Linear Metro Transport Systems for the 21st Century

Eisuke Isobe
Jinko Cho
Itaru Morihisa
Toshihiko Sekizawa
Ryuji Tanaka

Overview: Urban transportation systems are sought that reduce construction, maintenance, and operating costs, that offer improved comfort and convenience, and that are environmentally friendly. Hitachi, Ltd. has been working on the development of the Linear Metro since 1978 to meet these requirements. Driven by a linear motor and employing a steel wheel/steel rail track system, the Linear Metro is an advanced urban transportation system offering a wide range of features that are not available on other train systems. The Linear Metro is already operating in Osaka and Tokyo. Hitachi, Ltd. is in charge of coordinating the design and construction of the Series 12-000 cars for the loop portion of Tokyo Subway Line No. 12 that is now under construction. Exploiting all the advanced features of the Linear Metro including low-noise inverter equipment and one-man operation system, the cars offer enhanced intelligence as a new subway transport system for the 21st century. Many municipalities have expressed strong interest in the Linear Metro for its compatibility with smaller cross section tunnels and its ability to negotiate steep gradients and sharp curves. To satisfy these diverse requirements, Hitachi, Ltd. is continuing to further develop and refine the Linear Metro.

INTRODUCTION

THE Linear Metro is an advanced linear motor-driven urban transportation system featuring a steel wheel/steel rail track system that was put into subway service for the first time in the world in Japan. The system was deployed by the Osaka Municipal Transportation Bureau in 1990, followed by the Transportation Bureau of the Tokyo Metropolitan Government the next year. The Linear Metro will also operate on the loop portion of Tokyo Subway Line No. 12 which is now under construction, and three other municipalities in Japan currently have deployments of the Linear Metro under construction or in planning.

As an example of this new linear motor-driven train

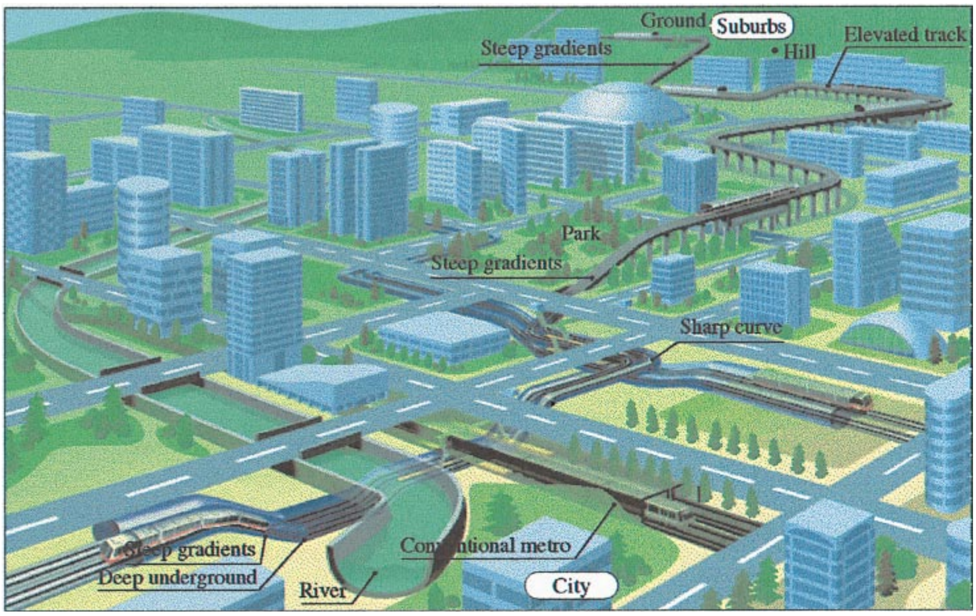

Fig. 1—Projection Image of the Linear Metro Subway Integrated in an Urban Transportation System. The Linear Metro fully exploits the advantages of the linear motor to achieve exceptional economy with low construction costs and easy maintenance, greater freedom of route planning since trains are able to negotiate steep gradients and sharp curves safely and smoothly, operations unaffected by weather conditions, and consideration for the environment with reduced noise.

for the 21st century, this article will provide a detailed overview of the Linear Metro for deployment on Tokyo Subway Line No. 12, highlighting the system's electrical systems, data control, and one-man operation systems.

