TECHNICAL AND SAFETY EVALUATION METHODS OF EMS MAGLEV TRANSPORTS

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INTRODUCTION

The normal conducting magnetic levitation system has excellent characteristics in connection of high speed and environment protection, and has been researched and developed as a new transportation system mainly in Japan and Germany. It is said that the magnetic levitation system is already in the stage of commercialization. This system, however, has double characteristics; that the supporting and guiding are magnetic and that the propulsion is non-adhesive by means of linear motors while the conventional railroad has wheel-rail contact support and adhesive propulsion by means of the rotary motor and rails. In order to introduce the magnetic levitation type of transportation system as a public transit system, it is necessary to evaluate and confirm the system from the viewpoints of safety and reliability, and to promote the preparation of technical standards.

For this reason, the Ministry of Transport set up a study committee titled "Survey/Study of Technical Evaluation Methods Concerning Normalconducting Magnetic Levitation Type Railroad" in 1989, and has been proceeding with the works to summarize the technical subjects based on the existing data of the normalconducting magnetic levitation railroad which is ready for practical use, to study the technical evaluation methods and standards, and to evaluate and confirm items to be secured for the public transportation system.

Among the primary type of the HSST vehicles, the H-100 type (maximum speed : approx. 100km/h) being tested in Nagoya was used to extract requirements, and to summarize technical subjects and evaluation points. Based them, safety evaluation tests were conducted. This paper outlines the tests, and shows an example of technical evaluation. Concerning the primary type of the HSST, the basic concepts are summarized based on the German Transrapid and M-Bahn, and results of extracting the requirements are described.

1. TECHNICAL EVALUATION METHOD FOR PRIMARY TYPE (H-100)

1.1 Requirements for practical use

In order to put the H-100 system to practical use as an urban traffic system, it becomes necessary to summarize the conditions to be equipped as the public transit system. Especially in this case, it is essential to summarize the requirements particular to the magnetic levitation type railroad.

On each subsystem, we will summarize the conditions required for the magnetic levitation system as the public transit system.

The system was classified into such subsystems as levitation/guidance system, propulsion system, vehicles, track/structure, electric facilities, and internal/external environment. The requirements during normal operation (landing, levitated stop, levitated running to about 100km/h, braking) are classified into those necessary within own subsystem and those necessary within other subsystems. Furthermore, the requirements during abnormal operation (failure of levitation/guidance system, failure and power failure of feeder system, external conditions such as earthquake and ice/snow) are grouped into hardware requirements to secure safety and software requirements such as safety control function.

Table 1 shows results of extracting the requirements concerning the levitation/guidance system.

Table 2 shows the requirements considered especially important for the levitation type railroad among those extracted in the same way for other subsystems.

1.2 Safety evaluation tests

1.2.1 Levitation/guidance system gap fluctuation test

We measured changes in levitation/guidance gap in powered running, coasting and braking at a straight section, each testing girder section, a curve section (curvature 100mR) and a vertical curve section (curvature 700mR). Fig. 1 shows an example of fluctuated wave form of the levitation gap in the vertical curve section.

The test results are summarized as follows: (1) The levitation /guidance gap fluctuation at each testing girder section of the straight section was within the specified fluctuation range ($\pm$ 4mm) with no difference in particular. (2) Concerning the running in the curve section, the fluctuation of the guidance gap and deviation (from the center position) increased in proportion to the speed. (3) The levitation gap fluctuation at passing through the vertical curve was within the specified fluctuation range with no difference from the values at other places.

1.2.2 Propulsion/brake system tests

The tests was conducted to check the braking performance (reduction in deceleration, stopping distance, etc.) by stopping the vehicle with the normal electric-hydraulic brake, and with the hydraulic brake while turning off the regenerative absorbing equipment to cancel the regeneration at each speed (40, 70, 100km/h), and to check the coordination of the opposite phase brake with the hydraulic brake when the vehicle is stopped on an up-gradient.

Fig. 2 shows examples of waveforms of stringing current and inverter

Table 1 Necessary Conditions on H-100 About Levitation and Guidance System

*Normal Operation (Landing, Levitated Stop, Propulsion, Braking)

I. Conditions in levitation/guidance system

(1) Levitation/guidance system

(Hardware)

1) The module must be of such a structure as not to be troubled when passing through places of specified roadway conditions at the specified speed under a given load condition.

