Presented at the 25thInternational Conference on Magnet Technology , 2017 Aug. 27 – Sept 1, Amsterdam; Session: D1 – Magnets for NMR, Tue-Af-Po2.05-04

MT25

25th International Conference On Magnet Technology

Analytical Method to Evaluate the Manufacturing Tolerance of a 400-MHz HTS NMR Magnet

Junseong Kim[1], Dongkeun Park[2], Seunghyun Song[1], Hyoungku Kang[3], Young-Gyun Kim[4], Haigun Lee[4], and Tae Kuk Ko[1]

1. School of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea.
2. Francis Bitter Magnet Laboratory, Massachusetts Institute of Technology, Cambridge
3. Korea National University of Transportation, Chungju, Korea
4. . Department of Material Science and Engineering, Korea University, Seoul, Korea.

Applied Superconductivity Lab, School of Electrical and Electronic Engineering, Yonsei University

1. Introduction

- **To make high field NMR HTS magnet, Many HTS wires and several coils are used.**
- **HTS wire contains errors in thickness and width at the time of production, and manufacturing error occurs due to accumulation and production of multiple coils.**
- **Therefore, in this paper, define the errors that occur during manufacturing the NMR HTS magnet as shown in Fig. 1 and analysis the influence of the errors on the magnetic field homogeneity.**
- **To summarize the contents of the paper :**
  - ✓ Definition of errors that occur when making NMR HTS magnet
  - ✓ Analysis of the influence of manufacturing errors on the homogeneity of magnetic field
  - ✓ In this paper, separate adjustable errors and non-adjustable errors during manufacturing HTS magnet and analyze the effect on the magnetic field homogeneity by errors

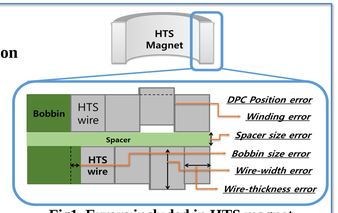


Fig1. Errors included in HTS magnet

2. Theoretical background and simulation

1) Spherical harmonic coefficient

- The magnetic field at any given point on the spherical surface can be calculated by solving Laplace equation.

$$\nabla^2\varphi(r,\theta,\phi)=0$$

$$\varphi(r,\theta,\phi)=\sum_{n=0}^{\infty}\sum_{m=0}^{n} r^n P_n^m\cos(\theta)\,[A_n^m\cos(m\phi)+B_n^m\sin(m\phi)]$$

$$B_z(r,\theta,\phi)=\sum_{n=0}^{4}\sum_{m=0}^{n}(n+m+1)r^n P_n^m\cos(\theta)\,[A_{n+1}^m\cos(m\phi)+B_{n+1}^m\sin(m\phi)]$$

- Consider 0-th to 4-th spherical harmonic coefficients.

2) Kind of error

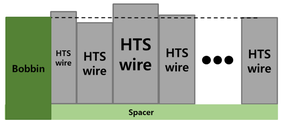


Fig2-a. Wire width & thickness error model

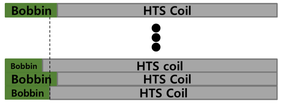


Fig2-b. Bobbin size error model

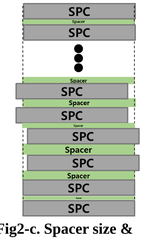


Fig2-c. Spacer size & DPC position error model

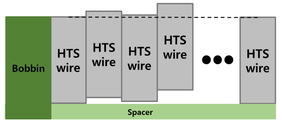


Fig2-d. Winding error model

Table 1. Error specification

Parameter	Avg.	Max. / Min.	S.D
Wire-thickness error [μm]	100	+30 / -30	1.9/2.58
Wire-width error [mm]	6.1	+0.2 / -0.2	0.1/2.58
Bobbin size error [mm]	41.3 41.7 (notched)	+10 / -10 [μm]	5/2.58 [μm]
Spacer size error [mm]	0.1	+10 / -10 [μm]	5/2.58 [μm]
DPC position error [mm]	0	+1 / -1	0.5/2.58
Winding error [mm]	0	+0.1 / -0.1	0.05/2.58

- In this paper, we consider the following six kinds of errors
- The thickness and width error of HTS wire itself.
- The Spacer and Bobbin thickness error.
- Winding and DPC position error induced by manufacturing magnet.
- As shown in table1, the error is represented by normal distribution, and the maximum and minimum values of the error are set so that the error is in a certain range.

3) Magnet specification

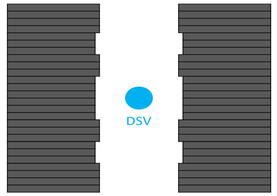


Fig3. Configuration of HTS magnet

Table 2. Magnet specification

Parameter	S.D
Frequency [MHz]	351
Field [T]	8.24
Operating current [A]	240
Operating current density [MA/m²]	417
# of DPC (notched)	14(12)
# of turns per pancake (notched)	187(183)
Winding I.D (notch) [mm]	41.3(41.7)
Winding O.D [mm]	60
Overall height [mm]	322.3

Table 3. HTS wire specification

Parameter	S.D
Average wire width [mm]	6.1
Average GdBCO thickness [μm]	1
Average Non-GdBCO thickness [mm]	0.1
Ic at 77K, self-field [A mm^{-1}]	>150/4.1
95% Ic reterntion stress	>550
95% Ic retention strain	>0.5

- As shown in Fig. 3, the virtual magnet used in simulation include notch.
- The specification of the magnet and HTS wire are presented in table 2 and 3.
- The magnetic field difference in the ideal magnet shape without manufacturing errors is about 289 ppm.

