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Investigation on Prototype Superconducting Linear Synchronous Motor (LSM) for 600-km/h Wheel-Type Railway

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Abstract

The existing wheel-type high-speed railway with a rotatable motor has a limit of 600 km/h speed. The normal conducting electromagnet has several disadvantages to realize 600 km/h speed. Several disadvantages are the increased space and weight, and the decreased electric efficiency to generate the required high magnetic field. In order to reduce the volume and weight, superconducting electromagnets can be considered for LSM (Linear Synchronous Motor).
Prior to the fabrication of the real system, a prototype demo-coil is designed and fabricated using 2G high temperature superconducting wire. The prototype HTS coil is cooled by the conduction using a GM cryocooler. To reduce the heat penetration, thermal design was performed for the current leads, supporting structure and radiation shield considering the thermal stress. The operating temperature and current are 30~40 K and 100 A. The coil consists of two double pancake coils (N, S pole, respectively) and it is driven on a test rail, which is installed for the test car.
This paper describes the design and test results of the prototype HTS LSM system. Thermal characteristics are investigated with additional dummy thermal mass on the coil after turning off the cryocooler.

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Keywords: HTS Coil; Linear Synchronous Motor; 2G high temperature superconducting wire; conducting cooling; wheel-type high-speed

1. Introduction

A superconducting Liner Synchronous Motor (LSM) as the propulsion system is applied to high-speed Maglev train in Germany, Japan, etc. In addition, the propulsion system for high speed railway is under development in Korea. Wheel-type high-speed railway using the technology of superconducting linear synchronous motor propulsion is under development in Korea Railroad Research Institute [1-3]. We have tested to see the possibility prior to the fabrication of actual system by making miniature demonstration of a HTS LSM magnet. Railway propulsion technology of the LSM method obtains vehicle's propulsion by electromagnetic force between armature coil of the ground track and electromagnet of the vehicle. Therefore, it is possible to reduce the weight of vehicle and make a high magnetic field using the HTS LSM magnet, compared with normal conducting electromagnet. Because of this feature, we can enlarge the distance between the ground track and electromagnet of the vehicle when designing LSM. In addition, there are advantages that it prevents contact problem with the ground track of the vehicle and it can mitigate construction

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precision of the ground track of high speed rail. The HTS LSM magnet is made by 2G high temperature superconducting (HTS) wire which can operate in high temperature in high magnetic field. The magnet can be cooled by conducting using a cryogenic cooler.

In this paper, design, fabrication and evaluation results are presented for the miniature demonstration LSM with the superconducting coil.

2. Design and fabrication of HTS LSM magnet

2.1. Design of HTS LSM magnet

Prior to the superconducting coil design, table 1 shows required specifications of the LSM propulsion system demonstration. The pole pitch is 420 mm and the length of the rail is 10 m. the Ground three phase coils of LSM are installed between the tracks. The HTS LSM magnet is installed in test vehicle and the distance between superconducting coil and ground coil is more than 60 mm. Fig. 1 shows conceptual design of demo superconducting LSM.

Table 1. Required specifications of demo LSM.

Item	Value
Rating speed	2 km/h
Thrust force	41 N
Length of rail	10 m
Winding number / ground coil-phase	20 turns
Operating current / phase	50 A
Pole pitch	420 mm
Magneto-motive force of field coil / pole	72 kA-Turn

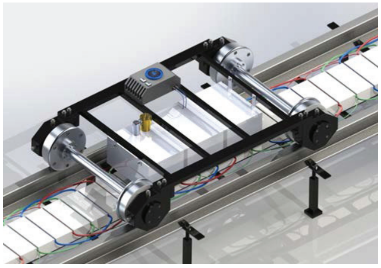

Fig. 1. Conceptual design of demo superconducting LSM.

Superconducting coil consists of two double pancake coils and they deliver the N and S pole, respectively. Dimensions of the coil are shown in Fig. 2. We used 2G HTS wire made by SuNAM. Width and thickness of HTS wire is 4 mm and 0.1 mm. The critical current is over than 200 A at 77 K, self field. 310 turns and 213 m of HTS wire is used for each single pancake coil. Magnetic field intensity of the center bore is 0.0035 T/A. Operating temperature and current are 30 K ~ 40 K and 100 A. Fig. 3 shows the 3D drawing of the double pancake coil.

