Summary of automatic operation of Linimo and achievement in opening year

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ABSTRACT: Tobu-Kyuryo-Line is a mid size transport system which adopts HSST system and automatic operation. In HSST system vehicle is levitated with normal conducting electro-magnet and is propelled with Linear Induction Motor. Low noise by levitation and stable acceleration by LIM is starting point for improvement of riding comfort and faster transport. Automatic operation is indispensable for stable operation and reduction of running cost. In the opening year Tobu-Kyuro-Line played very important role as an access transport for EXPO2005 carrying 20 million. So far it does not have serious trouble and is operated safely. In this paper, we describe automatic operation of Tobu-Kyuryo-Line and operating results such as number of passengers, power consumption and consumption of pads in opening year.

1 INTRODUCTION

Tobu-Kyuryo-Line connects Fujigaoka station which is a terminal of Nagoya city subway and Yakusa station of Aichi Loop Line.

More than 20,000 application were subscribed for nickname of this line. “Linimo” was selected as the nickname because it is familiar and easy to remember and it makes us imagine linear motor car.

Infrastructure such as piers and girders was constructed by Aichi prefecture and Nagoya city. Other part was constructed by Aichi Rapid Transit Co., which was founded as the third sector company in February 2000. The section from Fujigaoka station to Hanmizuki-dori station is underground and the rest is elevated.

Demand is estimated as 30,000 passengers a day and capacity during peak hour is 4000 passengers.

Figure 1 shows shape of this line. It is planned along roads and has as small as 75 m radius curve and as steep as 6 % slopes.

The system selection committee selected HSST system because it negotiates tight curve or steep slope and makes us feel sense of advancement.

Recently it is common for new transport system to reduce running cost by adopting automatic operation and this line also adopts automatic operation.

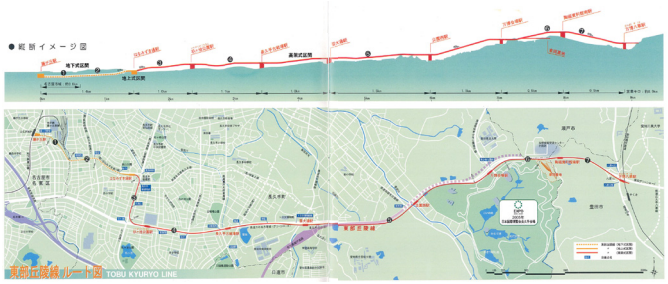

Figure 1: Shape of Tobu-Kyuryo-Line

2 EQUIPMENTS OF VEHICLE

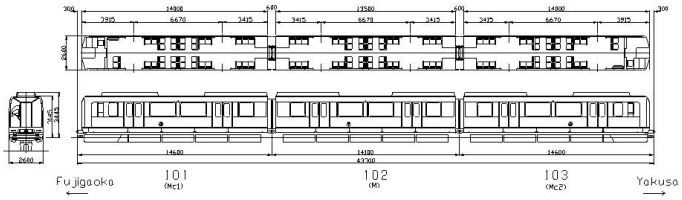

Figure 2: Outline of the vehicle

Figure 2 shows outline of the vehicle and Table 1 shows specification of the vehicle.

Table 1: Specification of the vehicle

Item	Content
Train	3 cars, 43.3 m
Size lead car	Length 14.0 m, width 2.6 m, hight 3.45 m
middle car	Length 14.0 m, width 2.6 m, hight 3.45 m
Capacity	244 passengers a train (incl. 104 seated)
	Lead car 80(34), middle car 84(36)
Body structure	Made of welded aluminum alloy
	Head part with emergency door
	Two double door type side doors per side with 1200mm opening width
Body suspension	10 flexible pair modules a car
	Air spring as secondary suspension
Levitation & guidance	U-shape normal conductive magnets & combined levitation and guidance
Propulsion	
Main motor	Linear induction motor (10 a car)
Control device	IGBT VVVF inverter control (1 a car)
Brake	
Normal	Electrical brake & hydraulic brake
Emergency	Hydraulic brake
Main power	DC1500V
Auxiliary power	DC-DC converter (2 a train)
Operation	ATO system
Performance	Maximum speed 100 km/h
	Maximum acceleration 4.0 km/h/s
	Maximum deceleration 4.5 km/h/s
	Maximum gradient 7 %
	Minimum curve radius 50 m

3 AUTOMATIC OPERATION

Automatic operation is already adopted on other transport system. Automatic operation of Tobu-Kyuryo-Line is designed on the basis of other transport system.