4) Mapping & Simulation

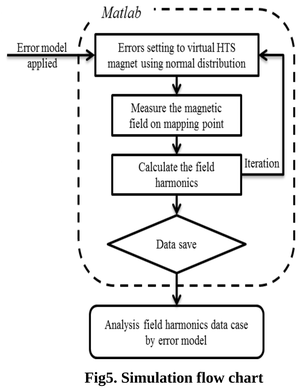


Fig5. Simulation flow chart

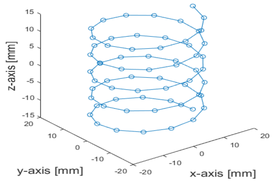
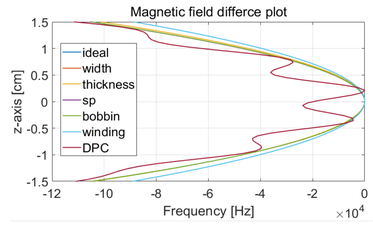


Fig4. Plot of Mapping points

- As shown in Fig .4, mapping is performed at 128 points on the surface of 15mm-radius and 30mm-height cylinder.
- Simulation is performed in the order shown in Fig. 4 using a virtual magnet.
- Magnetic field and harmonic coefficients data collected for several error cases.

3. Results and analysis

1) Ideal and each error case



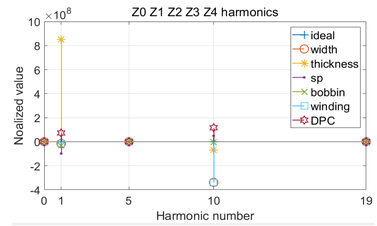


Fig6-a. Plot of field difference of ideal and each error case

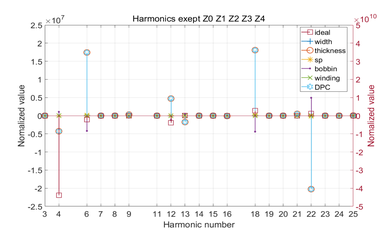
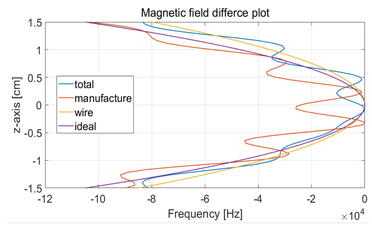


Fig6-b. Plot of harmonics of ideal and each error case

2) Adjustable, non-adjustable and total errors case



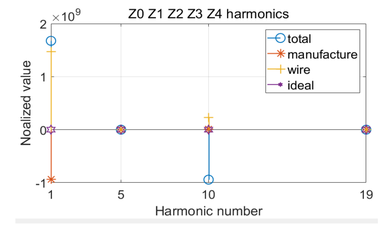


Fig7-a. Plot of field difference of ideal and Adjustable, non-adjustable and total errors case

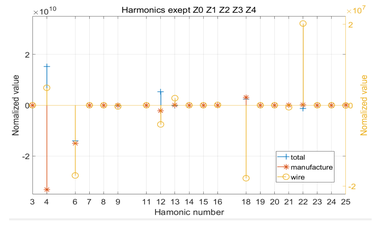


Fig7-b. Plot of harmonics of Adjustable, non-adjustable and total errors case

- **Only the DPC position error affects radial harmonic coefficient due to making asymmetry in z-axis of HTS magnet.**
- **The Wire error significantly affects to magnetic field coefficient in HTS magnet, especially Z0.**
- **The non-adjustable error is more influential than the adjustable error.**

4. Conclusion

➢Define the manufacturing errors in HTS magnet and classified into whether or not adjustable during manufacturing the HTS magnet.

- **Wire errors : wire thickness and width error.**
- **Manufacturing errors : bobbin, spacer size, winding and DPC position error.**

➢Design a virtual 360MHz HTS magnet and apply the errors in magnet, and calculate magnetic field and field harmonic coefficients on the DSV region.

➢The field harmonic coefficients were analyzed and the results were as follow:

- **The wire thickness, width, bobbin, spacer size, and winding error greatly make more asymmetry in xy plane than z-axis of HTS magnet, so axial harmonics are generated bigger than radial**
- **On the other hand, in the case of DPC position error, radial harmonics are largely generated.**
- **Results are represented that the harmonic coefficient increases greatly when the magnet is fabricated with the non-adjustable error.**
- **The adjustable errors greatly affect Z0 and Y harmonic coefficients.**

➢Therefore, when HTS magnet is manufactured, the wire thickness and width errors greatly affect the magnetic field homogeneity, and distortion occurred on assembling DPCs induces radial harmonics.

Do you have any question send me E-mail
Junsung0616@yonsei.ac.kr