LINEAR METRO OVERVIEW

Linear Metro Features

The Linear Metro is a new urban transportation system driven by a non-adhesive linear motor and guided by a steel wheels on a steel rail track system (Fig.1). Some of the remarkable features distinguishing Linear Metro from other transportation systems are:
(1) Its ability to easily negotiate steep gradients and sharp curves.
(2) The cross sections of subway tunnels can be markedly reduced.
(3) Considerable labor is saved in maintaining the drive system.
(4) Secures operation stability as weather conditions do not affect train operation.
(5) Absence of revolving motor and reduction gear makes for a quieter ride.

With this array of features, the Linear Metro meets all the requirements of next-generation urban transport systems: reduced construction, maintenance, and operating costs, improved comfort and convenience, and a system that is environmentally friendly.[1] Fig. 2 highlights the features of the Linear Metro, and Table 1 compares the Linear Metro with conventional subway systems.

Practical Deployment of the Linear Metro

After Hitachi came up with the original concept for the Linear Metro back in 1978, a two-phased R&D program was orchestrated by the Linear Metro Research Committee supported by the Ministry of Transport. The basic R&D was carried out during the first phase from 1981 to 1984, which was followed by a deployment-oriented R&D phase from 1985 to 1987.

Hitachi, Ltd. has been closely involved in R&D on the Linear Metro from the outset, and made substantial contributions to both the development and practical deployment of the system. Thanks to these efforts, the Osaka Subway Line No. 7 was put into service in 1990, and the Tokyo Subway Line No. 12 began operating in 1991.

LINEAR METRO CARS

Overview of Tokyo Subway Line No. 12

Subway Line No. 12 is under the authority of the Transportation Bureau of the Tokyo Metropolitan Government (TBTMG). The line is approximately 41 km in length, and consists of a loop portion and a spur

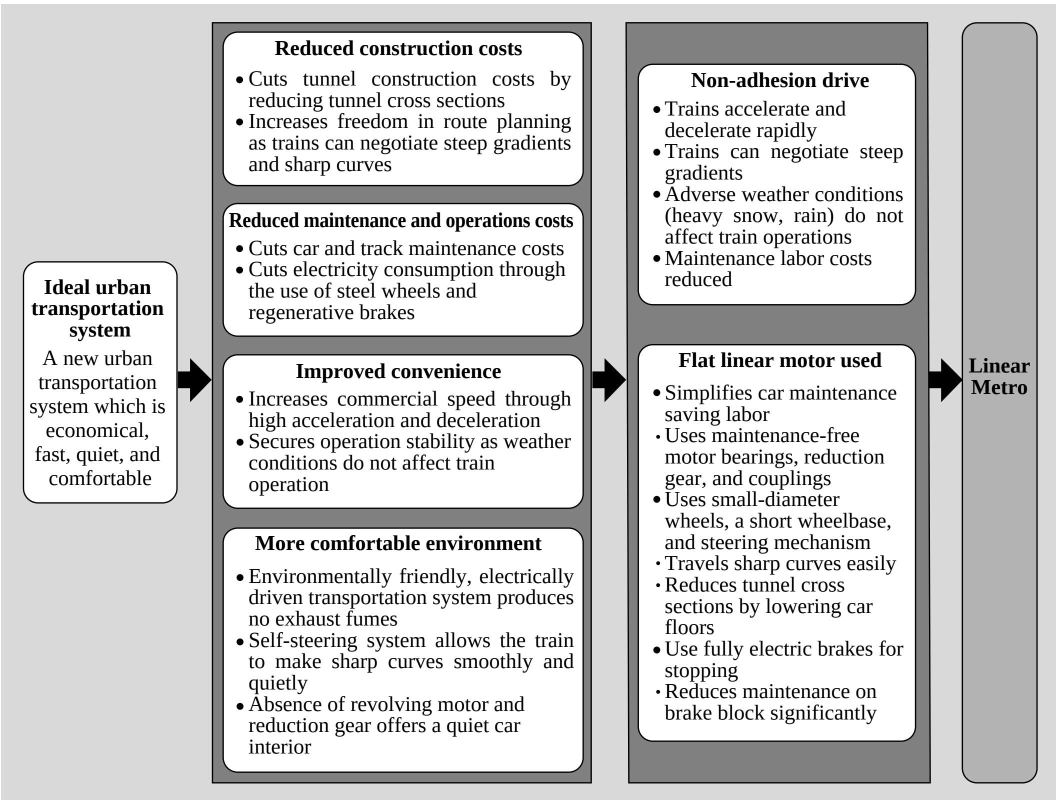

Fig. 2—Linear Metro's Advantages.
The Linear Metro meets all the requirements for next-generation urban transport: reduced construction costs, maintenance, and operating costs; improved comfort and convenience; and friendly to the environment.

