# Longitudinal gradient bending magnet(LGBM) permanent magnet for Korea-4GSR Project


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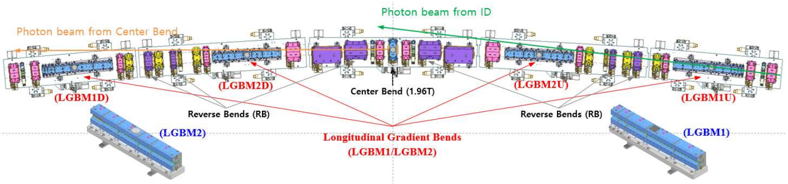
## Abstract


A 4th generation storage ring based light source is being developed in Korea since 2021. It features <60 pm rad intrinsic beam emittance, about 800 m circumference, 4 GeV e-beam energy, full energy booster injection, and more than 40 beamlines which includes more than 24 insertion device (ID) beamlines. To optimize the beam emittances, longitudinal gradient bending magnet is applied in the storage ring design. The initial design was using conventional electrical excitation, but the design is changed to use permanent magnet (Sm2Co17) to minimize energy costs. In this report, the physics design and prototyping is described including field integral, field tuning, and temperature compensation scheme.


[ Location of LGBM1, 2 in lattice ]

## PM version LGBM Magnet

- LGBM has longitudinal field profile ranging from 0.15 T – 0.75 T to minimize beam emittances..
- Old design used electric excitation following APS-U for concerns on the long term radiation damage.
- But ESRF-EBS operating experience shows no radiation damage after 2 year operation.
- 2023 MAC (Machine Advisory Committee), IAC recommended to consider PM version also.
- PM Version can save energy costs, Assuming, 1 kwh=150 Won, the design change can save 3.0 MWh/year, 7,000 MWon for 20 year operation. (about 4.50 MUSD/20 years)
- Also costs for MPS can be saved.
- PM version has advantage in designing photon stops due to its smaller physical size

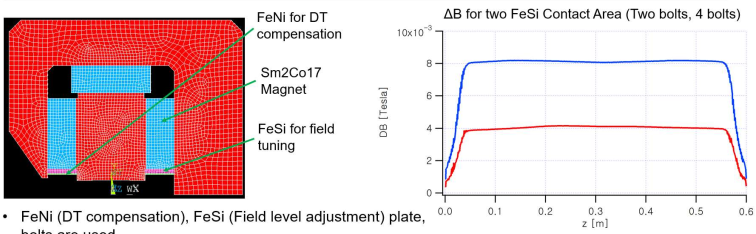
Technical Challenges

- No tunability like EM excitation, The final field profile should be met during measurement/tuning stage.
- Sm2Co17 PM has a temperature dependence about ΔB/B/ΔT= -3.3E-4/K.
- There is cross talk between the modules.

Engineering Solution

- Tunability using FeSi (Silicon Steel) shunts. FeSi can be in a sheet form (ESRF), or shunting bolt like HEPS. (always in decreasing direction).
- Weakening of Temperature dependence using FeNi (Ni steel) plate.
- Magnetic design taking into account the Cross-talk between the modules.

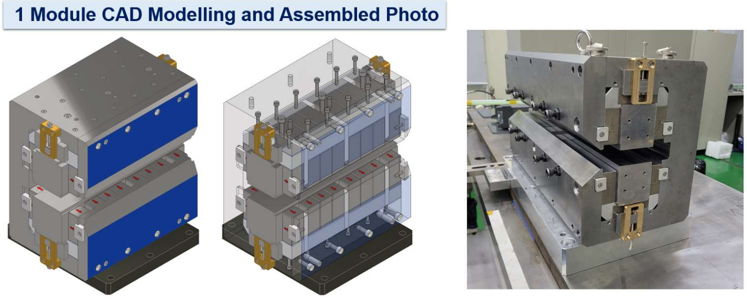
## Field tuning using FeSi (sheet, bolt), and Temperature Compensation scheme




- FeNi (DT compensation), FeSi (Field level adjustment) plate, bolts are used.
- FeNi material property from VAC for T=23, 28 C are applied to assess the temperature compensation.
- Magnetic property of Sm2Co17 Br=1.10 T is used conservatively. Thus M1 is designed slightly more than the specification, presuming negative tuning.

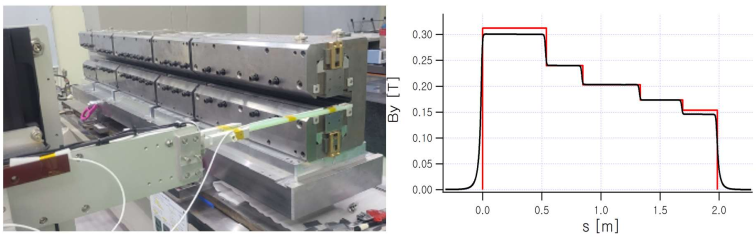
- Field tuning experiments using FeSi shunts. DB is proportional to the FeSi contact area (sheet, or bolts).
- Also for last modules (M1, M5) slidable flux shunts is installed for additional tuning.

## 1 Module CAD Modelling and Assembled Photo



- 1 pair (LGBM1, LGBM2) prototype worth quantities of Sm2Co17 already delivered
- All modules have same cross section, but different PM distributions.
- 4 Types of PM(Full size Top: FT, Full Size Side: FS, Quarter size Top: QT, Quarter size Side: QS) will be used depending on the module.