Main functions of automatic operation are start control, speed control, stop control and lower speed priority. 7 equipments are necessary for this system to work properly.

1. Automatic Train Operation equipment (ATO)
2. Train Integrated Management System (TIMS)
3. VELocity detection system equipment (VEL)
4. Inductive Radio equipment(IR)
5. Station control equipment
6. Automatic Train Control (ATC)
7. Train Detection equipment (TD)

3.1 Automatic Train Operation equipment (ATO)

Automatic Train Operation equipment (ATO) is necessary for Automatic Operation. Standard running pattern is saved in this equipment. This equipment gives instruction of propulsion or brake detecting speed and position. This instruction consists 31 steps for both propulsion and brake and makes speed control precisely. It is sent to VVVF inverter and brake controller through TIMS.

Running pattern was arranged once during EXPO2005. Former pattern took full advantage of vehicle performance. This pattern made running time shorter and gave longer staying time at stations. However acceleration and deceleration occurred by turns frequently and that made vehicle uncomfortable to ride in. This arrangement has made vehicle more comfortable.

Figure 3 shows basic running pattern. ATO always transmits and receive messages with other equipments.

3.1.1 Start control

ATO receives “start instruction” from station controller or “restart instruction” from operation room through IR. TIMS receives same instruction and levitates vehicle when it is ready. ATO check the information of TIMS and gives instruction of propulsion or brake to TIMS. TIMS orders release of brake and propulsion to relevant equipments.

3.1.2 Speed control

Vehicle runs in accordance with running pattern saved in ATO. Target speed of ATO is 3 km/h lower than limit speed of ATC, which is designed on every signal block. Running pattern is designed so as not to exceed limit speed of ATC.

3.1.3 Train Automatic Stop Control (TASC)

ATO detects distance to target position so that vehicle stops at correct position of the station. Position informations of unpowered wayside coils, P1, P2 and P3, are transferred to ATO through station controller. Vehicle remembers stopping pattern when it receives information of P1 and runs in accordance with this pattern.

3.1.4 Lower speed priority

Lowest speed among speed of running pattern, limit speed of ATC, temporary speed sent from operation room and temporary speed regulated depending on condition of vehicle is the target speed of ATO.

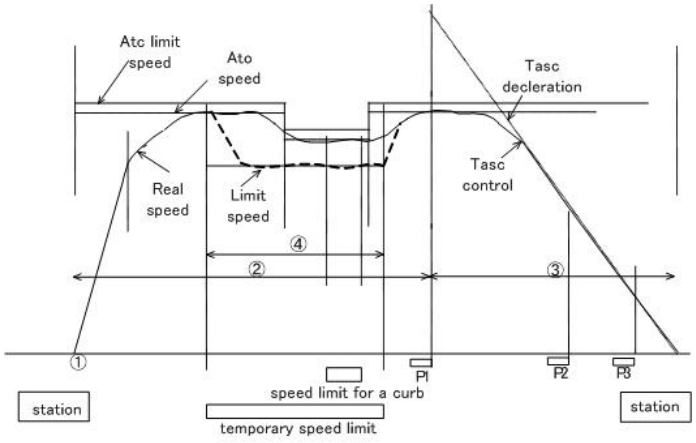

Figure 3: Outline of running pattern

3.2 Train Integrated Management System (TIMS)

Train Integrated Management System (TIMS) gets information of condition of vehicle and signal wayside system etc. and gives instruction to ATO when vehicle is operated automatically. Information of vehicle is not only displayed on the monitor at the drivers seat, but also set to operation room through IR.

TIMS can also record of malfunction and status of operation and support ordinary maintenance.

