Evaluation of Urban Magnetically Levitated Vehicles in Japan

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1. Introduction

In order to solve some various problems of urban transportation such as traffic congestion, pollution and accidents, various kinds of people mover systems have been developed, and parts of some are in practical use in Japan. Though most people mover systems in existence use rubber tires and wheel guide rollers, there are several problems such as high operating and maintenance costs in comparison with conventional railways. In order to settle these problems, several new transportation systems driven by linear motors are being developed in Japan and are partly in practical use. Generally speaking, linear motor driven systems have magnetic suspensions because of many merits of contactless systems. However, in Japan, many new linear driven systems with contact are being developed.

This paper describes some technical characteristics of new urban transportation systems driven by linear motors in Japan with not only magnetically levitated suspensions but also other suspensions such as air or mechanical. Moreover, we denote several evaluation items for urban transportation systems and show the comparison results according to these evaluation indices. Receiving these results, we propose technical evaluation method for new urban transportation systems and show an example to introduce magnetically levitated transportation systems of HSST in new region by using this method.

2. Development of magnetically levitated transportation systems in Japan

In Japan, as you know, big project of superconducting magnetic levitated vehicles (JR Maglev) has been proceeding in Yamanashi test track since 1996, but other urban transportation systems with linear motors are being developed for several kinds of urban needs for example, steep slope or steep curve.

This section describes the developing status of these transportation systems.

2.1 Super high speed systems (JR Maglev) [1)]

The magnetically levitated system using superconducting magnets aims at extremely high speed of 500 km/h in revenue service for intercity transportation such as Tokyo-Osaka. This system has reached the running tests on Yamanashi Maglev Test Line and realized the maximum speed of 550 km/h in December 1997. It is continuing to undergo several safety and reliability tests.

Figure 1 shows the outline and location of priority section in Yamanashi test line, and main specifications of the priority section are shown in Table 1.

Main tests are executed in this priority section, and after some verification of safety, Japanese government will judge the possibility of practical services. Considering these circumstances, final test line will be constructed as the part of the revenue line from Tokyo to Osaka.

Figure 2 shows the outline and main specifications of test vehicle MLX01.

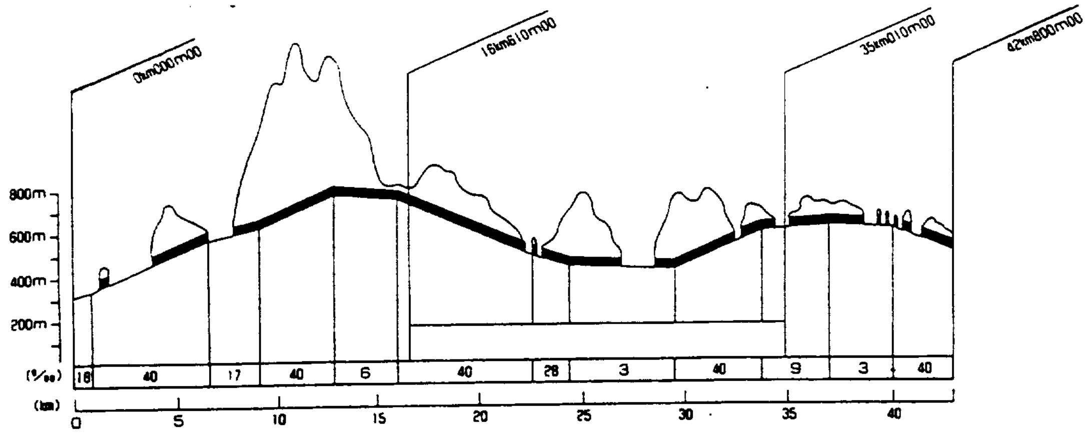


Figure 1 Outline and location of priority section in Yamanashi Test Line

Table 1 Specifications of the priority section of the Yamanashi Test Line

Length	Priority section 18.4 km , Tunnel section 16.0 km Open section 2.4 km
Maximum speed	550 km/h (operating speed 500 km/h)
Minimum curve radius	8000 m
Maximum gradient	4 %
Distance between the centeers of adjacent guideways	5.8 m
Passing	Relative speed is 1000 km/h
Main facilities	Control center, Substation , Test embarkation platform , Train depot
Turnout apparatus	High speed turnout , Low speed turnout