## LGBM2 Hall probe scan



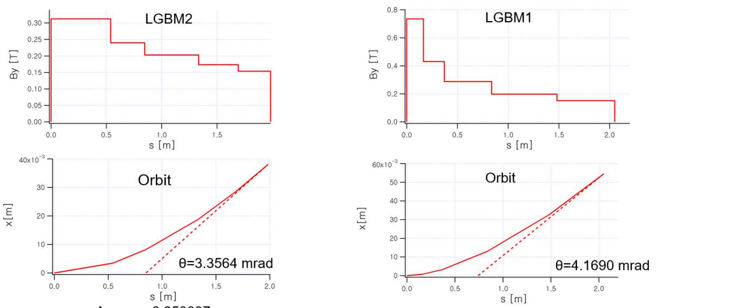

LGBM2 prototype on the measurement bench.
Hall probe is senis 3axis integrated sensor.

Measured (black), lattice (red) field profile.
The fields are tuned using FeSi plate, and tuning bolts.

## Contents and Background

- Requirements of LGBM magnet for K-4GSR
- Old Electromagnetic version of LGBM
- PM version of LGBM Magnet
  - Magnetic Design, Cross talk between the modules
  - Field tuning mechanisms
  - Temperature compensation
  - Field clamp effects to avoid interference with neighboring magnets
  - PM installation Jig design and application
- Summary and Future Plan

## Ideal Field profile, Apex points of LGBM1, LGBM2

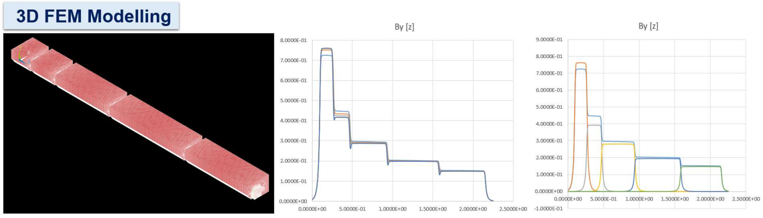



Apex $s_0$=0.850037 m

Apex $s_0$=0.742563 m

Actual magnets should satisfy the total bending angle, and apex points to meet the lattice requirements

## 3D FEM Modelling




Impact of separation between the modules DZ=5,10,15,20 mm.

Single Module vs 5 module field profiles showing cross talk between the modules. (DZ=5mm).

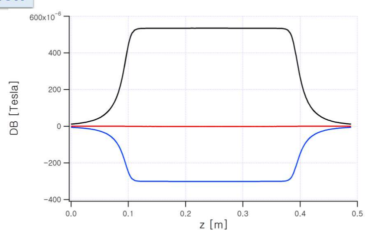
- Cross talk between the module are significant.
- Tuning using FeSi Shunt is always decreasing direction (design should be higher than the rated value).
- Final Field profile is also decreased by FeNi plate application (impact smaller than FeSi).
- Additional tunable shunting using Steel Bolt is also assumed (implemented in the design) (Results of HEPS visit).
- The final field profiles should have desired bend angle, apex positions, minimal deviation from the ideal orbit (~80 μm).

## Example of Optimal FeNi thickness simulation

With given thickness of FeNi, three cases are calculated.

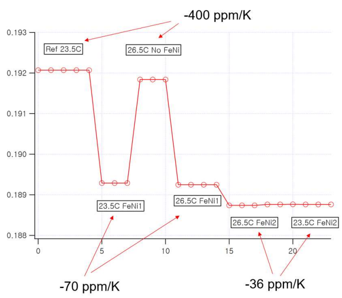
1) ΔT=0 K, FeNi BH table@23C
2) ΔT=5 K, FeNi BH table@23C
3) ΔT=5 K, FeNi BH table@28C

- FeNi thickness for same field for (1),(3) are determined for optimum thickness.
- The thickness of FeNi should be proportional to the main field for optimal compensation.
- Since we have only 1.0 mm, 2.0 mm thick FeNi, average thickness will be used for actual experiments, maintaining the total required FeNi volume.




Black : ΔB without ΔT compensation
Blue : ΔB for overcompensated case
Red : ΔB for optimal compensated case

## Temperature Impact Test : LGBM2 M3 case




- Temperature Dependence of the Sm2Co17 is ~-350 ppm/K.
- FeNi plate is placed on the magnet to reduce the temperature dependence.
- NMR probe with precision fixture is used to measure the central field of the each module.
- Measurement reproducibility is better than 0.05 G.
- Temperature of the measurement room changed from 23.5C to 26.5 resulting ΔT= 3.0 K.
- for ΔT= 3.0 K, uncompensated ΔB ~ 2.0 G
- Uncompensated measurement showed ~-400 ppm/K.
- 1st try showed ~-70 ppm/K.
- 2nd try showed -36 ppm/K.
- Requirements are < 50 ppm/K.
- Confirmed temperature compensation mechanism and estimated FeNi quantity agrees with expectations.

## Summary and Future Plan

- Current Status:
- PM version of LGBM1,2 are designed and prototyping is going on.
- Field tuning using FeSi sheets and FeSi Bolts are experimented and agrees with expectations.
- Temperature dependences are carefully evaluated using material properties at different temperatures.
- The crosstalk between the modules are evaluated and reflected .
- Jigs and Fixtures installing the Sm2Co17 magnet is designed/manufactured and implemented during assembly.
- Field clamps effects are experimented to limit the range of the fringe field.
- Many practical experiences are accumulated through the prototyping of LGBM2 magnet.
- We gained confidences in field tuning, temperature compensation of the PM based LGBM.
- ΔT compensation experiments of each modules will be carried out.
- Magnetic measurement of the full assembly is carried out meeting the 1st and 2nd field integral requirements.

- Near Future (~ 1 month)
- BD will confirm the magnetic measurements results to check the results.
- Fiducialization scheme of the magnet will be decided and implemented.