A Study of the Safety and Reliability Improvement for the Supporter and Epoxy Insulator of Urban MAGLEV Third Rail Systems

Byong-Chan Min, Sang-Hoon Cho, Du-Young Hong, Young-Tae Heo, Won-Joo Lee and Su-Yeon Jo

POSCO ICT, Green Industry Department Railroad E&M Team, 622, Sampyeong-dong, Bundang-gu, Seongnam-city, Gyeonggi-do, Republic of Korea, 463-400

Dong-Jin Lee

POSCO ICT, Green Industry estimation & specification Department, 622, Sampyeong-dong, Bundang-gu, Seongnam-city, Gyeonggi-do, Republic of Korea, 463-400

ABSTRACT: MAGLEV is a form of rail transport that uses magnetic levitation. Since MAGLEV floats in the air without direct contact with the rail, it is an eco-friendly form of transport because no dust is raised, almost no vibration occurs due to mechanical reasons, and almost no noise is generated. In its running performance, MAGLEV can easily run on a hillside area with steep slopes because it doesn't skid on the hill, unlike the wheel type of rail transport. MAGLEV is also suitable for operation in the city center, as sharp curve driving can be done. The third rail systems of the urban MAGLEV is composed of the power rail, expansion equipment, section insulator, the connecting device for power supply line connection, and a supporter that sustains accessories. The main materials that compose the structure sustaining the tram rails include an insulator, supporter base, claw, etc. The strength of these parts should match the third rail systems, and should be highly erosion resistant, durable, and not loosened or broken by train vibration. In addition, equipment should be composed in consideration of the convenience in construction and future maintainability. The structure and supporting interval of these supporters should be selected by considering the dynamic load and the static load of the power rail, insulator, incidental equipment, the uplift forces of current collectors, the repulsive power from the short-circuit current, and linear characteristics. Also, hot-dipped galvanized rolled steel should be used to prevent corrosion.

1 GENERAL INSTRUCTIONS

Urban MAGLEV third rail systems have configuration and installation conditions similar to the mono rail systems. Positive and negative power rails are installed to the left and right side of engineer structures to supply to the MAGLEV train. The third rail systems installed at Expo Park in Daejeon, republic of Korea, have some problems due to the poor interface between train, track, engineering, and third rail.

In particular, a porcelain insulator is mostly used as an epoxy insulator. However, the product imported from overseas countries like Japan is preferred, due to insufficient reliability and use history of domestic products. Therefore, this paper will attempt to understand the requirements, which is appropriate for interface execution and environmental characteristics of each area, by studying how to secure stability and reliability of the third rail systems that will be applied to the exhibition route of Practical Use Project for Yeongjong-do, Incheon International Airport.

2 DOMESTIC AND OVERSEAS TECHNOLOGICAL TREND

The development and application status of the third rail systems in Republic of KOREA is as follows: the side sliding rail system was installed on the Kyeongsan K-AGT test line under the management of the Korea Railroad Research Institute (KRRI). The positive and negative pole rails are fixed on the same support with porcelain insulators and a direct current of 750V is supplied.
As the third rail system for magnetic levitation, rail equipment composed of aluminum and a stainless (STS) sliding surface is installed on the initial magnetic levitation test line inside the Korea Institute of Machine & Materials (KMMI). In addition, rail equipment installed on the 1Km single-track section at the National Science Museum and Daejeon Expo Science Park, is installed in such a way that the grooved trolley wire is fixed on the strained rigid body T-bar system without long ears, using bolts, and a direct current 1,500V is supplied.
The third rail system for steel wheel and LIM light rail transit has also been installed for the Kimhae Light Rail Transit and Yongin Light Rail Transit. They imported and installed composite third rail systems (upper and lower side sliding types) by welding aluminum and stainless steel together.
Japan uses a power tail that combines aluminum with stainless steel, and a porcelain insulator for the supporter that allows up/down adjustment. In addition, the U.S. and Germany have developed third rail systems, based on decades of experience in design, manufacturing, and construction. They mainly use epoxy insulators, which are different from Asian countries like Japan that use porcelain insulators.