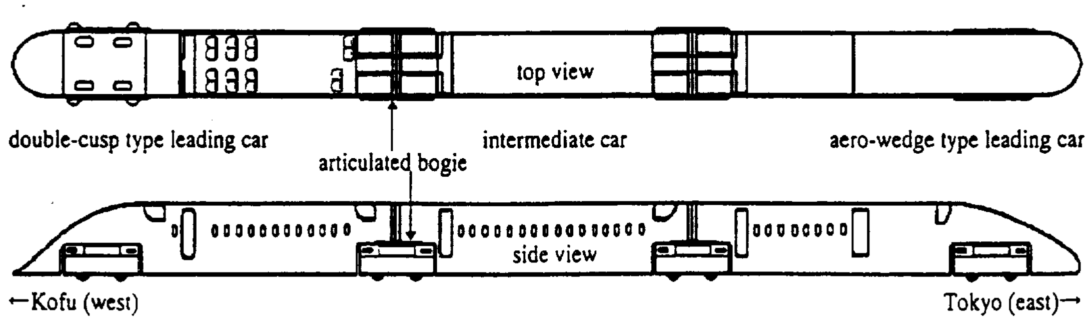


Fig.2 Outline and main spesification of test vehicle MLX01

Figure 3 shows the outline and general diagram of truck suspension. The truck on which the superconducting magnets are mounted serves to transmit the propulsive and levitational force generated by the magnets to the vehicle. It is also fitted with landing gear and guide wheel needed when running at low speeds genarally below 150 km/h , and with hydraulic apparatus that raises and lowers these wheels. Moreover apparatus for cooling the superconducting magnets are mounted. Also, various measures to improve cruising comfort , such as the double suspension spring and the vibration control devices, are incorporated on same trucks.

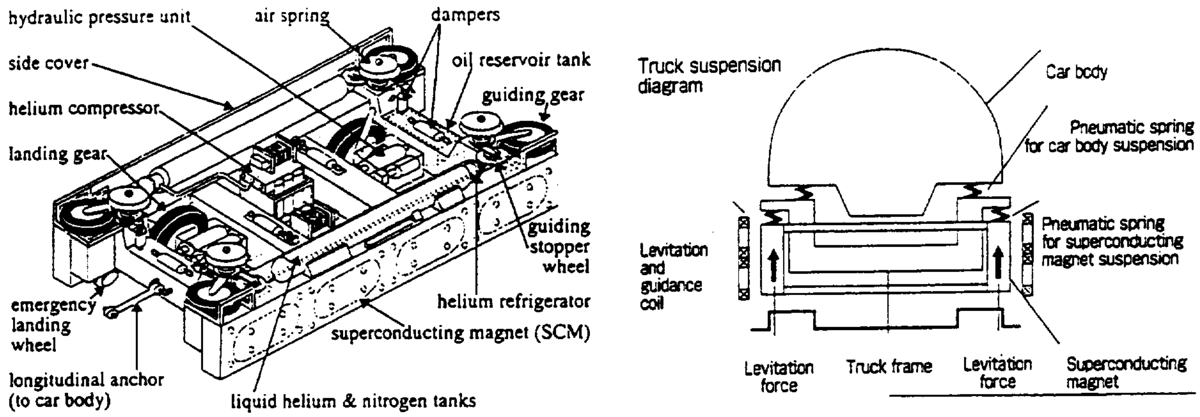


Fig.3 Outline and general diagram of truck suspension

Figure 4 shows the sample measurements of displacements between the truck and guideway at low speed. When the vehicle speed is lowered to about 100 km/h, an indication of instability is the gradual increase in the amplitudes of the vibrations of the lateral displacements between the truck and guideway. For the fundamental vehicle running tests on the Yamanashi Maglev Test Line , the speed at which the vehicle commences levitaion was set to be 135 km/h for the straight guideway sections , and 150 km/h for the curved guideway sections.

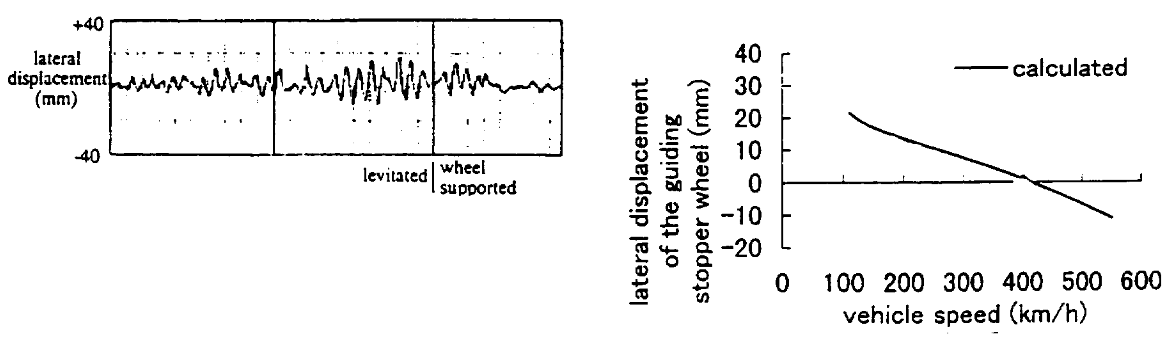


Fig.4 Sample measurements of the displacements between the truck and guideway at low speeds

2.2 Urban transportation systems

In Japan, according to several needs considering specific characteristics of urban problems, some new transportation systems driven by linear motors are being developed and are partly in practical use. In this section, some magnetically levitated transportation systems are denoted in technical viewpoints, and other systems are taken up for the sake of comparison.

