Introduction of Automatic Train Operation system in JAPAN

Current state of ATO in Japan
Newly developed intermittent type ATP-based ATO system

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Outline

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Current state of ATO in Japan

1-1 Grade of Automation by IEC 62267
1-2 Outline of typical ATO lines in Japan
1-3 Comparison with ATO introduction status in Japan and overseas
1-4 Future development of ATO in Japan

Chapter 2
Newly developed intermittent type ATP-based ATO system

2-1 Concept of intermittent type ATP-based ATO system
2-2 System overview
2-3 Functional verification tests
2-4 Commencement of commercial operation as GoA 2
Outline

Chapter 1

Current state of ATO in Japan

1-1 Grade of Automation by IEC 62267
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1-4 Future development of ATO in Japan
### Grade of Automation by IEC 62267

#### Basic functions for each GoA

<table>
<thead>
<tr>
<th>Basic Functions</th>
<th>GoA 0</th>
<th>GoA 1</th>
<th>GoA 2</th>
<th>GoA 3</th>
<th>GoA 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ensuring safe movement</strong></td>
<td>Staff</td>
<td>Staff/System</td>
<td>System</td>
<td>System</td>
<td>System</td>
</tr>
<tr>
<td><strong>Driving</strong></td>
<td>Staff</td>
<td>Staff</td>
<td>System</td>
<td>System</td>
<td>System</td>
</tr>
<tr>
<td><strong>Supervising guideway</strong></td>
<td>Staff</td>
<td>Staff</td>
<td>Staff</td>
<td>System</td>
<td>System</td>
</tr>
<tr>
<td><strong>Supervising passenger transfer</strong></td>
<td>Staff</td>
<td>Staff</td>
<td>Staff</td>
<td>Staff/System</td>
<td>System</td>
</tr>
<tr>
<td><strong>Dealing with emergency</strong></td>
<td>Staff</td>
<td>Staff</td>
<td>Staff</td>
<td>Staff</td>
<td>System/OCC</td>
</tr>
</tbody>
</table>

**Staff**: responsibility of operation staff (may be realized by technical system)

**System**: realized by technical system

**OCC**: Operation Control Center

Railway applications
- Automated urban guided transport (AUGT)
- Safety requirements
Outline of typical ATO system in Japan

About 40 lines (more than 700 km) in operation as ATO

<table>
<thead>
<tr>
<th>Currently Introduction case</th>
<th>GoA 2</th>
<th>GoA 3</th>
<th>GoA 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>STO</td>
<td>DTO</td>
<td>UTO</td>
</tr>
<tr>
<td></td>
<td>Semi-automated</td>
<td>Driverless</td>
<td>Unattended</td>
</tr>
<tr>
<td></td>
<td>30 lines</td>
<td>1 line</td>
<td>9 lines</td>
</tr>
<tr>
<td></td>
<td>Marunouchi line</td>
<td>Disney resort line</td>
<td>Yurikamome Port liner</td>
</tr>
<tr>
<td></td>
<td>Tsukuba Express Etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overseas</td>
<td>About 350 lines</td>
<td>About 10 lines</td>
<td>About 140 lines</td>
</tr>
<tr>
<td></td>
<td>RATP line 3, 5 Etc.</td>
<td>BART Etc.</td>
<td>RATP line 1, 14 Nuremberg U2, U3 Etc.</td>
</tr>
</tbody>
</table>

Current ATO preconditions in Japan
- Introduced continuous type ATP called Automatic Train Control, ATC
- Physically separated from outside by dedicated elevated tracks, underground tracks and platform screens
Outline of typical ATO system in Japan

Introduction example: Marunouchi line, Tokyo Metro

Marunouchi line, GoA 2 with ATC
between Ogikubo and Ikebukuro via Shinjuku,
Nakano-sakaue and Honancho (branch line)
27.4 km (Number of stations: 28), Maximum speed: 75 km/h
Outline of typical ATO system in Japan

Introduction example: Tsukuba Express line, MIR

**Tsukuba Express line, GoA 2 with ATC**
between Akihabara and Tsukuba
58.3 km (Number of stations: 20),
Maximum speed: 130 km/h
Outline of typical ATO system in Japan

Introduction example: Yurikamome

Yurikamome, GoA 4 with ATC between Shimbashi and Toyosu
14.7 km (Number of stations: 16), Maximum speed: 60 km/h

Upper left photo: Shiodome station platform
Comparison with ATO introduction status in Japan and overseas

Current status of introduction in Japan

- ATO include GoA 4 have a long history – first GoA 4 example in the world
- About 40 lines operated mainly in subway (GoA 2) and AGT (GoA 4)
- No example of ATO in a general lines
  1) General lines: not separated from outside
     Ex. with level crossings, without platform screens

Current status of introduction in overseas

- GoA 2 is progressing not only in subway but also urban railways
- More than 100 lines operated mainly in subway (GoA 3 and GoA 4)