3 STUDY OBJECTIVES

The composite power rail, which uses the stainless steel sliding surface, is easy to install at the site and provides strong durability in cases of abrasion. However, based on the same allowable current there seems to be some problems where conduction properties and collection efficiency are low, and where collection noise and the area and weight of a conductor increase. The rail system installed as a model at Daejeon Expo provides excellent conducting performance and collection efficiency and reduced collection noise and conductor area, because it uses a copper (Cu) conductor sliding surface. However, the grooved trolley wire should be installed on the site, which results in low work efficiency, and safety measures are required for high place work at a girder side.
As the manufacturing technology and properties of the used materials affect the quality and performance of the epoxy insulator, the optimal manufacturing method and materials should be selected by considering the manufacturing conditions in Republic of KOREA. Many countries, including European countries, are using epoxy insulators that have the same environmental resistant characteristics as porcelain insulators. These two materials offer mechanical strength and water repellent characteristics that are stronger than the epoxy insulator that is used for highs-speed railroad.
Based on these technical characteristics, the study project is being implemented to secure the safety and reliability of the third rail system facilities that will be used for the demonstration line of Incheon International Airport, in order to carry out the MAGLEV Practical Use project. The study objectives of each year are as written below.
- 3rd year (9/21/2008-6/20/2009): To analyze the characteristics of the third trail system facility component.
- 4th year (6/21/2009-6/20/2010): To standardize work for third rail facility installations.
- 5th year (6/21/2010-6/20/2011): To set up the safety and reliability proof criteria, in order to create the procedures for a comprehensive third rail facility performance test and to select the test items.(Step1)
- 6th year (6/21/2011-6/20/2012): To set up the safety and reliability proof criteria, in order to create the procedures for a comprehensive third rail facility performance test and to select the test items.(Step2)

4 STRUCTURE AND COMPOSITION OF THE THIRD RAIL SYSTEMS

The power rail of the third rail systems is the electric facility for transferring power to MAGLEV. It also has high reliability and strong publicity. Positive and negative pole trolley wires are installed to the left and right side of the engineering structure, and the train's collecting shoes are contacted to provide the operational electric power to MAGLEV.
The power rail is manufactured in such way that cadmium free copper 275 ㎟ trolley wire is inserted into the crack of the 2,546 ㎟ aluminum alloy power tail, and joined tightly with nuts every 200 ㎜. Then, it is installed on the side of the girder using the supporter, as shown in Figure 1. The power rail is composed of Figure 2. In addition, the power rail is installed vertically at the straight and curves section,

and ±20 mm up/down deviation is allowed for preventing partial abrasion.

To absorb the expansions that are due to temperature changes of the power rail, the expansion joint will be installed every 120 meters, and the mid-point anchor is installed at the center. The expansion length of the expansion slot will be calculated to fit into the installation conditions, and will be adjusted on the spot.

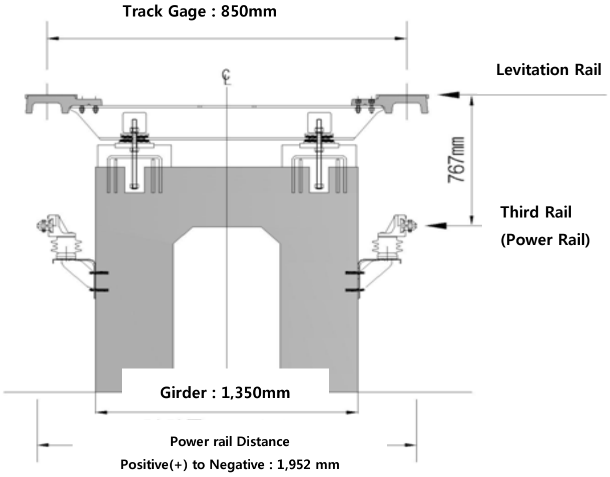


Figure 1. Installation type and structural section.