2.2.1 Normal conducting magntic levitation vehicle systems HSST[2)]

HSST that has been developed since 1974 is a magnetically levitated vehicle (maglev) transportation system using electromagnetic suspension (EMS) and short stator linear induction motors. Ministry of Transport of Japan has clarified it's safety and practicality for revenue services through several test results in Nagoya test track.

Figure 5 shows the outline of test line in Nagoya and figure 6 shows the outline of HSST vehicles.

As HSST has developed for satisfying urban transportation demands, it aimed at a maximum speed of 100 km/h and comfortable riding performances because of levitation.

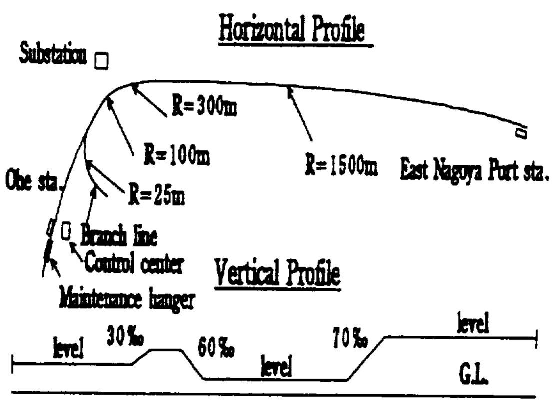


Fig. 5 Outline of test line in Nagoya

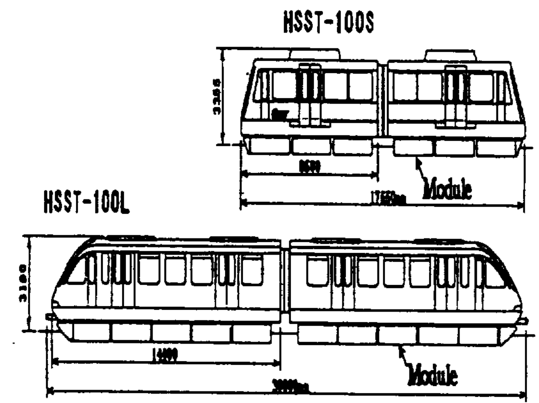


Fig.6 Outline of HSST vehicles

Table 2 shows several main specifications of HSST vehicles and figure 7 shows the cross section of the car body. Moreover, it is shown the cross section of the module that is the main element for controling levitation and propulsion in figure 8.

Since HSST-100S was developed as the same size of standard rubber tire transportation systems (generally speaking as people mover) in Japan, length of car is restricted 8.5 m by Japanese standards for medium transportation demands such as 8,000 ~ 20,000 people per peak one hour. On the contrary, HSST-100L has been designed to realize larger transportation demands.

Table 2 Major specifications of HSST vehicles

Items	HSST-100S	HSST-100L
Length of end car	8.5 m	14.4 m
Width of car	2.6 m	2.5 m
Vehicle weight Empty Full load	 10 ton 15 ton	 15 ton 25 ton
Passenger number (at peak hour)	44 (67)	68 (110)
Max speed	100 km/h	100 km/h
Acceleretion	4.5 km/h/s	4.5 km/h/s
Number of module	6 /car	10 /car
Magnetic gap of levitation	8 mm	8 mm
Lateral suspention system	Hydraulic control	Mechanical control
Number of Linear Induction Motors	6 LIMs/car	10 LIMs/car