Table 2 shows information being transferred between ATO and TIMS

Table 2: Information being transferred between ATO & TIMS

Direction	Content	
TIMS→ATO	Direction	Forward/Backward
	Door	Full open
	Category	Local/Express/ Out of service/ Chartered/Test run
	Start order	Start/Restart
	Speed limit	Limit by wayside/ Limit by TIMS
	Trouble brake	Brake 1/Brake 2
	Station trouble	System 1 trouble/ System 2 trouble
	Clock	Year/Month/Day/Hour/ Minute/Second
	Vehicle condition	Emergency roller Levitated/Landing Propel/Brake Status of Hydraulic brake Trouble of VVVF
ATO→TIMS	Station	Previous station Next station
	Propulsion control	Effective Propulsion (31 steps) Brake (31 steps) Inching brake Slope brake
	Wayside coil	Number of noticed coils
	Stop position	S/J/O/Out of station
	Speed limit	Feedback from wayside Feedback from TIMS Feedback on speed limit
	Control condition	ATC signal Speed Position Distance from target Acceleration rate Deceleration rate Code of condition
	Position	Information from station controller

3.3 VELocity detection system equipment (VEL)

It is impossible for maglev to calculte speed by detecting revolution of wheel because it does not use wheels when levitated. To calculate speed, cable which is called “pattern belt” and has 0.03 m pole pitch is put on guideway and three aerial antennas a train receives signal from the cable. Combination of signals received by these antennas is changed every 0.01 m of vehicle move. Speed can be calculated by dividing 0.01 m by the time between change of signal combination. Backward moving can be detected because how combination changes depends on the direction of vehicle move.

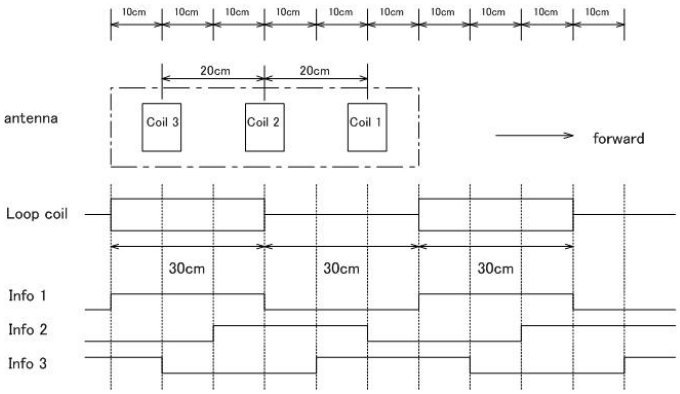

Figure 4: How to detect speed

3.4 Inductive Radio equipment(IR)

IR consists of automatic guidance display, vocal guidance on board, communication radio between operating room and vehicle and data transmission equipment which transmits and receives information of vehicle condition etc.

Communication radio provides three kinds of communication. One is between operator and intercoms in cabin. Another is between operator and driver. The rest is vocal guidance in cabin from operating room. This radio includes emergency signal which warn operator and makes power cut in case of opening emergency door or separation of cars.

Data transmission transfers instructions from wayside equipments to each vehicle for automatic operation. It also transfers information of conditions of all cars to operating room using polling function.

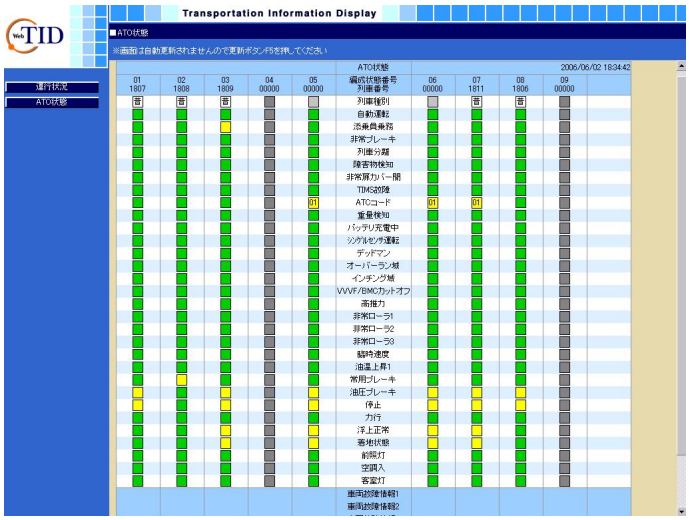

Figure 5: Display of information of vehicle condition

3.5 Station control equipment

Station control equipment uses transponder. Information of potion is transferred between stations for vehicle to stop at correct position and information of doors etc. is transferred at station. When a strain stops Just position where is within 0.05 m from correct position, this equipment makes vehicle open doors, close doors and leave the station.