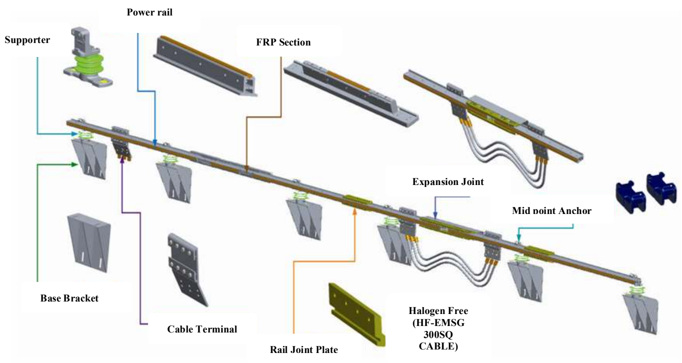


Figure 2. Composition of the third rail system

4.1 Power Rail

The equipment that provides the load power of the vehicle while sliding over the vehicle's current collector. The copper alloy sliding plate is assembled on the aluminum body. Aluminum and copper should be assembled at a proper length by considering material movement and installation, and the area should be selected by considering load power and voltage dropping. In addition, the trolley wire is processed with tin (Sn) to prevent corrosion.

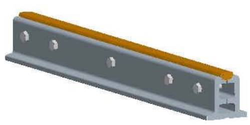


Figure 3. Power Rail

4.2 Supporter and epoxy insulator

The structure and supporting interval should be selected by considering the dynamic and static load of the power rail, the epoxy insulator, the accessories, the uplift forces of the current collector, the repulsive power due to short-circuit current, and linear characteristics. Also, coated steel should be used to prevent corrosion, and the structure should be able to comply with the limitation of the construction tolerances of engineering works and tracks. Epoxy insulator is used to fix the conducting rail and to electrically insulate equipment. It should be able to resist the load of the conducting rail and accessories, and epoxy family materials should be used.

Figure 4. Insulator and Supporter

4.3 End approach

The end approach should have a structure that allows for the smooth transit of a vehicle's current collector and it should be able to sufficiently resist mechanical shock, by manufacturing at a shallow angle of 1:20 or 1:50 by considering the train speed at the power rail starting/ending point, the starting point of the maintenance shop in the depot, and the characteristics of the current collector.

Figure 5. End approach (1:20 or 1:50)

4.4 Expansion joint

This is the equipment that absorbs power rail expansion and contraction due to temperature changes. The proper installation interval should be selected by considering outdoor temperatures, the temperature rises due to load current, the characteristics of the material, and the maximum gap of the expansion absorber. The expansion joint should be structured to absorb length variations of the conducting rails, and to secure the carrying capacity of the load current. Cables are used for the current of the main circuit, and cables with excellent flexibility are applied. Halogen free nontoxic flame retardant DC 1,500V HF-EMSG (LS CABLE) is applied.

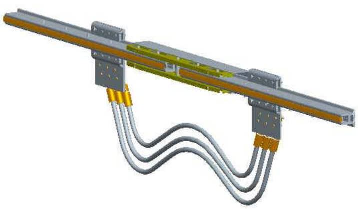


Figure 6. Expansion joint

4.5 Midpoint anchor

The equipment used to fix the conducting rail so that the current collector is not moved due to frictional force. It is installed in the middle of the expansion joints. The midpoint anchor should be able to resist the load caused by the left/right displacement of the conducting rail.

Figure 7. Midpoint anchor

4.6 Rail joint plate

The equipment that joints the power rails electrically and mechanically, and that prevents the voltage from dropping. The plate is manufactured with high precision to prevent a gap between contacting points, and mechanical deviation should not occur.

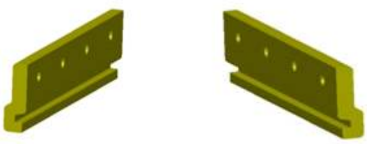


Figure 8. Rail joint plate

4.7 FPP section insulator

The equipment that is to be installed at the power supply breakpoint of the substation or at the branch line at the depot. The section insulator should provide excellent insulation characteristics when the train passes, and an arc should not be generated.

Figure 9. FPP Section insulator

4.8 Cable terminal plate

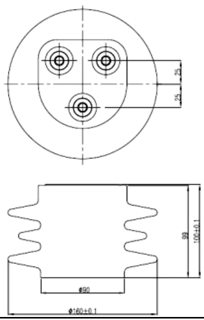
The equipment used to connect the contact point of the power supply cable, the conducting rail, and the non-insulated solder-less terminal of the conducting rail connection cable. The plate should not interfere with the vehicle.