Ref.1 Aoyagi: “Efforts for automatic driving in railways and the concept of safety and reliability” Reliability Forum 2021, REAJ (in Japanese)
Future development of ATO in Japan

Driverless operation in general lines, aiming for GoA 3 and 4

- Need to sort out new requirements that are different from AGT

<table>
<thead>
<tr>
<th>AGT with ATC</th>
<th>General lines with ATC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex. Yurikamome</td>
<td>Ex. Yamanote line</td>
</tr>
</tbody>
</table>

- Physical separation from guideway
- Full-height platform screens
- Prevention of physical obstacles to adjacent lines
- Without level crossings
- Evacuation taxiway for easy evacuation
- Physical barriers along track
- Track intrusion detection
- Partial-height platform screens
- Track intrusion detection
- Derailment detection or detection of obstacles to adjacent lines
- Warning detection
- Detection of obstacles
- Automatic stopping avoiding places for difficult evacuation

Currently, **driverless operation** in general lines is one of the topics in the study group of Ministry of Land, Infrastructure, Transport and Tourism (MLIT). And this topic is beginning to be considered by JR East

Ref.1
Future development of ATO in Japan

Aiming to realize new definition “GoA 2.5”

- Reduction of train operating costs to maintain rural lines

Realizing ATO based on intermittent type ATP called **Automatic Train Stop, ATS**

- In current Ministerial Ordinance in Japan, GoA 3 and GoA 4 are assumed to be performed by ATO system under protection of ATC
- Introducing ATC would entail a huge amount of investment costs to replace ATS

As of 2021.3
Future development of ATO in Japan

Aiming to realize new definition “GoA 2.5”

- Reduction of train operating costs to maintain rural lines
  
  \textit{ATO with staff who does not have driver’s license}
  
  - Staff who is not required the driver’s license is placed at front end of the train instead of the licensed driver
  - \textbf{Staff at the front} end is in charge of roles such as stop operation and evacuation guidance in emergencies

<table>
<thead>
<tr>
<th>Basic Functions</th>
<th>GoA 2</th>
<th>GoA 2.5</th>
<th>GoA 3</th>
<th>GoA 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STO</td>
<td>Not defined in IEC 62267</td>
<td>DTO Driverless</td>
<td>UTO Unattended</td>
</tr>
<tr>
<td>Ensuring safe movement</td>
<td>System</td>
<td>System</td>
<td>System</td>
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<td>Staff</td>
<td>System/OCC</td>
</tr>
</tbody>
</table>

\textit{Currently, a type of the train operation tentatively called GoA 2.5, is one of the topics in the study group of Ministry of Land, Infrastructure, Transport and Tourism (MLIT)}
Chapter 2

Newly developed intermittent type ATP-based ATO system

2-1 Concept of intermittent type ATP-based ATO system
2-2 System overview
2-3 Functional verification tests
2-4 Commencement of commercial operation as GoA 2

JR Kyushu Kashii line
Saitozaki – Kashii (12.9 km) in operated by ATS-based ATO system

ATS-based ATO system
Concept of intermittent type ATP-based ATO system

Background and purpose

- Reduction of train operating costs to maintain rural lines

*Realizing ATO based on intermittent type ATP*

- Based on ATS-DK introduced in Kyushu Railway Company (JR Kyushu) general lines
- Reducing cost by utilizing established ATS for automatization of driving operation

<table>
<thead>
<tr>
<th>Current system</th>
<th>GoA 2</th>
<th>GoA 3</th>
<th>GoA 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATC-based ATO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous type ATP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Target:** AGT, subway, urban lines

<table>
<thead>
<tr>
<th>This system</th>
<th>GoA 2</th>
<th>GoA 2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATS-based ATO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermittent type ATP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATS-DK</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Target:** rural lines, established ATS lines

*Realizing ATO with staff at front end without driver’s license*

- Staff at the front end is in charge of roles such as stop operation and evacuation guidance in emergencies

*Development of ATS-DK based ATO system equivalent to GoA 2.5*
Concept of intermittent type ATP-based ATO system

Outline of ATS-DK

- Introduced in JR Kyushu general lines
- Intermittent type ATP with permissible speed profile
- Continuous detection of absolute position for using on-board database

**Maximum section speed**

**Speed profile for speed limit**
Generated by on-board database

**Speed profile for stop signal**
Generated by beacons

ATs-DK
On-board transceiver

Database

On-board antenna

Tacho-generator

D type beacons attached to signal
Distance to stop signal

Stop signal

Signal box
### Concept of intermittent type ATP-based ATO system

#### Comparison with ATC-based ATO

<table>
<thead>
<tr>
<th>Key difference</th>
<th>ATC</th>
<th>ATS with permissible speed profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed check</td>
<td>Verification from 0 km/h</td>
<td>No verification from 0 km/h</td>
</tr>
<tr>
<td>Control information update freq.</td>
<td>Continuous signal transmission</td>
<td>Intermittent signal transmission</td>
</tr>
<tr>
<td></td>
<td>by rails etc.</td>
<td>by beacons</td>
</tr>
</tbody>
</table>