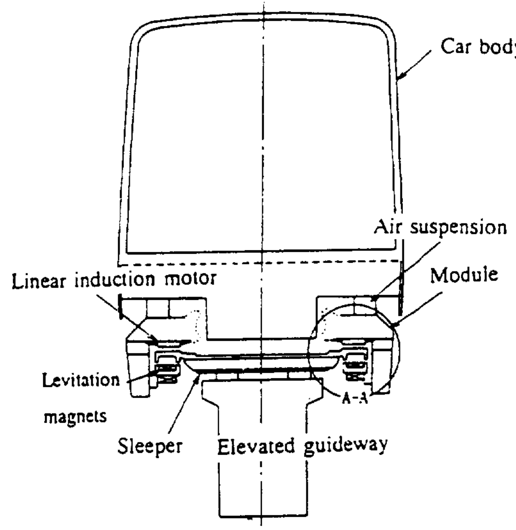


Fig.7 Cross section of car body

The relation between the fluctuation of levitation gap and vehicle speed is shown in figure 9. In this figure, levitation gap is defined as the length between levitation magnet and rail. It can be seen that the fluctuation of gap is proportion to the root of speed and no probability of contact between magnets and rail can be expected because the normal levitationgap is 8 mm. At 100 km/h with full load , the fluctuation of gap in RMS was 0.9 mm in average.

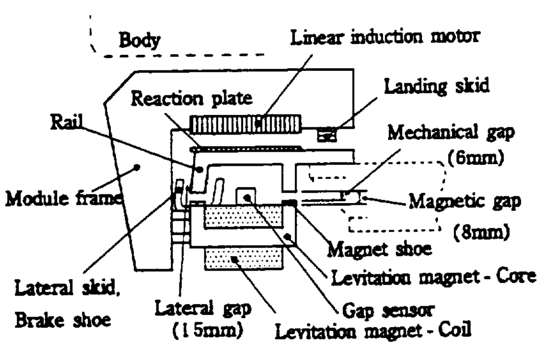


Fig. 8 The cross section of module

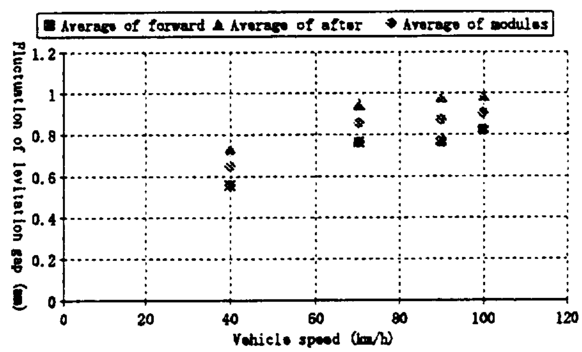


Fig. 9 Fluctuation of levitation gap

Presently, construction plan has been proceeding in east side of Nagoya that connects 11 km between subway station and suburban areas. HSST-100L system is now preparing for revenue service with continuing durability running tests in test line.

2.2.2 Permanent magnet levitation system [3)]

Formerly, M-bahn system has operated in west Berlin in 1989 and this system has characteristics in levitation with permanent magnets and propulsion with linear synchronous motors of primary side on ground type. However, this system is not perfect contactless but supported by wheel with mechanical system for compensating for the load variation from empty to full conditions. Though this system vanished unfortunately in Germany for the sake of several political reasons, it has been studied in Japan as the short trip urban transportation systems utilizing high economic performance such as 0 energy for levitation.

This section introduces the Japanese study status for easy transportation system with permanent magnet levitation .

Figure 10 shows the outline of simple vehicle with permanent magnet levitation in the experimental line and gap control mechanism is shown in figure 11. As gap between permanent magnet on the vehicle and iron core of primary coil on the ground is controlled mechanically with the weight through link mechanism, vertical wheels do not support the normal load. The role of these wheels are to support the temporary load change such as running through on the joints in the track. You can see the relation between gap and load. That is to say , according to increasing loads, gap is gradually smaller mechanically.

Figure 12 shows the example of running results in the test line of about 50m. Running of this system is controlled automatically by computers that has running patterns and orders driving currents on the ground side.