2) The structure must be such that it generates the electromagnetic force which can support the full load at a specified gap length and can guide the maximum transverse force at the specified gap.

(Control)

3) The levitation control must be made in such a way that the levitated amount is controlled within the specified fluctuation range under specified conditions.

(2) Riding quality

4) The standard running must not cause discomfort to the passengers because of the vibration acceleration by controlling within the specified range.

(3) Resistance

5) Movement must be assured against external interfering electromagnetic wave, icing/snowing of rails, rusting of rails, and contraction/expansion of track and rails.

II. Conditions to other systems

(1) Within system

6) (To propulsion system) It must maintain stable propulsion against fluctuation in levitation gap.

7) (To current collecting system) It must maintain good current collection in levitated stopping and running on straight, curve, gradient sections, and turnouts.

8) (To body system) The levitation force of the electromagnets must not adversely affect the strength of the vehicle and track.

9) In the cars, the leakage electromagnetic field level and noise level must be kept within the specified ranges.

10) (To signal safety system) The noise from the electromagnets must not adversely affect the operation of the safety system.

11) The fluctuation in levitation/guidance gap must not adversely affect thefunctions of the train position detection and speed detection sensors.

(2) External environment

12) (Electromagnetic interference) Against the surrounding environment, the discharge level must be lower than the specified value.

13) (Noise) Against the surrounding environment, the discharge level must be lower than the specified value.

14) (Vibration) The vibration due to vehicle running must not adversely affect the surrounding environment.

* Abnormal operation (failure of a levitation/guidance system, failure/power, failure of a feeder system, external conditions (earthquake, birds, etc.), etc.)
I. Securing of safety 15) (Rails, track system) Even during landed running by means of skids, the skids, rails, and track must have sufficient strength without derailing. 16) (Module) Even when contacting, levitating or dropping occurs, the module and its installation must have sufficient strength. 17) (Body system) It must withstand the deceleration and impact caused when the levitation system is abnormal.
II. Safety control function 18) (Process to stopping) When failure occurs, landing by means of the skids must be possible. 19) (Switching of abnormal portion) It must be possible to detect failure quickly, to switch to the spare system, and disconnect the abnormal portion at failure. 20) (Relationship with other modules) Failing a magnet(s) or a module(s) must not adversely affect operation of the healthy magnet or module.

Table 2 Necessary Conditions on H-100 About Other Subsystems

1. Propulsion system 1) When both an electric brake and a mechanical brake are used, the control must achieve coordination between electric and mechanical brakes. 2) The structure must be such that it can secure specified deceleration from a high-speed range to stopping, and can stop the vehicle within the necessary braking distance.
2. Track/structure 1) The track, the bridge girder, and the structure must withstand the load to which they are subjected. The structures and materials of the track, etc. must be selected taking into consideration durability against fatigue and wear, workability, and maintainability. 2) The structure of rails and reaction plates must not hinder vehicle running regardless of the operated condition of levitation equipment and guidance equipment and of meteorological condition.
3. Vehicle 1) Even when subjected to external load and loaded with maximum load, the modules, a vehicle-supporting equipment, and the vehicle must be sufficiently strong and robust. 2) In abnormal situation such as abnormal levitation, the modules, body supporting equipment, and body must be sufficiently strong and robust.
4. Electric facilities 1) The train speed detecting equipment must be able to accurately detect the train speed and highly reliable. 2) The conductor system must have such structure as to be able to cope with specified operating speed and fluctuation in levitation/guidance gap.