- Two main impacts of the above differences for control functions
  1. Departure control from stopped state
  2. Response to sudden signal changes to stop in emergency and the like

**Ensuring the required safety by complementing functionality**
System overview

System configuration

- Added new ATO equipment and beacons to existing ATS-DK equipment

- On-board antenna
  - ATS-DK on-board transceiver
  - ATS signal / TASC information
  - Safety ensured by staff at front end

- Emergency braking
- Change over / mode selective switch
- Power running / Brake control

- FS-ATO
  - Fail-safe equipment
  - Running speed profile generated by FS-ATO
  - Speed check profile generated by FS-ATO

- Beacon
- Verification from 0 km/h by FS-ATO
- Added beacons for SPAD prevention

- Speed curve
  - + 8 km/h
  - - 13 km/h

- Stop position: 80 m in front of stop signal

Complemented functionality against ATC
System overview

Method of achievement for function complement

- Introducing fail-safe ATO on-board equipment called FS-ATO

*Ensuring required safety by whole system with combination of FS-ATO and ATS-DK*

- This concept is different from the current ATO and indicates one direction for realizing ATO without redesigning of existing ATS

<table>
<thead>
<tr>
<th>Automatic operation function</th>
<th>ATC-based ATO</th>
<th>ATS-based ATO</th>
</tr>
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<tbody>
<tr>
<td>ATO</td>
<td>Equipment and function are not required to be safety-related</td>
<td>FS-ATO</td>
</tr>
<tr>
<td>FS-ATO</td>
<td>Safety-related fail-safe equipment is applied and performs the part of safety-related functions</td>
<td></td>
</tr>
<tr>
<td>ATC</td>
<td>Equipment and function are required to be safety-related</td>
<td>ATS-DK</td>
</tr>
<tr>
<td>ATS-DK</td>
<td>Safety-related fail-safe equipment is applied and performs the part of safety-related functions required as ATS</td>
<td></td>
</tr>
</tbody>
</table>
# Functional verification tests

## Test method

- Carried out with mass-produced prototype equipment

<table>
<thead>
<tr>
<th>Phase</th>
<th>Test type</th>
<th>Periods</th>
<th>Location</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Factory test</td>
<td>Aug. ‘19</td>
<td>Manufacturer’s factory</td>
<td>Functional verification with simulator</td>
</tr>
<tr>
<td>2</td>
<td>Static test</td>
<td>Aug. ‘19</td>
<td>Rolling stock depot</td>
<td>Combination test with vehicle, Input / output confirmation</td>
</tr>
<tr>
<td>3</td>
<td>Running test 1</td>
<td>Sep. – Oct. ‘19</td>
<td>Rolling stock depot</td>
<td>Basic function, reproduction anomaly in test track</td>
</tr>
<tr>
<td>4</td>
<td>Running test 2</td>
<td>Oct. – Nov. ‘19</td>
<td>JR Kashii Line between 3 stations</td>
<td>Basic function, reproduction anomaly in commercial line</td>
</tr>
</tbody>
</table>

- Train start request button
- Emergency train stop button
- Monitor
- Operation mode selective switch
- FS-ATO equipment
- Test vehicle Series BEC819, 2-car train
### Functional verification tests

#### Test results

- Control function of safety and operation
- Distance calculation and stop position accuracy

*No problem in practical use because the functions of this system were operating according to the specifications through functional verification tests*

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**Example of control state at departure from first station**

Verified following functions by analyzing operation status record data of ATS-DK and FS-ATO equipment:

- Speed profile generation
- Receiving beacon information
- Automatic running control
- Distance calculation accuracy

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![Graph showing speed profile and control states](chart.png)

- Speed check profile by ATS-DK
- Speed check profile by FS-ATO
- Speed limit for turnout
- Speed limit for curve
- Running speed profile
- Distance
Commencement of commercial operation as GoA 2

Verification of control stability

- 2,500 km running test
- 1,000 station stops

Tuning and verification of stop position accuracy, driving time, and ride quality were carried out

Commercial operation as GoA 2 for proving runs

- Since the end of 2020
- A licensed driver has been onboarding a commercial train on JR Kashii line for proving runs toward the realization of GoA 2.5
Conclusions

Current state of ATO in Japan

- ATO include GoA 4 have a long history – *first GoA 4 example in the world*
- About 40 lines operated mainly in subway (GoA 2) and AGT (GoA 4)
- No example of ATO in a general lines

In the future

- Driverless operation in general lines, aiming for GoA 3 and 4
- Aiming to realize new definition “GoA 2.5”