TABLE 1. Comparison of Linear Metro and Conventional Subway
Featuring a non-adhesion drive system, a flat motor, and flexible steering, the Linear Metro requires smaller tunnel cross sections and can easily negotiate steep gradients and sharp curves.

VVVF: variable voltage, variable frequency

Item	Conventional subway	Linear Metro	Effects of new technology
Drive system	Friction between the wheels and rails drives the car	Attraction and repulsion of linear motor magnets drive the car	• Capable of traveling gradients as steep as 6% to 8% (compared with 3.5% for conventional cars)
Motor type	Rotary motor and gear assembly	Non-rotary linear motor	• Reduced friction between wheel and rail • Absence of motor, drive rotation noise (quieter ride)
Motor shape	Bulky	Flat linear motor and reaction plates	• Floor of car is lowered, comfortable interior • Tunnel cross section reduced by about 50%
Traction inverter (VVVF inverter)	Current pattern control	Voltage pattern control, efficiency-maximizing slip pattern control, acceleration rectifying control	• Responds to variations in the distance between linear motors and reaction plates • Optimize efficiency of linear motor • Maintain performance while changing reaction plate material
Bogie type	Wheel angle static	Wheel angle variable (self steering)	• Improved ability to negotiate sharp curves (minimum curve radius from about 160 m to about 50 m) • Reduction of creaking noise when rounding curves • Reduced friction between wheel flange and rail

portion. The spur segment radiating out from Shinjuku was put into operation in December 1997, and the loop portion is scheduled to begin operation in the year 2000.

Hitachi, Ltd. is in charge of the total system to design and build 388 Series 12-000 cars that will provide the rolling stock on both the spur and loop portions of the line.

Overview of 12-000 Series Cars

Design concept and features

The 12-000 series cars take full advantage of the advanced Linear Metro features described earlier. The design concept was conceived to produce an advanced subway car that will satisfy the requirements of the 21st century. For example, it features traction inverters using IGBTs (insulated gate bipolar transistors) to minimize noise; a one-man operating system based on ATO (automatic train operation) and a free-space optical transmission system for monitoring the platform; an ATI (autonomous decentralized train information control system) endows cars with enhanced intelligence and the ability to coordinate with the above-ground CTMS (comprehensive train maintenance supervisory system).

Compact lightweight aluminum carbodies

Car exteriors are sheathed in aluminum alloy to reduce weight and also to reduce lifecycle costs, including eventual recycling costs. Exteriors of the cars are given a hair-line brushed finish and not painted to reduce maintenance. To minimize weld distortion in welding the outside sheathing, a new technique called friction stir welding was employed, that was first put into practical use by Hitachi, Ltd. for welding car bodies of railway. Though built more compactly, the car interior of the 12-000 series cars is as spacious and comfortable as that of conventional subway cars. This greater space efficiency is made possible by using flat linear motors that permits the floor to be lowered and by adopting trim-line air conditioners for mounting on the roof.

Linear motor

The cars are powered by a bogie frame-mounted primary linear induction motor that permits the floor of the cars to be lowered, that is capable of negotiating steep gradients and sharp curves, and that reduces maintenance labor.

The linear motor was designed for maximum efficiency; and the same principal was applied to secondary conductor reaction plates mounted on the sleepers. Construction costs were held down and energy consumption reduced by deploying efficient copper reaction plates on powering and braking sections of track, and low-cost aluminum reaction plates on coasting sections.[3)]

Traction inverter (VVVF inverter)

The traction system uses an IGBT 3-level inverter that substantially reduces the magnetic distortion noise from the linear motor and reaction plates.[2)]

The control system automatically compensates for differences in the reaction plates that are fixed to the sleepers (some of which are copper and other aluminum) and differences in car performance due to variations in the distance between the linear motor and the reaction plates. It also controls the electric negative-phase brake system that exploits the features of the linear motor drive.

Reliability and maintainability have also been markedly improved by implementing a gate controller with self-diagnosis and dynamic monitoring capabilities, and vacuum high-speed circuit breakers (VHB). Fig. 3 shows a schematic of the main circuits of traction inverter.