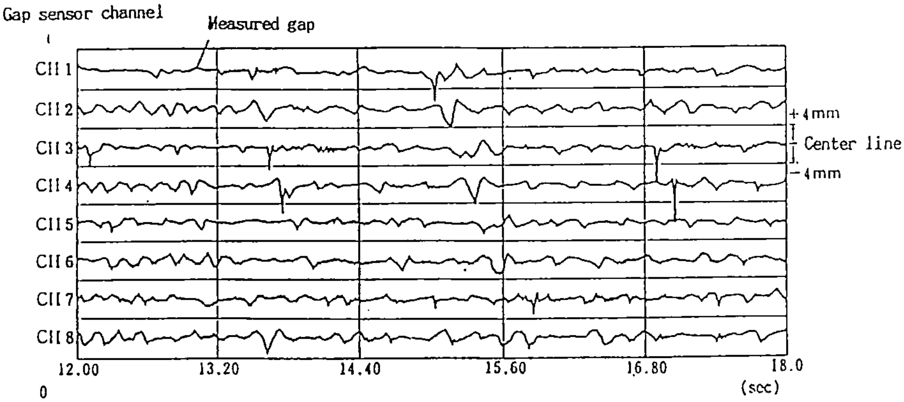

Fig.1 Levitation gap waveforms measured at the speed of 100km/h

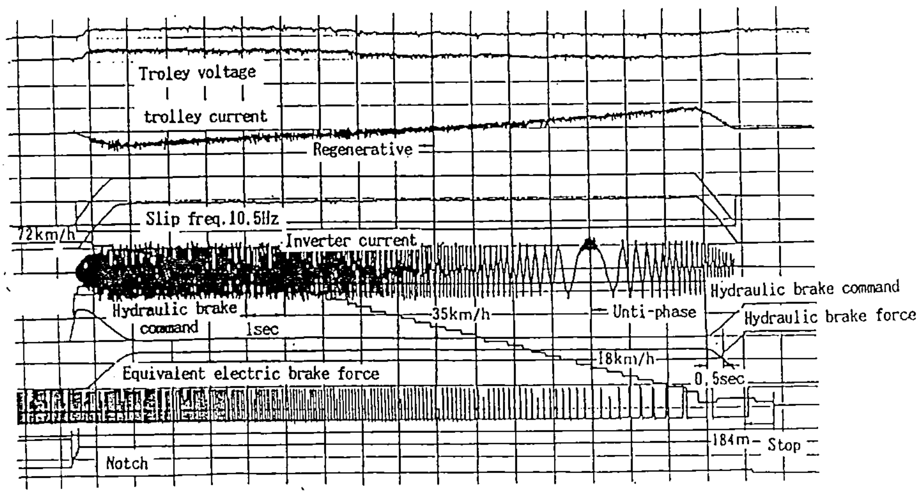

Fig.2 Measurement waveforms in braking

current when the service brake is applied at 70km/h.

The test results are summarized as follows: (1) It was confirmed that the deceleration rate was kept almost constant, and especially in braking by the electric brake from the high-speed, the reduction in deceleration due to the end effect was not recognized. (2) In braking on the up-gradient, no such phenomenon as reverse movement of the vehicle was observed, but some delay was found in the opposite-phase/hydraulic brake switching timing. (3) When the regeneration was canceled by turning off the regenerative absorbing equipment, it was switched to the hydraulic brake and stopping was done, but the stopping distance was a little increased.

1.3 Electric equipment test

As electric equipment tests, we conducted ground-fault tests, and the ground fault of a conductor system was detected at a substation. A circuit breaker worked to stop power supply, and the higher harmonic measuring test at the substation receiving end while the vehicle running.

Fig. 3 shows measured results of voltage distortion factors of high harmonic waves.