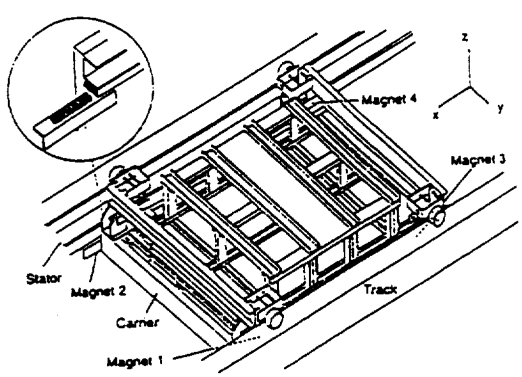


Fig. 10 Outline of test vehicle

Fig.12 Example of running results

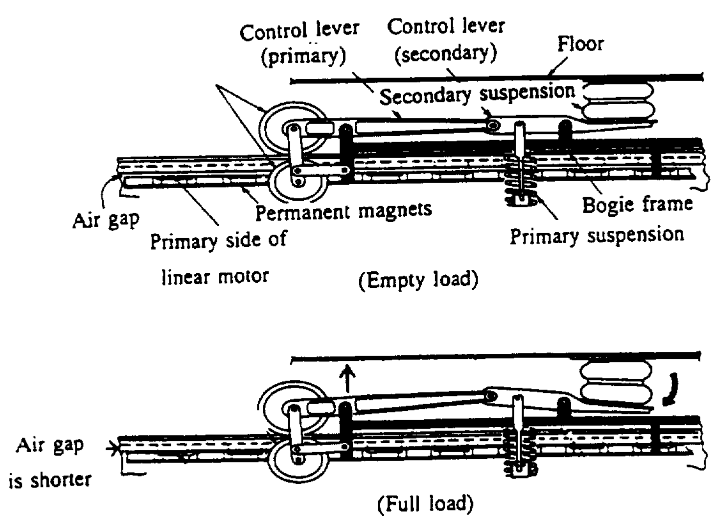


Fig. 11 Outline of gap control mechanism

2.2.3 Aerodynamic levitation system [3]

It is well known that the aerodynamic levitation system such as OTIS shuttle has quietness inside and outside vehicle. In Japan, rope driven system was realized in Narita airport by OTIS and now, linear motor driven system is refining in test line also by OTIS.

This section describes the characteristics of aerodynamic levitation transportation systems driven by linear motors.

Figure 12 shows the outline of vehicle and suspension system.

This system is driven by linear induction motors with primary side on vehicle like HSST, but has characteristics in air suspension that supports the vehicle through air pads without perfect levitation. The distances between road surface and air pads are within 0.1 mm or 0 mm that is contact. But the system was designed for this contact between air pads and road surface and has no problems from the viewpoint of running and wear. No contacts are realized in other parts such as linear motors (primary coils and reaction plate) or brake skids (skid and road surface). Figure 13 shows the relation of gap and speed at some parts of vehicle.

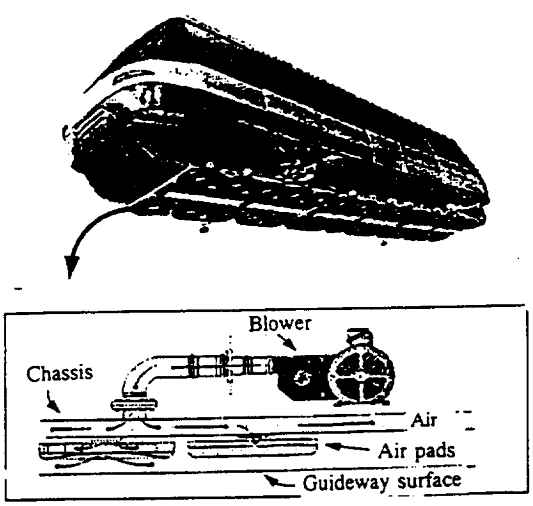


Fig.12 Outline of vehicle and air suspension

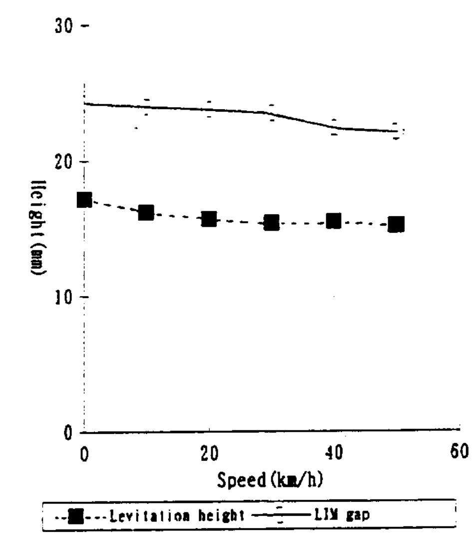


Fig.13 Relation of gap and speed

It is shown that levitation height is on the decrease in proportion with speed, but margins for contacts have secured enough. Presently, several tests are executed under the directions of technical committee in Railway Electrical Engineering Association of Japan at test line of about 450m. It realized maximum speed of 55 km/h and secured low noise characteristics inside and outside vehicle.

2.2.4 Other systems for urban transportation

1) Linear metro system [5]

In Japan , in big cities , though subway sytems are popularized for eliminating road traffic congestions , many subjects such as large financial costs and long term planning are pointed out by local government sides that generally operate subway systems. For these reasons, linear metro was developed for realizing low construction costs under the instructions of Ministry of Transport.

Figure 14 shows the section of linear metro system. According to this figure you can see the small cross section because of flatness of linear motor. It can be realized to be about 70 % of diameter of tunnel in comparison with conventional subway.

