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# Design and Evaluation of Prototype High-$T_c$ Superconducting Linear Synchronous Motor for High-Speed Transportation

Chang-Young Lee [a], Jin-Ho Lee [a], Jung-youl Lim [a], Suyong Choi [a], Jung-Min Jo [a], Kwan-Sup Lee [a], Yoon Do Chung [b], Seokho Kim [c], and Hunju Lee [d]
a. Korea Railroad Research Institute, Uiwang-si, South Korea  b. Dept. of Electrical Engineering, Suwon Science College, Suwon, South Korea
c. Dept. of Mechanical Engineering, Changwon National University, Changwon, South Korea  d. SuNAM CO., LTD, South Korea

KRRI 한국철도기술연구원 Korea Railroad Research Institute

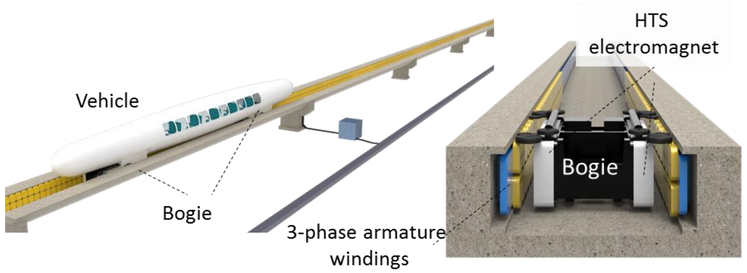
## Summary

We developed a prototype of a high-Tc superconducting (HTS) linear synchronous motor (LSM) and evaluated its operational performances to obtain the preliminary design data for a test vehicle having a speed of 500 km/h.

The HTS electromagnet was fabricated using a non-insulated (NI) GdBCO HTS coil, which was designed to produce a magnetomotive force of 300 kA-turns at a cooling temperature of 20 K. A two-stage Gifford-McMahon cryocooler was used to cool the electromagnet. The prototype was tested up to 2.7 kN sufficient to the required thrust of the test vehicle.

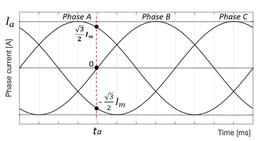
The thrust characteristics shown by changing the operating conditions were also consistent with the simulation results. The HTS electromagnet was successfully operated during the test, and there was no fault in the NI HTS coils. Finally, we confirmed the design feasibility of HTS LSM for a test vehicle.

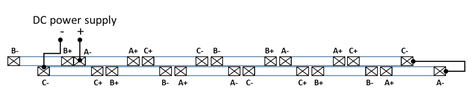
## Conceptual Design of LSM-propelled Test Vehicle




### ➢ Specifications of test vehicle (Tentative)

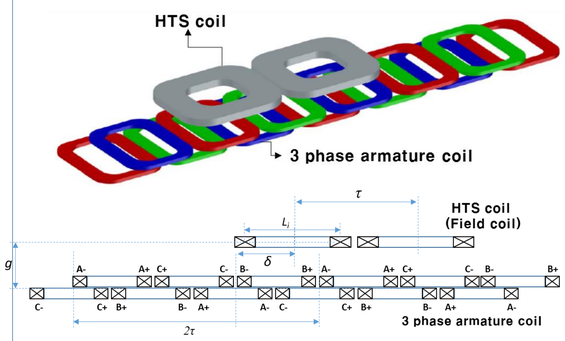
| Parameters | Specification |
|---|---|
| Max. test speed | 500 km/h |
| Max. weight of vehicle | 3,000 kg |
| Max. starting acceleration / braking deceleration | 0.2 g / 0.3 g |
| Acceleration force /deceleration force | 5.9 kN / 8.8 kN |
| HTS electromagnet (2 pole) | 4 set |
| Thrust per HTS electromagnet | 2.2 kN |




## Design and Fabrication of Prototype High-Tc Superconducting Linear Synchronous Motor

### ◈ Design Summary




$$v_s = 2f\tau$$
$$F_{thrust} = F_{max} sin\delta$$
$$F_{max} = 4\mu_0 m_a p\sqrt{2} N_a I_a k_{w1} N_f I_f k_{wf} \frac{L_i}{\tau} e^{\frac{\pi}{\tau}g}$$