Table 3: Contents being transferred by station controller

	Content	Coil category
Wayside→Vehicle		
1	Category of information	Both
2	Train direction	Both
3	Coil number	Unpowered
4	Code of station	Unpowered P1
5	Information of position	Powered
6	Code of previous station	Powered
7	Code of track of previous station	Powered
8	Code of next station	Powered
9	Code of track of next station	Powered
10	Code of destination	Powered
11	Code of change of train category	Powered
12	Instruction of locking half doors	Powered
13	Instruction of controlling doors	Powered
14	Information of prohibiting opening doors	Powered
15	Instruction of start	Powered
16	Information of position	Powered
17	Information of terminal	Powered
Vehicle→Wayside		
1	Category of information	
2	Train direction	
3	Mulfunction of coil	
4	Code of set of cars	
5	Locking half doors or not	
6	Acknowledgement of instruction of door control	
7	Condition of doors	
8	Applying brake or not	
9	Enable to open doors or not	
10	Detection of weight level 2	

3.6 Automatic Train Control (ATC)

ATC and TD plays core role of safe operation and automatic operation is working under these systems.

Information between vehicle and wayside is transferred successively through aerial antennas under car body and inductive loop cable located at the center of guideway.

Wayside equipment of ATC determines limit speed depending on position of previous train, state of switching and curve radius etc. and transmits ATC signal to vehicle. Vehicle equipment of ATC receives the signal and compares speed shown by the signal with vehicle speed. When vehicle speed is higher than limit speed of ATC, ATC brake is applied immediately until vehicle speed becomes lower than limit speed.

In addition ATC makes vehicle stop with 01 or 02 signal, prevents from overrun at terminals and changes train direction at terminals.

3.7 Train Detection equipment (TD)

TD continuously transmits check in signal from antenna at the head of train and check out signal from that at the tail of train to the inductive loop cable located at the center of guideway. Wayside equipment of TD receives these signals, activates relays and detects signal block occupied by train.

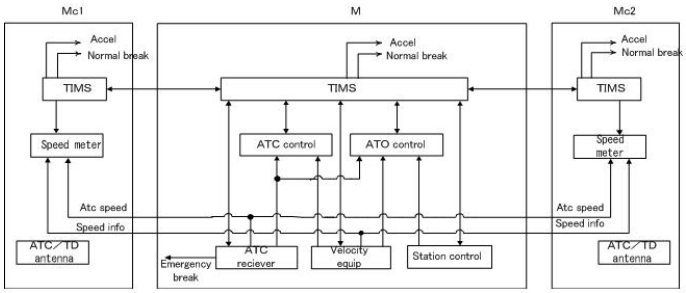

Figure 6: Composition of safety equipments

4 ACHIEVEMENT IN OPENING YEAR

Table 4 and Table 5 shows the number of passengers and consumption of power, brake pads and power collecting pads of each month from opening month, March 2005 to March 2006..

Running distance is calculated by multiplying line length 8.9 km by the number of operation. The number of operation is calculated by multiplying that per day by the number of days in each month. The number of operation per day is basically 220 on weekdays and 204 on weekends, but 300 on weekdays and 316 on weekends during EXPO2005. Power consumption is calculated by dividing total power consumption measured at the substation by running distance and the number of cars a train, 3.