This system has characteristics of using wheel and rail for supporting vehicles like conventional railways. Moreover, truck can be easily improved to have simple steering functions because of flatness of linear motor without steering link. The outline of truck is shown in figure 15 and it can run smoothly on steep curve by this structure. Since Table 3 shows the comparison of mechanical dynamic gap between primary coil and reaction plate of design values and running results, it can be judged that the standard gap of 12 mm is appropriate.

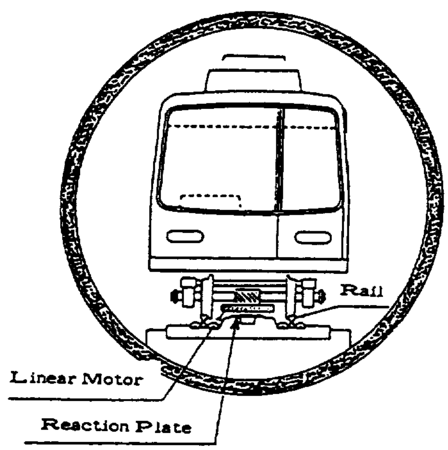


Fig.14 Section of linear metro system

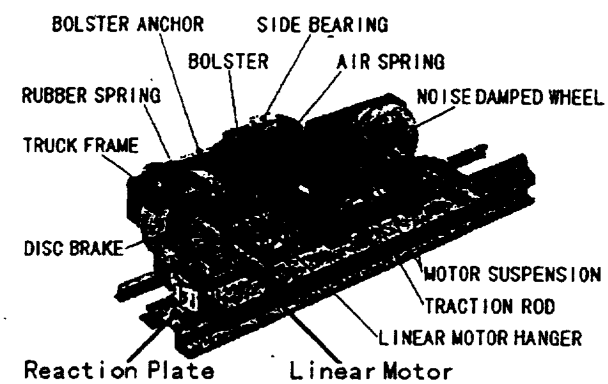


Fig.15 Outline of bogie truck

Table 3 Comparison of gap between designs and results

(Unit:mm)

Items for causing gap fluctuations		Design value	Measurement results	
			Straight line	Curve line
Setting error of linear motor coils		1. 0	1. 0	1. 0
Deflection of support and linear motor coils		0. 5	0. 9	0. 7
Wheel wearing up to maintenance		1. 0	1. 0	1. 0
Gap margin	Deflection by temparature	3. 5	0. 4	0. 4
	Others		——	——
	deflection of reaction plate		0. 7	1. 1
Deflection of reaction plate		0. 5		
Setting error of reaction plate		2. 0	2. 0	2. 0
Rail sinking		0. 5	0. 3	0. 7
Fall on rail joint		1. 0	(1. 0)	(1. 0)
Rail wearing up to maintenance		2. 0	2. 0	2. 5
Total amount		·1 2. 0	9. 3	1 0. 4

2) Sky rail system [6]

This system has developed for transporting people who live on the top of mountain hills at steep garadient districts to the railway stations that are located on the flat spaces in short trips. This system has characteristics in driving by rope and linear motors with primary side on ground. Though vehicles are suspended by the elevated girders like suspended monorail with wheels (vertical and guide) , they are driven by rope between stations and by linear induction motors with primary side on ground at the station areas. Figure 16 shows the outline of sky rail systems. It is interesting that vehicles are accelerated by linear motors at the station and grasp the rope with synchronous speed and are pulled by rope between stations and at the next station edge detach the rope and are decelerated by linear motor and stopped automatically. This system has just started as practical use in Hiroshima districts in 1998 on 1.3 km length.