Figure 10. Cable terminal plate

5 SPECIFICATIONS FOR THE SUPPORTER AND EPOXY INSULATOR

A supporter is composed of the claw support, which sustains the power rail, mover, epoxy insulator, and base plate. Cast iron is used for all parts, and corrosion prevention plating is applied. The base plate should have a structure that allows for a 30mm deflection adjustment upward/downward, when directly attached to the girder.
The structure and supporting interval of the supporter should be selected by considering the dynamic load and static load of the power rail, insulator, incidental equipment, uplift forces of the current collectors, the repulsive power due to short-circuit current, and linear characteristics. Also, surface treatment should be used to prevent corrosion.
The epoxy insulator mechanically fixes the claw part, which then fixes the base plate and power rail, and electrically insulates the third rail system. It should be able to resist the load of the power rail and accessories. An outdoor Hydrophobic cycloaliphatic epoxy is used for the supporter.
A KS D 5101 brass inserter is used to fix the supporter to the insulator. Table 1 shows the configuration and dimensions ; 100±1mm insulation clearance height , 75mm minimum insulation clearance, 3 wings, and 160Φ in radius.

Table 1. Characteristics of the Epoxy Insulator

Characteristics		Unit
Dimension	Arcing distance	235 ㎜
	Insulation clearance	100mm
Mechanical performance	Bending load resistance test	Over 1,500 kg f
	Tensile load resistance test	Over 2,000 kg f
	Tensile failure load test	2,500 kg f
Electrical performance	Commercial frequency dry voltage withstand	30 kV
	Commercial frequency wet voltage withstand	25 kV
	Commercial frequency dry flashover voltage	40 kV
	Commercial frequency wet flashover voltage	32 kV
	Lighting impulse flashover voltage	75 kV
Insulator shape		
 		

6 SIMULATION THE SUPPORTER FOR THE LINEAR AND CURVED REGION TEXT AND INDENTING

If we assume that a MAGLEV train applies approximately 900kgf force to the power rail when it passes through, then the deflection amount and binding repulsive power of the power rail was analyzed based on this and through simulation. Power rails are connected with the rail joint and expansion joint. The maximum distance between supporting points of 4 meters, 3.6 meters, and 2.5 meters are applied for the linear and curved sections, respectively, by considering and bending and the allowable deviation of the route.

Supporting parts are divided into the linear and curved sections. It is assumed that 900kgf momentary maximum force is applied when an accident occurs. This is assumed by considering the dynamic load of the vehicle at the maximum cant 3.4° on the curved section.

The assembly model for the linear supporter and curved supporter is made as shown in Figure 11, using the finite element model.

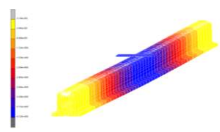
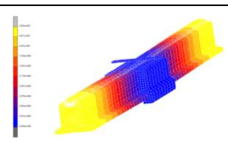
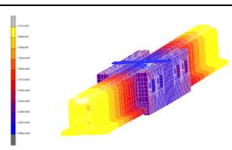
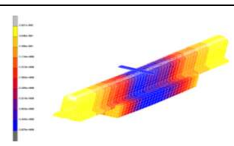
The supporter and power rail for the linear region — The supporter and power rail for the curved region

Figure 11. Finite Element Models for the Supports

According to analysis, the maximum y direction deflection, the maximum y direction repulsive power, the maximum strain, and the maximum stress are 0.77mm, 1.7kN, 0.0058, and 131.2Mpa respectively, when the current collector passes over the center of the rail. On the other hand, those of the linear supporter are 5.11mm, 35.6KN, 0.0082, and 323.3Mpa.

Table 2 and 3 which is shown below, summarizes the simulation result of the linear and curved supporter. According to the power rail simulation result there were no significant differences in deflection amount or repulsive power strength among products. About 4mm deflection occurs when 100kA/1s short-circuit current flows and about 1kN repulsive power is created under the maximum uplift force condition. About 0.7-0.8 mm deflection occurred in the linear supporter, whereas 5mm deflection occurred in the curved supporter. The different type of supporter structure that sustains the insulator causes the difference. The insulator supporter and reinforcement don't support the insulator sufficiently in the curved supporter.