Table 4: Achievement in opening year 1

A	B	C	D	E	F	G	H
3	31	426,089	1,194,464	1,136,720	9260	82,414	4.598
4	30	2,293,765	2,422,625	1,168,920	9160	81,524	4.779
5	31	3,302,533	3,009,994	1,255,910	9492	84,479	4.956
6	30	3,577,008	3,165,392	1,280,760	9128	81,239	5.255
7	31	3,287,635	3,147,397	1,363,781	9490	84,461	5.382
8	31	4,035,794	3,589,211	1,432,050	9444	84,052	5.679
9	30	5,146,790	3,902,172	1,379,440	8840	78,676	5.844
10	31		326,742	736,280	6644	59,132	4.150
11	30		300,961	720,320	6440	57,316	4.189
12	31		239,514	780,960	6628	58,989	4.413
1	31		249,407	770,060	6628	58,989	4.351
2	28		216,891	692,420	6032	53,685	4.299
3	31		234,615	753,690	6676	59,416	4.228
Sum						924,372	
Previously estimated value							4.046

A. Month
B. The number of days
C. The number of visitors of EXPO2005
D. The number of passengers
E. Power consumption measured at substation (kWh)
F. The number of operation of trains
G. Running distance (km)
H. Average power consumption (kWh/car/km)

Table 5: Achievement in opening year 2

A	B	C	D	E
3	1,194,464	82,414	3	133
4	2,422,625	81,524	10	100
5	3,009,994	84,479	2	108
6	3,165,392	81,239	6	126
7	3,147,397	84,461	12	178
8	3,589,211	84,052	12	77
9	3,902,172	78,676	13	88
10	326,742	59,132	9	110
11	300,961	57,316	3	52
12	239,514	58,989	1	79
1	249,407	58,989	0	58
2	216,891	53,685	1	86
3	234,615	59,416	0	119
Sum		924372		
Previously estimated value per year			917	1849
Actual value / Estimated value (%)		7.9	71.1	

A. Month
B. The number of passengers
C. Running distance (km)
D. The number of exchanged brake pad
E. The number of power collecting pad

4.1 The number of passengers

Estimated number of passengers of Tobu-Kyuryo-Line is 30,000 a day. The number of passengers was 3.5 times estimated one during EXPO2005, but one third of estimated one after EXPO was over. However we expect that the number will increase as the area is being developed.

4.2 Power consumption

Average power consumption is shown as power consumption for a car to run for one kilometer. Previously estimated value is 4.046, but measured one in September was 44 % more than estimated one because of extremely high carrying weight and full working of air conditioner. In October or November, measured value came close to estimated one, but it had grown higher since December because of heater working.

4.3 Consumption of brake pad

The number of exchanged brake pad is estimated using the result of running test of HSST-100L. 72 pads, only 8 % of estimated number, were exchanged. One of the reasons is that vehicle speed at which brake is switched from electric to hydraulic, changed to 3 km/h from 10 km/h. Another reason is that hydraulic brake usually generates smaller brake force when operated automatically than manually because automatic operation has 7 steps for brake control which generate smaller brake force than the lowest step of manual operation.

4.4 Consumption of power collecting pad

The number of exchanged power collecting pad is estimated using the result of running test of HSST-100L. 1314 pads, about 71 % of estimated number, were exchanged. Material and shape of the pad are not changed from HSST-100L.

Pads are worn like they are grooved. We flatten them with grindstone. That leads smaller consumption of pads.

Figure 7 shows comparison between worn pad and flattened pad. Left is worn pad and right is flatten pad.

Figure 7: Comparison of power collecting pad

5 CONCLUSION

More than one year has passed since we start operation of Tobu-Kyuryo-Line on March 6. EXPO2005 was held soon after we started operation. Average number of passengers exceed 100,000 and total number was close to 20 million during EXPO. The number got larger and larger as the final day came closer and in September almost all trains were full of passengers from early morning to late at night. That situation was as hard as endurance test for first commercial application of HSST system. But we had accomplished very important role of access to EXPO site with technical skill obtained by HSST-100L or HSST-100S and support of manufacturer of this system.

We will make efforts to operate safely on time as important transportation system and to improve our service so as to increase the number of passengers.

Finally, we are grateful to Chubu HSST Development Co. which has played an important role since planning and thank all of companies which designed, manufactured and constructed Tobu-Kyuryo-Line.