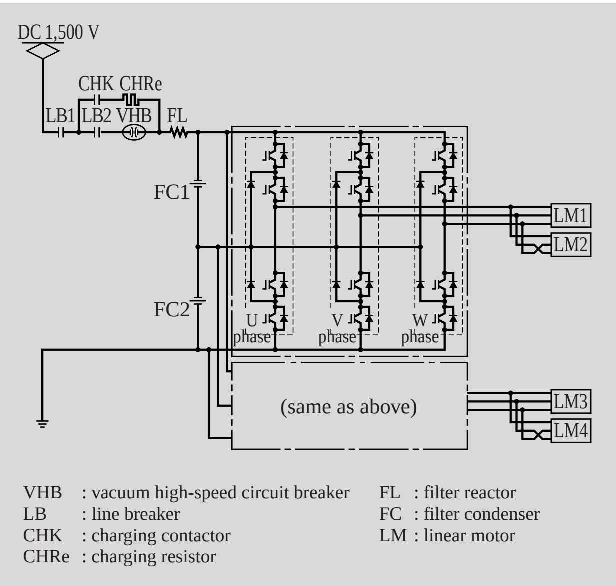

Fig. 3—Schematic Drawing of Main Circuits of Traction Inverter for Series 12-000 Cars.

CAR INTELLIGENCE AND ONE-MAN OPERATION SYSTEM

Car Information Systems (ATC, ATO, and ATI)

The intelligence systems for the Series 12-000 cars — ATC (automatic train control), ATO, and ATI — have been integrated, thus permitting operation data, service data, equipment monitoring data, and maintenance data to be shared. And by integrating data transmissions over fiber-optic transmission facilities, this reduces equipment wiring, enables equipment to be implemented more compactly, and improves functional capabilities.[4] A robust system for transmitting data between the cars and the CTMS system above ground is implemented by the free-space optical transmission system that speeds up train testing, improves accuracy, and saves considerable labor. A schematic of the system is shown in Fig. 4.

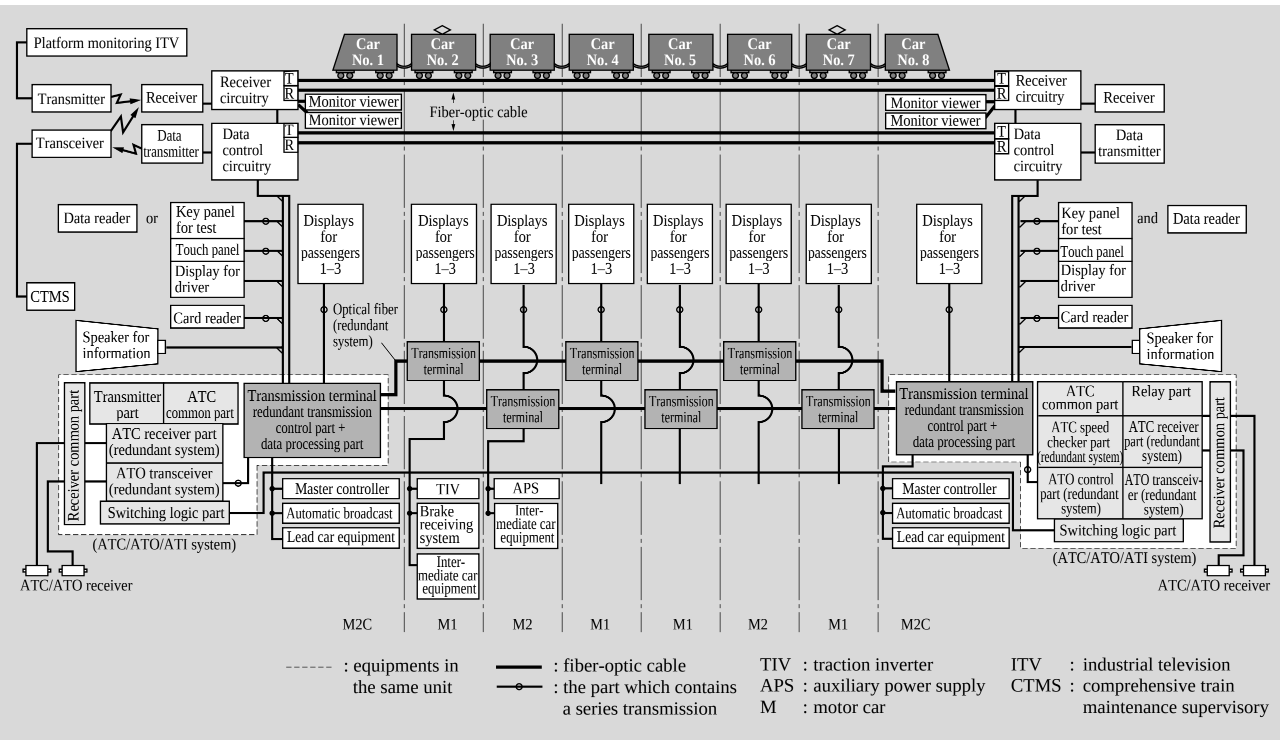

Fig. 4—Configuration of ATC/ATO/ATI System for Series 12-000 Cars.
Integrating the ATC, ATO, and ATI systems makes it possible to share various types of data (operational control data, service data, motor data, and maintenance data), and thus achieve more intelligent control of cars.