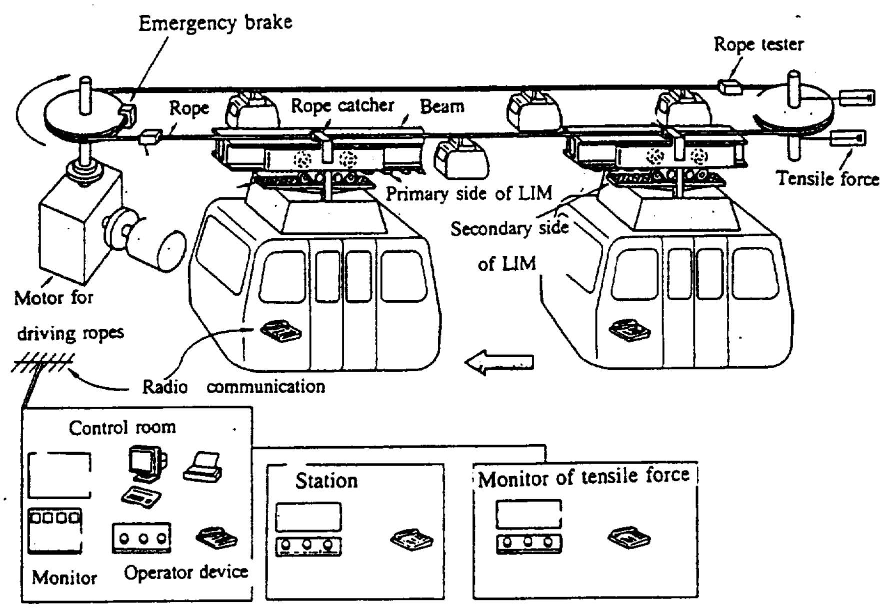


Fig.16 The outline of skyrail

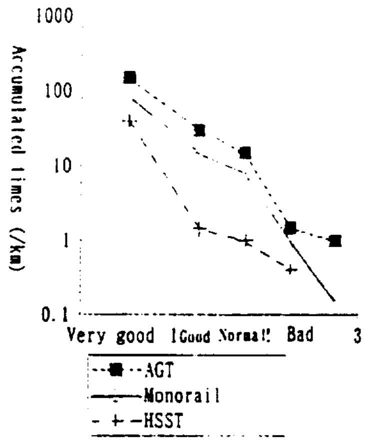
3 . Evaluation of urban levitated transportation systems

As you know, many new urban transportation systems are developing and some are in partly practical use. However, it is not said that the best solution to solve urban transportation problems is to prepare in Japan, It is said that some systems that are developed by each manufacturer are introduced somewhere by plausible reasons. In the section, it is denoted to evaluate these systems objectively in the viewpoints of technical, energy, and environmental sides.

3.1 Technical evaluation

As technical items that can be evaluated for maglev systems are taken up various topics, it is difficult to say that these systems are prior to conventional railways. For example, figure 17 shows the comparison of riding comfort between maglev systems and other urban transportation systems. As you understand by this figure, it is clear that magnetic suspensions have secured good riding comforts. The running resistance of several urban transportation systems are shown in figure 18.

You can find the profitability of levitated or linear motor driven systems in comparison with conventional railways. Through these comparisons , the characteristics of maglev systems are confirmed.



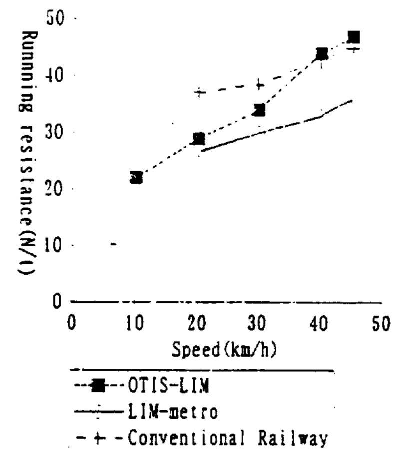


Fig.17 Riding comforts of transporation systems   Fig.18 Running resistances of transportion systems

3.2 Evaluation on environment

It is supposed for maglev systems to be silent in and outside vehicles because of non-contact and non adhesion drive. It is one of the most important merits to develop maglev systems in Japan for urban transportation systems. This is only realized by using magnetic or aerodynamic suspensions. Figure 19 shows the example of noise characteristics outside vehicle. According to this result, it is easily understood that levitation systems are friendly on noise environment. Moreover, it is natural for these electric railway systems including levitation systems to be superior to other transportation systems such as automobiles and buses.

3.3 Evaluation on energy

Levitation systems need extra energy for levitation, except for those using permanent magnets and high temperature superconducting magnets, beside propulsion energy. Moreover, in most cases, linear motors are used for levitation systems because of flatness and separate constructions. Therefore, it is supposed that levitation systems consume more energy for driving vehicles because of gap of linear motors. Figure 20 shows the running energy consumptions of several transportation systems with distances between stations. Generally speaking, energy consumption decreases in proportion to distances between stations. Though considering this tendency, it must be said that levitated systems need much more energy than conventional railway systems.

