>
<tr>
<td>Each monorail adopts systems and facilities according to its scale and policy of operations and is implementing labor-saving measures such as one-man operation.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Tokyo Monorail</th>
<th>Kita-Kyushu Monorail</th>
<th>Osaka Monorail</th>
<th>Tama Monorail</th>
<th>Maihama Monorail</th>
<th>Okinawa Monorail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total line length</td>
<td>16.9 km</td>
<td>8.8 km</td>
<td>23.8 km</td>
<td>16 km</td>
<td>5.01 km</td>
<td>12.9 km</td>
</tr>
<tr>
<td>No. of electric-power substations</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Feeder voltage</td>
<td>DC 750V</td>
<td>DC 1,500V</td>
<td>DC 1,500V</td>
<td>DC 1,500V</td>
<td>DC 1,500V</td>
<td>DC 1500V</td>
</tr>
<tr>
<td>No. of stations</td>
<td>9</td>
<td>13</td>
<td>16</td>
<td>19</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Station format</td>
<td>Island platform: 1 Opposed platforms : 8</td>
<td>Island platform : 2 Opposed platforms : 11</td>
<td>All stations: island platform</td>
<td>All stations: island platforms</td>
<td>Single platform : 2 Opposed platforms : 10</td>
<td></td>
</tr>
<tr>
<td>Platform screen doors</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Track dimensions, width \times length \times height (m)</td>
<td>0.8 \times 20 \times 1.4</td>
<td>0.85 \times 20 \times 1.5</td>
<td>0.85 \times 22 \times 1.5</td>
<td>0.8 \times 22 \times 1.5</td>
<td>0.8 \times 25 \times 1.7</td>
<td>0.8 \times 20 \times 1.4</td>
</tr>
<tr>
<td>Car composition</td>
<td>6 cars permanently coupled</td>
<td>4 cars permanently coupled</td>
<td>4 cars permanently coupled</td>
<td>4 cars permanently coupled</td>
<td>6 cars permanently coupled</td>
<td>2 cars permanently coupled</td>
</tr>
<tr>
<td>Total no. of cars</td>
<td>19 sets (114 cars)</td>
<td>10 sets (40 cars)</td>
<td>13 sets (52 cars)</td>
<td>15 sets (60 cars)</td>
<td>5 sets (30 cars)</td>
<td>13 sets (26 cars)</td>
</tr>
<tr>
<td>Axle load</td>
<td>9.2 t</td>
<td>11 t</td>
<td>11 t</td>
<td>11 t</td>
<td>10 t</td>
<td>10 t</td>
</tr>
<tr>
<td>Car control equipment</td>
<td>Camshaft control and VVVF</td>
<td>Man-circuit chopper</td>
<td>Field chopper</td>
<td>VVVF</td>
<td>VVVF</td>
<td>VVVF</td>
</tr>
<tr>
<td>Train radio</td>
<td>Space waves</td>
<td>Space waves</td>
<td>Space waves</td>
<td>LCX</td>
<td>Space waves</td>
<td>Space waves</td>
</tr>
<tr>
<td>Signal and protection system</td>
<td>ATC</td>
<td>ATC</td>
<td>ATC</td>
<td>ATC</td>
<td>ATC</td>
<td>ATC</td>
</tr>
<tr>
<td>Driving system</td>
<td>2-man crew</td>
<td>One-man operation</td>
<td>One-man operation</td>
<td>One-man operation</td>
<td>Automatic operation with one man aboard</td>
<td>One-man operation</td>
</tr>
<tr>
<td>Automatic drive equipment (ATO)</td>
<td>—</td>
<td>Yes</td>
<td>—</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
</tr>
<tr>
<td>ATO ground-unit system</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Transponder</td>
<td>IR</td>
<td>—</td>
</tr>
<tr>
<td>ATO ground-unit installation section</td>
<td>—</td>
<td>Transposition under beam</td>
<td>—</td>
<td>Upper section of main pillar (ceiling and station sections)</td>
<td>Within track beam</td>
<td>—</td>
</tr>
<tr>
<td>Ground/train transmission system</td>
<td>—</td>
<td>IR</td>
<td>—</td>
<td>Transponder</td>
<td>IR</td>
<td>—</td>
</tr>
</tbody>
</table>

VVVF: variable voltage, variable frequency  LCX: leakage coaxial cable  ATC: automatic train control  ATO: automatic train operation  IR: inductive radio  FY: fiscal year
function that performs distance correction and generates a stop pattern by receiving positional information from ATO ground units. It then automatically halts the train at a specified station position by TASC (train automatic stop control).