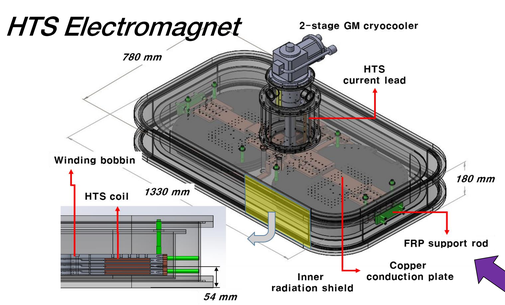
### ➢ Prototype HTS LSM

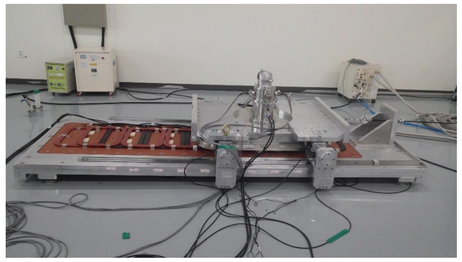
| Symbols | Parameters | Values |
|---|---|---|
| $f$ | Current frequency at the max. speed | 120 Hz |
| $v_s$ | Synchronous speed | 500 km/h |
| $m_a$ | Number of phases of LSM | 3 phase |
| $p$ | Number of poles of the HTS coil | 2 |
| $W$ | Effective width of LSM | 520 mm |
| $N_a$ | Number of windings of armature coil | 12 turns |
| $I_a$ | Current of armature coil | Variable |
| $L_a$ | Length of armature coil | 200 mm |
| $k_{w1}$ | Form factor of armature coil | - |
| $N_f I_f$ | Magnetomotive force of HTS coil | > 300 kA-turns |
| $k_{wf}$ | Form factor of HTS coil | - |
| $L_i$ | Length of HTS coil | - |
| $\tau$ | Pole pitch | 600 mm |
| $g$ | Magnetic gap | Variable |
| $\delta$ | Magnetic angle | Variable |

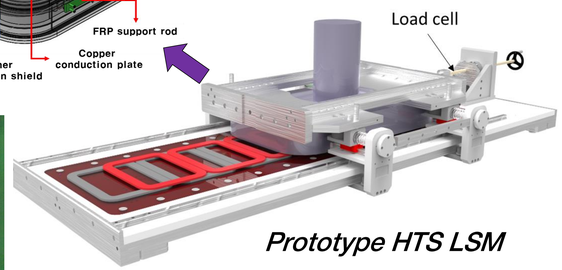
### ➢ HTS Electromagnet

| Parameters | Value |
|---|---|
| **HTS tape** | SuNAM Co. |
| Material | GdBCO (Stainless steel substrate / Cu plating) |
| Min. $I_c$ (77K, self-field) | ≥ 150 A |
| Average width / thickness | 4.1 mm / 0.14 mm |
| **HTS coil** | |
| $L_x$ / $L_y$ / $T_c$ | 420 mm / 520 mm / 108 mm |
| Number of DP | 3 sets |
| Number of windings per DP | 870 turns |
| Total number of windings of a coil | 2610 turns |
| Turn-turn insulation | Non-insulation |
| Critical current, $I_c$ @ 20 K | 168 A (Simulation) |
| Operating current, $I_{op}$ | 126 A ($I_c$ margin 25 %) |
| Current density, $J_c$ | 109 A/mm$^2$ |
| **Cryocooler** | 2-stage GM cryocooler (Sumitomo Co., RDK-415D) |
| **Total heat load** | 8.4 W @ 20 K |
| **Overall size** | 1330 mm × 780 mm × 180 mm |
| **Weight** | 380 kg |
| **Operation** | |
| Operating temperature | < 20 K |
| Cooling method | Conductive cooling |
| Current operation mode | Driven mode |

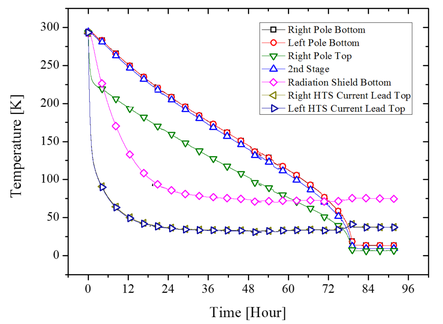
### ◈ Fabrication



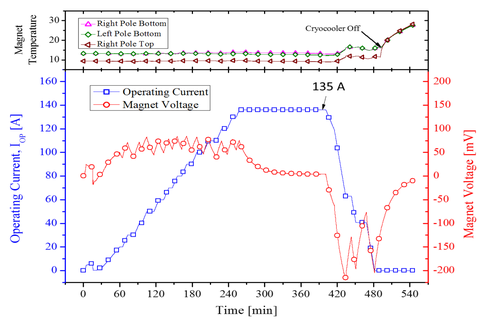





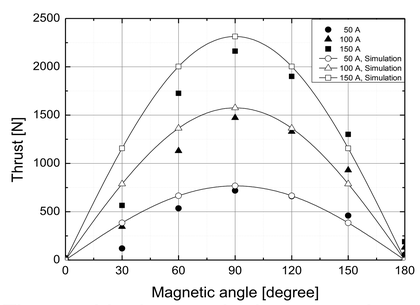

## Evaluation



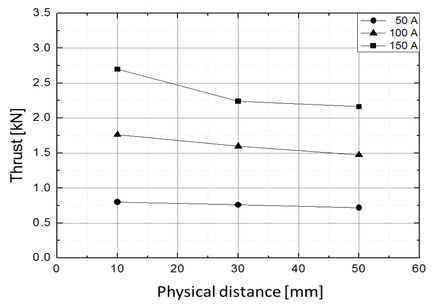

⟨Cooldown Test of HTS Electromagnet⟩




⟨Current Charging Test of HTS Electromagnet⟩




⟨Thrust with changes in the magnetic angle (300 kA-turns, physical distance : 50 mm)⟩




⟨Thrust with changes in the physical distance (300 kA-turns, magnetic angle : 90o)