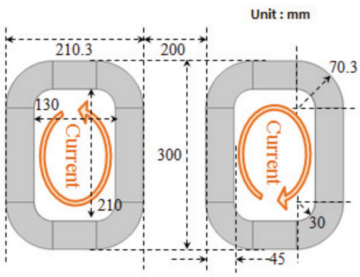

Fig. 2. Dimension of superconducting coil.

Fig. 3. Double pancake coil.

2.2. Fabrication of demo HTS LSM magnet

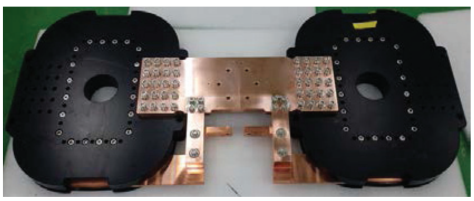

Fig. 4. N, S pole double pancake coil.

Fig. 4 shows the fabricated DPCs of N, S pole. Bobbin was made of aluminum with anodized surface to give electric insulation between the superconducting wire and the bobbin. DPC was wound by dry-winding method without insulation layer (no insulation winding) to avoid the delamination problem of 2G HTS wire. After dry-winding, epoxy layer (Stycast 2850FT) was painted between the coil surface and the bobbin plate to enhance the thermal conduction.

To increase the heat capacity of the magnet system, the thickness of the bobbin was increased. The current lead blocks of the coil were connected to the 2nd stage cold head of the cryocooler. The heat load through the metal current leads is removed by the 1st stage cold head of cryocooler.

HTS current leads were installed between the coil and metal current leads to minimize thermal penetration by conduction. Fig. 5 shows the installed HTS current lead and fig. 6 shows operating characteristics of the HTS current leads at 77 K. The measured critical current is 400 A and the resistances of HTS current leads are 165 n are 141 n including resistance of the copper block, respectively. The expected resistive heat generations of 1.65 mW and 1.41 mW are acceptable values when operating current is 100 A.

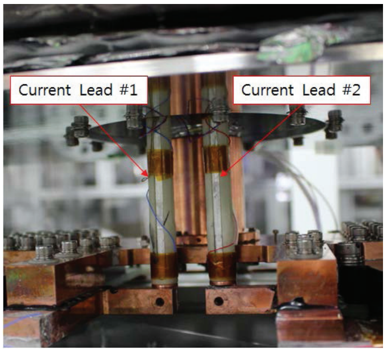

Fig. 5. HTS current lead.

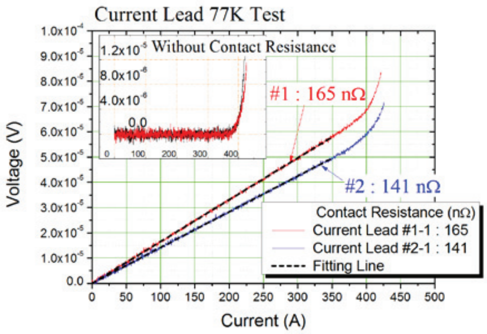

Fig. 6. Characteristics of HTS current lead at 77 K.

The overall assembled drawing is shown in Fig. 7 with its dimensions. High vacuum cryostat can minimize the thermal penetration by convection from the outside. Radiation shield was installed in the cryostat to minimize the thermal penetration by radiation. Fig. 8 shows the finally assembled HTS LSM magnet.

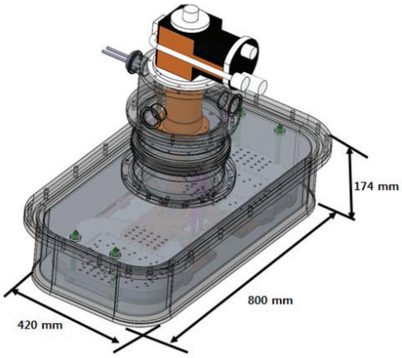

Fig. 7. Dimensions of cryostat.