The Tama Monorail, moreover, deploys LCX throughout the line with the plan of transmitting data between stations in the future. It will be used together with train radio and be given the role of an information-transfer system between the train and ground separate from the information received by transponders.

Platform screen doors
Control operations for opening and closing the platform screen doors are interlinked with those of the car doors and is performed from either the operations panel on the train or by a “door-handling button” near the motorman’s door.

1. The control sequence for “opening” the platform screen doors is as follows. First, manipulation of the door-handling button initiates the open operation for the platform screen doors, and second, a command for opening car doors is immediately output. The time from initiating this operation to completing door and fence opening is 4.6 seconds on the average.

2. In the control sequence for “closing,” manipulation of the door-handling button results in simultaneous output of close commands to the car doors and platform screen doors. Here, the car doors are activated before the platform screen doors only because of the slight difference in the time it takes to transfer control information, and the total time of the close operation is 4.4 seconds on the average.

In the above manner, opening and closing control can be performed according to passenger behavior and safety can be enhanced by verifying the state of passenger boarding/disembarking by the motorman monitor and the platform observation monitor. The control sequences for the platform screen doors and car doors are shown in Fig. 2.

Transportation Control System
1. Bearing in mind the scale of control objects, the transportation control system of a monorail does not treat the various functions of operation control, power control, station facilities, and disaster control as independent subsystems. Instead, functions are integrated and an autonomous distributed control system is applied.

2. In each station, distributed control equipment and the central computer are interconnected by an optical-loop transmission path. Functions on the loop can therefore cooperate with each other, and a system can be constructed that helps raise the efficiency of command operations by appropriate exchange of information and that contributes to the rationalization of station work by supporting, for example, a no-man platform.

3. A monorail transportation control system features a “total system” that functions in unison with

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### Fig. 2—Control Sequence for Moving the Platform Screen Doors and Car Doors.
The platform screen doors and the car doors for boarding/disembarking can be controlled according to the movement of passengers by linking their opening and closing.
communication equipment like CCTV and broadcasting equipment that act as the arms, legs, eyes, and ears of the system. A no-man platform is realized as part of this total system.

Car Control Equipment (VVVF Control Equipment)

The new 2000 series car for the Tokyo Monorail was the first challenge to adopt VVVF control equipment [using IGBT (insulated gate bipolar transistor) devices] toward rubber tires. The following tests were performed before implementation.

(1) Car performance tests on controlling torque variation and pulsation that cause the diameter of rubber tires to vary dynamically, on adopting flexible coupling, etc.
(2) Tests on countermeasures to inductive faults

Based on the results of the above tests, the Tama Monorail has also adopted the VVVF control system. Control performance for DC 1,500 V has been confirmed, and countermeasures to inductive faults on the transponder have been implemented.

Against the background of the above achievements, VVVF control equipment will also be adopted by both the Maihama Resort Line Monorail and the Okinawa Monorail.

DEVELOPMENT OF A COMPACT AND INEXPENSIVE MONORAIL

Considering the demand for transport in many major cities in Japan and abroad, the need for medium-scale transport systems is being felt. A number of issues must be addressed, however, to achieve such systems, such as (1) the difficulty in turning a profit due to construction costs in the case of existing large-size monorails, and (2) narrow roads where the monorail is to be deployed.

To solve these problems, Hitachi, Ltd. aims to reduce construction costs significantly by pursuing the comprehensive development of total monorail systems centered about the development of compact and inexpensive monorail cars. This development work spans both the infrastructure like track beams and pylons, switches, stations, etc., in support of these cars, and non-infrastructure elements like signals and communications, electric-power facilities, and control systems.

The basic idea here is that costs can be lowered by constructing a compact monorail system (cars, stations, tracks, etc.) in a standardized form having necessary and sufficient functions, and then adding options according to the individual needs of each operator.

CONCLUSIONS

To conclude this paper, we describe Hitachi’s approach to providing straddle-type monorails and its future direction.

Hitachi, Ltd. provides unified support of straddle-type monorails from the time of initial deployment studies to the route-permit application, building-permit design work, detailed design, manufacturing, and start of service, constructing a project in unison with the user.

In recent years, the need for bundled support of operation and maintenance has been increasing, especially overseas. In this regard as well, Hitachi, Ltd., in cooperation with the Tokyo Monorail Company, demonstrates its total-engineering expertise in both operations and maintenance to meet the needs of users.

REFERENCE