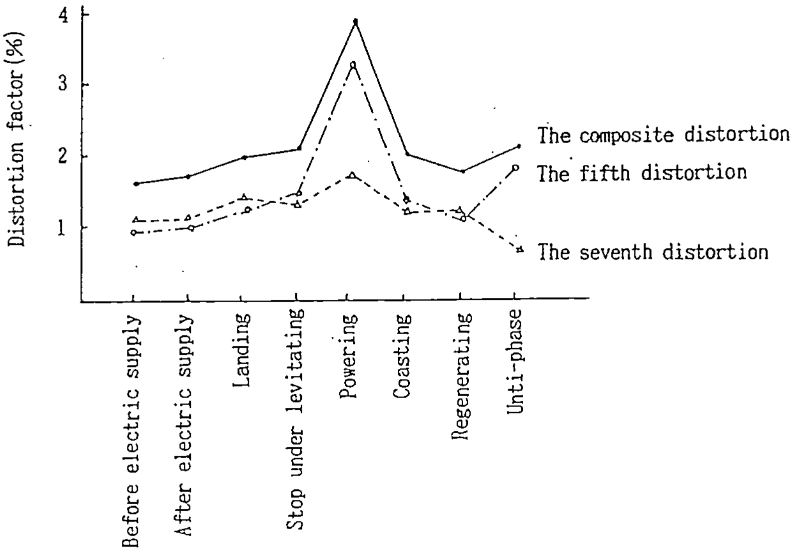

Fig.3 Voltage distortion factors of higher harmonics

The test results are summarized as follows. (1) The ground-fault test in the high resistance grounded neutral system was conducted, and it was confirmed that the ground fault was detected by the ground relay on the substation side while the vehicle was in power running and was braked, and that the AC circuit breaker worked after about 60ms to stop the power supply. (2) Even during the power running when maximum current was supplied from the substation, the total voltage distortion factor was about 4%, and the higher harmonic wave of which the degree was different from that of the conventional railroad was not found.

1.4 Safety evaluation

1.4.1 Levitation/guidance system

The test conducted this time was to check the levitation/guidance gap fluctuation while vehicle running, that is, to check whether the H-100 satisfies requirements for the public transportation system, to confirm that "the levitation control is made in such a way that the levitation amount is controlled within the specified fluctuation range under specified conditions" as is indicated in the "survey/study of technical evaluation methods concerning normalconducting magnetic levitation type railroad in accordance with which the Ministry of Transport implements test.

It was confirmed that the levitation gap fluctuation was within the standard gap, 3mm, and within the allowable gap fluctuation, 4mm, during running on the straight line (maximum 100km/h), the curve, and the gradient. It was judged that the specified gap control was made. Concerning the guidance gap, the fluctuation of about 11mm was found during running at the speed of 100km/h and while passing through the curve of 100mR, but it was not controlled like the levitation gap. The fluctuation of 15mm was incorporated in designing, and it did not pose any problem in practical use. In the future, it will become necessary to check the characteristics of the levitation/guidance gap fluctuation against the fluctuation in track condition due to aging, etc.

1.4.2 Propulsion/brake systems

The tests were conducted to confirm the requirements that "almost constant deceleration rate was secured from high-speed to stopping, that the vehicle was stopped within specified braking distance", and that "coordination between electric brake and mechanical brake was achieved when the electric brake was applied." Since the H-100 system uses the electric brake most often, it is important to evaluate its performance. Especially for the braking from the high-speed, it is necessary to consider the efficiency reduction due to the end effect of the linear motor when designing the brake, and to verify it. The result revealed that the brake system did not pose any problems because the braking force almost as designed was obtained. In this system, the opposite phase brake works in the low speed range, and the opposite phase brake and the hydraulic brake is employed (blended) together just before stopping. If the switching timing is bad, a decrease or increase in deceleration may be caused. In the test, some reduction in deceleration was found when blending the brake systems, but there is no problem in practical use because reverse movement of the vehicle does not occur even when braking on the up-gradient. However, it is necessary to investigate the switching timing.

1.4.3 Electric equipment

In order to confirm requirements that "ground fault is accurately detected, and that the protective circuit at the substation is operated safely," the ground detection test was conducted on the H-100 during running in the high resistance grounded neutral system. It was confirmed that it could be accurately detected, and that the protective circuit was operated (power supply was stopped by the AC circuit breaker). Concerning the higher harmonic wave, the test was conducted to confirm the requirement that "the higher harmonic wave at the sending end and receiving end of the substation is controlled within the specified range."

As a result, the maximum voltage distortion was about 4%, and higher harmonic of the 5th degree was maximum. The degree of the higher harmonic wave was the same as that of the conventional railroad, not posing any problems, and no higher harmonic wave particular to the linear motor was produced.

Concerning voltage distortion, this testing line receives the power from the distribution system of 6600V, and the control index of 5% or less in the distribution system, recommended by the electric joint research meeting, is satisfied. In the actual system, it will be further decreased because the power is received at a higher voltage (66kV, 22kV) and via transformer, etc.

