Recent advancement in linear drives applied to traction in Japanese Subways; Linear Metros

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ABSTRACT: Japan started the technical studies on application of linear induction motors (LIM) to subways in 1976. The achievement of technical studies was brought into commercial operations in Osaka Tsurumi Ryokuchi-Line, Tokyo Oedo-Line, Kobe Kaigan-Line, Fukuoka Nanakuma-Line, Ohsaka Imazatosuji-Line, and Yokohama Green-Line. They are also called "Mini-subways" and transport 15-40 thousand passengers per hour. They are playing significant roles in urban public transports. This paper deals with recent topics from linear induction motor application to railways including Japanese linear metros.

1 INTRODUCTION

Japan started the technical studies on application of linear induction motors (LIM) to subways in 1976. The first test run of 330m length was in 1982, and commercial prototype vehicle was tested at Ohsaka-Nanko test track of 1.85km from 1987 through 1988. The achievement of technical studies was brought into commercial operations in Osaka Tsurumi Ryokuchi-Line, Tokyo Oedo-Line, Kobe Kaigan-Line, Fukuoka Nanakuma-Line, Ohsaka Imazatosuji-Line, and Yokohama Green-Line. They are also called "Mini-subways" and transport 15-40 thousand passengers per hour. They are playing significant roles in urban public transports for suppressing initial investment for subway construction in Japanese large cities. From 2003 through 2004, Japan Subway Association discussed the technical feasibility of driver-less subway systems based on automatic train operation for next generation intensively. After the study, The infrastructure of Fukuoka Nanakuma-Line has been constructed using an operational system technically ready for the full automatic train operation and driver-less operation.

2 HISTORY OF LINEAR INDUCTION MOTOR APPLICATIONS TO PUBLIC TRANSPORT

Japanese application of the linear induction motors to public transportation was initially motivated by the development of magnetically levitated urban-suburban public transport named HSST: High Speed Surface Transport. The history of the Japanese maglev with electromagnetic suspension and linear induction drive is summarized briefly as follows:

1972 Japan Air Line started research and development of the Maglev
1975 Test vehicle HSST-01 with 2 seats
1978 Test vehicle HSST-02 with 9 seats
1985HSST-03 with 50 seats was demonstrated at Tsukuba Expo in Japan
1986 HSST-03 was demonstrated at Vancouver Expo in Canada: The demonstration line included curved sections
1988 HSST-04 with 40 seats was demonstrated at Yokohama Expo: This vehicle had onboard inverters
1989 HSST-05 with 2 cars and 150 seats were demonstrated at Yokohama Expo with official license for public demonstration
1989 The development works were transferred to Chubu-HSST Corp.
1991 The construction of Oe-test line of 1.5km-length was complete in Aichi prefecture. The test operation of HSST-100S started.
1990-1993 Discussion on technical feasibility at Ministry of Transportation base on the test resulkts from Oe-test line.
1995 A prototype vehicle HSST-100L with two cars and 220 nominal passenger number started test-runs
2000 Operational company Aichi-Kosoku Railway Corp. was founded.
2004 The first commercial maglev line Tobu-Kuryo Line started test runs.
2005 The commercial operation of the line was started: The trains shown in Figure 1 are called "LINIMO."

The commercial line of 8.9km connects 9 stations from Fujigaoka-subway station. There are 9 train-sets consisting of three cars whose maximum speed is 100km/h. The train operation is fully automated. The shortest train-head is six minutes. It transports 34 thousand passenger per day.

Figure 1. LINIMO starting its commercial operation in 2005.

On the other hand, successful commercial operations are observed in subway systems in large cities.人 In 1976, there was a technical proposal on linear metros, and feasibility study for 4 years was started.

1982 The first test run

1984 The test run with 70km/h was realized.

1987-1988 A continuous test runs of a prototype train were executed at Osaka-Nanko loop test-line of 1.85 km/h.

After the prototype test, the commercial lines in next section were constructed and successfully operated.