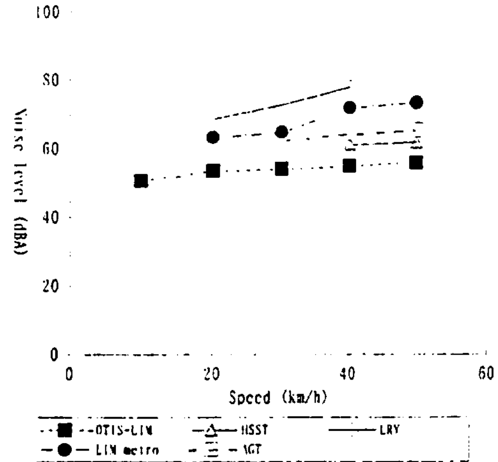


Fig.19 Noise characteristics outside vehicles

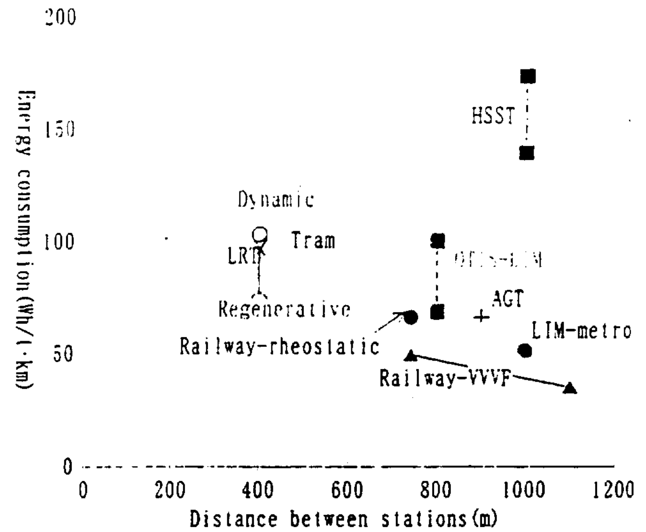


Fig.20 Energy consumptions of transportation systems

3.4 Synthetic evaluation

Above mentioned, levitated vehicles have several features in comparison with conventional railways . Some of these are merits and others are demerits. We must choose the proper transportationsystems by synthetic judgements. As one of the evaluation techniques, we propose new evaluation method using applied AHP (Analytic Hierarchy Process). Figure 21 shows the calculation example of this method. This example shows the traffic demand changes after introducing several systems instead of bus systems at present stage. According to this calculation, maglev system (HSST) has secured top priority to introduce.

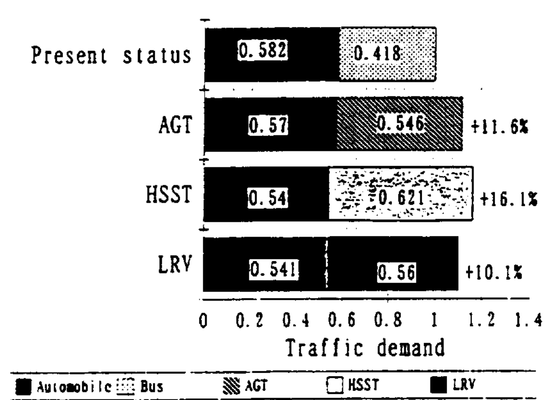


Fig.21 Example of results for evaluation transportation systems on traffic demand

4 . Scenario to be practical uses of maglev systems in Japan

Presently, no maglev systems have revenue services in Japan. But, linear motor driven systems that are the first step to realize levitation systems are in practical use in some districts in Japan. And several types linear motors such as primary side on vehicle and ground are used. Namely, the foundation of practical use for maglev systems are arranged at this present stage. Receiving these trends, in the near future, the construction plan will be finally fixed to realize maglev system of HSST for urban transportation systems on Aichi prefecture. This construction plan was decided by committee through the above evaluation method. Moreover, environment assessments are starting for construction of HSST line from airport to railway station in Hiroshima districts. In Japan, for new urban transportation systems, it seems to proceed steadily in realizing practical use. At first , linear metro systems that have linear motors with wheel and rail are practical uses because of easy control of support and guidance. Secondly, aerodynamic systems such as OTIS that are supported by air and guided by wheels are realized because of easy levitation. And finally, perfect levitation systems that are supported and guided by magnetic suspensions will be introduced after many kinds of technical verifications step by step for public transports.

5 . Conclusions

In Japan, maglev systems are developed for two purposes. One is for a super high speed and large capacity transportation system and the other is for urban transportation systems. For urban transportation systems it does not always follow that magnetically levitated vehicles are the only solutions. In Japan, to conquer the subjects of urban transportation problems and to turn public transportation systems from automobiles, magnetically levitated vehicles systems have been developing for the sake of low noise and low costs such as construction costs and maintenance costs. It was gradually successful to introduce new urban transportation systems in Japan. From automated people mover supported by rubber tires and guide wheels , thorough linear motor driven systems supported and guided by wheels and rails like conventional railways , supported only by aerodynamics and finally maglev systems are to have revenue service. According to these flows, it will be expected for high temperature superconducting magnets levitation systems to develop as urban transportationsystems

References

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6) Mizuma et al. 「Several urban transportation systems」 The journal of the institute of electrical engineers of Japan, Vol.119 No.3 March, 1999

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