One-man Operating System

The ability of a single operator to run the train is indispensable to save labor in the operation of urban transport systems, and a one-man operating system was introduced when the Tokyo Subway Line No. 12 was opened.

One-man operation in the Series 12-000 cars is made possible by a number of support systems including the fuzzy control-based ATO system, the platform monitoring system using close infrared ray image transmission, engineer support monitoring and service capabilities of the ATI system. In addition, video links have been upgraded along with the above-ground facilities to two channels in order to accommodate curved platforms and the lengthening of trains from six to eight cars. Two 10.4-inch. liquid-crystal displays have therefore replaced the single display in the operator’s compartment for monitoring the platform.

CONCLUSIONS

This article gave an overview and brief summary of the development process leading to the deployment of the Linear Metro. We discussed the cars that operate on Tokyo Subway Line No. 12, the information systems used in the cars, and the one-man operation system.

At the present time, three domestic municipalities have committed to the Linear Metro for a total combined distance, either actually deployed or planned, of greater than 120 km.

Offering an array of advanced new features and capabilities, the Linear Metro is an ideal urban transportation system for the 21st century. Meanwhile, research is continuing in order to further enhance the maintainability, lessen the environmental impact, and achieve greater energy savings with linear motor-driven subways. Building on its accumulated wealth of experience and expertise, Hitachi, Ltd. will remain in the forefront of efforts to realize these objectives.

Finally, the authors gratefully acknowledge their colleagues in government, academia, and industry whose support and guidance were indispensable in developing, designing, and building the Linear Metro.

REFERENCES

(1) Investigation Committee for Promoting Linear Metro Overseas, Linear Metro Brochure, produced by the Japan Subway Association (Aug. 1998).

(2) M. Fukuda, et al., “Third-generation Production Series 12-000 cars on Tokyo No. 12 Line,” *Railway Car Engineering* **213**, 26 (June 1997).

(3) S. Masuda, et al., “Linear Motor-driven System for Subway Trains,” *Hitachi Hyoron* **73**, 311 (Mar. 1991) in Japanese.

(4) M. Shimizu, et al., “New ATC/ATO/ATI System for Railcars (ATC/ATO/ATI System for Third and Fourth Production Series 12-000 Cars on the Tokyo No. 12 Line),” 35th Cybernetics Applications Symposium, No. 524 (1998).

ABOUT THE AUTHORS

Eisuke Isobe

Joined Hitachi, Ltd. in 1971, and now works at the Transportation Systems Division. He is currently engaged in planning and development of railcar systems. Mr. Isobe is the consulting engineer (Electrical and Electronics, and Mechanical Department) as authorised Japan Government and is a member of the Japan Consulting Engineers Association, and a member of the Institute of Electrical Engineers of Japan, and can be reached by e-mail at e_isobe@cm.head.hitachi.co.jp

Jinko Cho

Joined Hitachi, Ltd. in 1980, and now works at the Rolling Stock Engineering Dept., Transportation Systems Division. He is currently engaged in coordinating railcar systems for the public railroads. Mr. Cho can be reached by e-mail at j_choh@cm.head.hitachi.co.jp

Itaru Morihisa

Joined Hitachi, Ltd. in 1975, and now works at the System Engineering Division. He is currently involved in work on subway-related systems. Mr. Morihisa is the consulting engineer (Electric and Electronic Department) as authorised Japan Government and is a member of the Institute of Electrical Engineers of Japan, and can be reached by e-mail at morihisa@cm.head.hitachi.co.jp

Toshihiko Sekizawa

Joined Hitachi, Ltd. in 1986, and now works at the Drive System Design Group, Rolling Stock System Design Dept, Mito Transportation Division. He is currently engaged in the design of control systems for electric vehicles. Mr. Sekizawa can be reached by e-mail at toshihiko-mito_sekizawa@ccgoz.hitachi.co.jp

Ryuji Tanaka

Joined Hitachi, Ltd. in 1991, and now works at the Operations Systems Design Group, Rolling Stock System Design Dept, Mito Transportation Division. He is currently engaged in designing and coordination work on maintenance systems for trains (ATC/ATO/ATI monitor). Mr. Tanaka can be reached by e-mail at ru_TANAKA@cm.mito.hitachi.co.jp