Table 2. Analysis(SAMCEF) Results for 100KA/1sec, a Maximum Y direction deflection and repulsive power.

Item	Maximum Y direction deflection
Power Rail	 4.129[mm]
Rail Joint	 4.259[mm]
Expansion Joint	 4.055[mm]
Section Insulator	 3.892[mm]

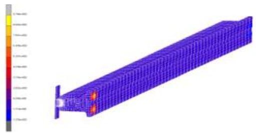
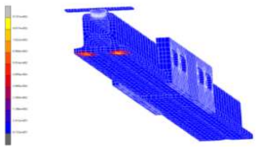
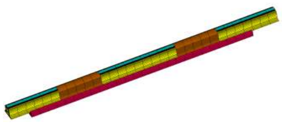
Item	Maximum Y direction repulsive power
Power Rail	 974.4[N]
Rail Joint	 998.7[N]
Expansion Joint	 973.1[N]
Section Insulator	 969.9[N]
Results	1. Result of Maximum force : 102kgf (998.7N) 2. Supporting Epoxy Insulator Mechanical performance : - Tensile failure load test : 2,500kgf - Tensile load resistance test: 2,000kgf 3. O.K.

Table 3. Supporter Analysis Results

Supporter	Maximum Y direction deflection (mm)	Maximum Y direction repulsive power	Maximum strain	Maximum stress (Mpa)
Linear supporter	0.77	1.7	0.0058	131.2
Curve supporter	5.11	35.6	0.0082	323.3

7 CONCLUSION AND FUTURE ACTIVITY STRATEGIES

For the development of the third rail system to be designed to supply electric power to MAGLEV, which is being applied for the first time in Republic of KOREA, high reliability and safety were secured, and its verification has been implemented from the early days of the project. Manufacturing design and test line installation was performed for the evaluation of system reliability and safety.

The Korea Electro technology Research Institute performed system simulation and the short-circuit 100kA/1s test during the 3rd and 4th year of the project, and they are currently verifying the performance of the third rail system by considering the requirements that were identified during the train running test on the test line. Subsequently, reliability and safety will be reviewed again during the product approval design phase to provide materials for the demonstration line, and safety in the manufacturing and engineering phases will be evaluated.

At present, there are no other domestic studies with regard to securing safety and reliability, and many trial and errors have occurred because of isolated research and development in each area, and the isolated attempts to integrate the study results. However, if research organizations and related agencies such as the Korea Institute of Machine & Materials cooperate actively to improve rail system technologies in response to the high-speed system in the future, more reliable systems could be developed.

8 ACKNOWLEDGEMENTS

This paper was prepared for, “A Study on Securing the Safety and Reliability of the Urban MAGLEV Third Rail Systems”, which is one of 3-0 main core projects for the “Urban MAGLEV Practical Use Project" that has been implemented by the Ministry of Land, Transport, and Maritime Affairs as a large-scale national R&D practical use project. We’d like to thank the people from the Korea Institute of Machine & Materials and the Korea Rail Network Authority who helped design, manufacture, and construct the domestic product for the test line.

9 REFERENCES

1. ″Incheon Urban Maglev line 1step final Report″, Korea Rail Network Authority, pp.341-459, 2009.07
2. Korea Ministry of Construction and Transportation, ″Railway Vehicles standard specification″, pp.81-156, 1998.
3. Korea Power Supply Company KEPCO Standard Code, ES 5970-0010 Insulator Test Method, 2007
4. Dong-Jin Lee, “A study of the reliability improvement for supporting insulator at urban maglev train system” , Korea University Master’s degree thesis, pp.17~30, 2010
5. Byong-Chan Min, Sang-Hoon Cho, Young-Tae Heo, Du-Young Hong, Chang-Hwan Kim, Nam-Cheol Jeong, “The Organization of Interface for safety and reliability of Urban Maglev Third rail System” 2011 Spring Conference of the Korean Society for railway, pp.1189~1194,2011
6. ″Urban Maglev Working Design Final Report″ Korea Rail Network Authority, pp.10-25, 2010.