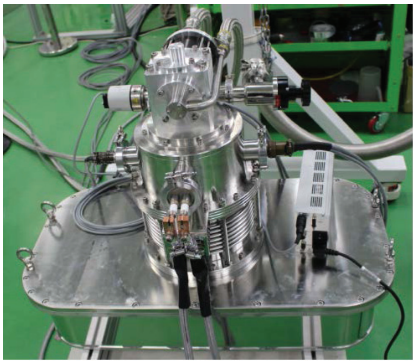
Fig. 8. Superconducting magnet system

3. Test of HTS LSM magnet

The superconducting magnet system was cooled by conduction cooling using a cryocooler. Fig. 10 shows cooling curves of the superconducting magnet system and Fig. 9 shows positions of the temperature sensors. It took about 15 hours for the superconducting magnet system to be cooled down. The silicon diode sensors were used as a cryogen temperature sensor. The final temperatures of DPCs are 11.7 K, 8.9 K. The temperature of the HTS current leads at the connection with metal current leads is 31.9 K.

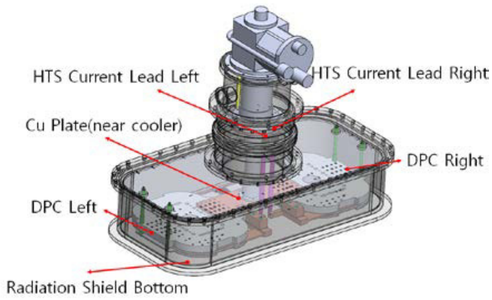

Fig. 9. Position of temperature sensor

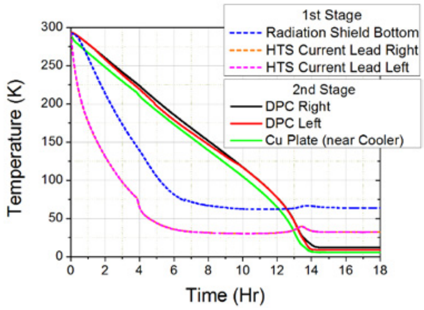

Fig. 10. Results of cooling the magnet

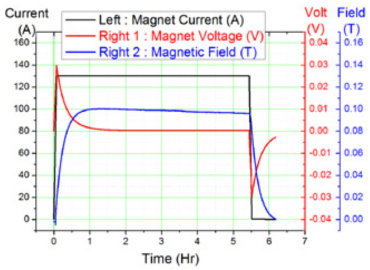

Fig. 11. Magnetic field and current

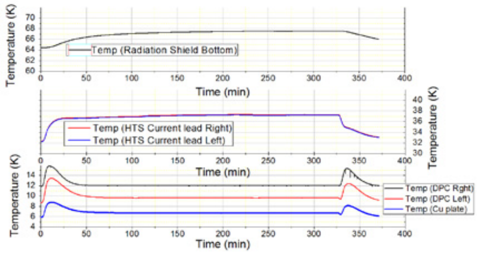

Fig. 12. Temperature variation of magnet at 130 A

Fig. 13. Test of demo LSM system

Fig. 11 shows the results of magnetic field and current. It was possible to charge the magnet to 130 A because of the low operating temperature. Since non-insulation winding was applied, the magnetic field intensity was not saturation immediately after charging to target-current. It took about 1 hour for magnetic field intensity to reach target field. The magnetic field intensity of the magnet was about 0.1 T. Fig. 12 shows temperature variations of each part of the magnet when operating current is 130 A. The temperature of DPC rose 4 K and after reaching to target-current. The temperature of HTS current lead rose 5 K when operating current was 130 A. We confirmed that stable operation of the magnet with the rated current.

After testing the HTS magnet in a static environment, it was installed on the rail to perform the propulsion experiment. Fig. 13 shows the test of demo LSM system assembled with vehicle. The specifications of the demo LSM system are described in table 1. The results of this test will be presented a separate paper.

4. Conclusion.

We have designed and fabricated the demonstration HTS LSM magnet using 2G HTS wire. Electromagnetic and thermal characteristics are investigated. The results showed stable operation of the HTS magnet with the design magnetic field and operating current. We have assembled the magnet with the test vehicle and succeed the propulsion test on armature coil of ground track. The results of this paper will be used to develop a real system.

Acknowledgements

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