3 COMMERCIAL AND TECHNICAL DEVELOPMENT

3.1 Ohsaka municipal transport

The first commercial operation of Japanese linear metros was started at Osaka-Tsurumiryokuchi-Line in 1990. Figure 2 show a rolling stock at this line. The linear motors were driven by GTO-inverters. The line has 17 stations and length of 15km.

In 2006, the new Imazatosuji-Line started its commercial operation in 2006. The new technology of IGBT inverters were introduced. The line has 11stations and length of 12km. Figure 2 shows a technical visit of IEC/PT62520-project team members in January 2008.

Figure 2. Osaka Tsurumi-Ryokuchi-Line.

Figure 3. Depo for Osaka Imazatosuji-Line. (Technical visit by IEC/PT62520 members)

Figure 4. Primary of a linear induction motor for Oedo-Line.

3.2 Tokyo municipal transport

Oedo-Line, which started its commercial operation in 1991, are playing significant role in urban passenger transport in Tokyo. The ring-shaped line has 38 stations in length of 41km. The rolling stocks have IGBT inverters. The linear motor applied to this line in Figure 4 became a standard in Japanese further applications. Figure 5 shows a rolling stock in Tokyo.

Renewal of the Japanese standard rolling stocks are under investigation for introducing new technologies as described briefly in section 3.7.

Figure 5. Oedo-Line.

3.3 Kobe municipal transport

Kobe-Kaigan-Line in Figure 6 started its commercial operation in 2001. It has 10 stations and length of 8km.

Figure 6. Kobe-Kaigan-Line.

3.4 Fukuoka municipal transport

Fukuoka-Nanakuma-Line, which has 16 stations and length of 13km, started its commercial operation in 2005. Its train operation control is fully automated, *i.e.*, driverless-operation ready. Figure 7 shows the rolling stock in Fukuoka.

Figure 7. Fukuoka-Nanakuma-Line.

3.5 Yokohama municipal transport

Yokohama-Green-Line is the newest commercial linear metros in Japan presently. The maximum operational speed is 80 km/h, and it is the fastest linear metros in Japan. It has also sections above ground.

3.6 Sendai municipal transport

Sendai city is constructing its second subway line using linear metros technology. The line is under construction and may start its revenue service in 2015. It will have 13 stations ad length of 14km.

(a) Conventional secondary rail

(b) Secondary rail under investigation for better efficiency.

Figure 8. Technical effort for higher efficiency at JSA.

3.7 Technical studies

Low energy efficiency and relatively heavy primary are substantial disadvantages of linear induction motors. For better efficiency, effective use of regenerating braking is significant. Also he design of secondary rail is also under study as shown in Figure 8.

For reducing primary weight and volume, effective cooling may be a key. By introducing forced cooling, the weight and volume of the primary can be reduced drastically as shown in Figure 9.

(a) Primary of a conventional linear induction motor.

(b) Primary of a linear induction motor under study.

Figure 9. Technical effort for lighter traction system at JSA.

Figure 10. Project team members of the international standardization of linear induction motors for railway traction: photograph at the second project meeting at Kingston, Canada in December 2008.

4 CONCLUSIONS

After technical research and development of technologies of linear induction motors, Japan has presently one maglev and seven linear metros lines. The total length of the commercial lines is more than one hundred km. Based on the experience of the revenue services and technology, Japanese engineers proposed international standardization of linear induction motor technologies applied to railway traction to Technical Committee 9 in International Electrotechnial Commission in 2006. In cooperation with Canadian, Chinese, Korean, French, Swiss and German experts, the documentation work is completed. Figure 10 shows a part of the project team members. A new international standard "IEC/ TC9/ PT62520 ----- Railway applications -- Electric traction - Electrical machines for railway - Short primary type linear induction motors fed by power converters--" has been just published[1].

5 REFERENCE

[1] Information on the new international standard on linear induction motors applied to railway traction, IEC Home page: http://webstore.iec.ch/preview/info_iec62520%7Bed1.0%7Db.pdf