1.5 Conclusion

So far we have described the outlines of the basic safety evaluation tests on the H-100 system and the evaluations, and it can be said that the basic running safety is secured. In order to establish it as a public transportation system, however, it is necessary to verify more necessary conditions and also to confirm reliability, etc.

2. TECHNICAL EVALUATION METHOD OF PRIMARY SIDE ON GROUND SYSTEM

As the normalconducting magnetic levitation railroad of primary side on ground type, the Transrapid and M-Bahn have been developed in Germany, but the detailed specifications have not yet been grasped by us. We, therefore, considered only the basic concepts of the two systems when extracting the necessary conditions to be equipped for the public transportation system.

Table 3 shows the technical features and essentials of necessary for the Transrapid and B-Bahn of the primary types.

Table 3 Technical Features an Essentials of Necessary Conditions on Primary Side on Ground Type

Levitation/guidance
(Features) M-Bahn - The levitation is based on the levitating force of the permanent magnet and LSM stator core, but it has a mechanical system to cope with fluctuation in vehicle load and vertical guidance wheels in case that when it cannot cope with. - The guidance is the double-sided system which is proved with the new traffic system.
Transrapid - The levitation is based on the levitating force of the electromagnet and LSM stator core, and has gap control made by the gap sensor. - The guidance is also based on the levitating force, and has the gap control made, but there is no skid protection when contacted.
(Essentials) M-Bahn - Conditions related to structure functions of vertical guidance wheels and mechanical gap adjusting system. - Relationship between attracting force and gap fluctuation range. - Relations between levitating force and vehicle, track, and signal safety system.
Transrapid - Conditions related to the function of truck structure having magnets for levitation and guidance. - Controllability of levitation control and guidance control. - Conditions related to contact between magnets and ground. - Coping with abnormality of the levitation/guidance system.
Propulsion
(Features) M-Bahn - The propulsion is made by installing the inverter, linear motors of the primary side, and switches on the ground, and supplying the current synchronizing with the vehicle speed. The braking is based on the electric brake. - In abnormality, the mechanical brake works. - ATO operation is basic.
Transrapid - The propulsion is made by installing the inverter, linear motors of the primary side, and switches on the ground, and supplying the current synchronizing with the vehicle speed. The braking is based on the electric brake. - At abnormality, the vehicle is stopped by means of the eddy current brake and skid landing.
(Essentials) M-Bahn - Function/controllability of section switch. - Connection of inverters and the primary side of linear motors. - Coping with failure of the primary side of linear motors.
Transrapid - Function/controllability of section switch. - Securing of deceleration from high-speed region. - Coping with failure of the primary side of linear motors.

Electric
(Features) M-Bahn - The substation supplies the frequency and current to meet the train position and speed for one feeder section allowing an entry of only one train into one feeder section. - Information of train speed and acceleration is exchanged between substations. - Position detection is made by detecting the pole position of the permanent magnet on the primary side of linear motors.
Transrapid - The substation supplies the frequency and current to meet the train position and speed for one feeder section allowing an entry of only one train into one feeder section. - Information of train speed and acceleration is exchanged between substations. - Position detection is made by detecting the change in the magnetic flux caused on the primary side of the linear motors.
(Essentials) M-Bahn & Transrapid - Securing of safety and reliablity of position detecting equipment and information transmission system. - Securing of reliability and durability of switching equipment of a feeder section. - Securing of coordination of control and information transmission among substations.

POSTSCRIPT

So far we have explained the technical evaluation methods for the normalconducting magnetic levitation railroad by raising examples of the primary type (HSST) and the primary type (Transrapid, M-Bahn). The H-100 is now being run on the testing line in Nagoya, and tests are being conducted in accordance with this evaluation method. We earnestly hope that the magnetic levitation railroad will be put to practical use as soon as possible through the sufficient running test on the testing line and through correct evaluation of the results.

Reference

1. Mizuma et al. "Outlined technical evaluation of normalconducting magnetic levitation type urban traffic system" 1990 Conference of Traffic Safety and Nuisance Research Institute.