Mon-Af-Po1.03-03

A Field-Shaking System to Eliminate the Screening Current-Induced Field in the 800-MHz HTS Insert of the MIT 1.3-GHz LTS/HTS NMR Magnet: A Small-Model Study

Jiho Lee[1], Dongkeun Park[1], Philip C. Michael[1], So Noguchi[1,2], Juan Bascuñán[1], and Yukikazu Iwasa[1]

[1]*MIT Francis Bitter Magnet Laboratory/Plasma Science and Fusion Center, Cambridge, MA, USA*

[2]*Graduate School of Information Science and Technology, Hokkaido University, Sapporo 060-0814, Japan*

Abstract

- A small-model study from which we plan to develop and apply a field-shaking system to minimize or even eliminate SCF in 800-MHz HTS insert of the MIT 1.3-GHz LTS/HTS NMR magnet
  - In 1.3G, H800 is the chief source of a large error field generated by its own SCF.
  - Two NI REBCO double-pancakes, one from each of the two H800 coils (HCoil2 & 3)
  - A 5-T/300-mm room-temperature bore external magnet is used to not only induced SCF in the double-pancakes but also eliminate it by the field-shaking.
- Test summary
  - For the induction of SCF: at an axial location where the external radial field, B_R>0
  - For the field-shaking: at an axial location where external axial field, $B_Z >> B_R$
- Purpose
  - In this paper, we report 77-K experimental results, develop an analysis that satisfactorily explains the results, and apply the analysis to design a field-shaking system for 1.3G at full operation.

Background

- HTS insert coil
  - For the development of >1 GHz NMR, with LTS outsert coil, HTS insert coil must be used owing to its large in-field current-carrying capacities.
- SCF of HTS
  - The screening current-induced field (SCF), a diamagnetic field generated by each turn of HTS coil, is major field error to in-corporate an HTS insert for a high field LTS/HTS magnet.
  - The magnitude of diamagnetic field, SCF is proportional to the superconductor size and c ritical current density. Various studies have reported the screening current-induced field (SCF) generated by HTS coils.
  - Since SCF by an HTS insert can be >100 times greater than those typical by an LTS outs ert, it is critical to minimize or even eliminate the SCF-generated error field.
- “Field-shaking” technique
  - Although much less serious with LTS magnets than with HTS magnets, the so-called field-shaking technique to minimize SCF error fields was proposed in 1986 for LTS magnets.
  - This technique has since been demonstrated, theoretically and experimentally to be appli cable to HTS magnet.

Test coils

TABLE I

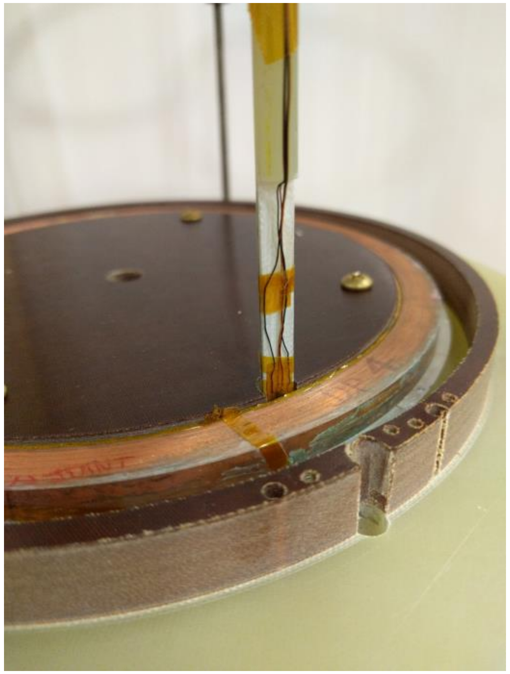
SPECIFICATIONS OF TESTED HTS DOUBLE PANCAKE COILS

Parameters	HCoil2 DP	HCoil3 DP
Conductor (REBCO)		
Width; thickness [mm; µm]	6.02; 76	6.04; 75
Cu stabilizer thickness [mm]	0.01	0.01
I_c @ 77 K [A]	188	190
NI Double pancake Coil		
ID [mm]	151.04	196.90
OD [mm]	169.18	211.50
Height [mm]	12.198	12.200
Turn per pancake	120	96
Self-inductance [mH]	18.06	16.60
Characteristic resistance, R_c [µΩ]	322.1	491.9
Time constant, τ [s]	56.07	33.75
I_c @ 77 K, self-field [A]	42.81	67.41

TABLE II

SPECIFICATIONS OF 5-T/300-MM ROOM-TEMPERATURE BORE EXTERNAL MAGNET

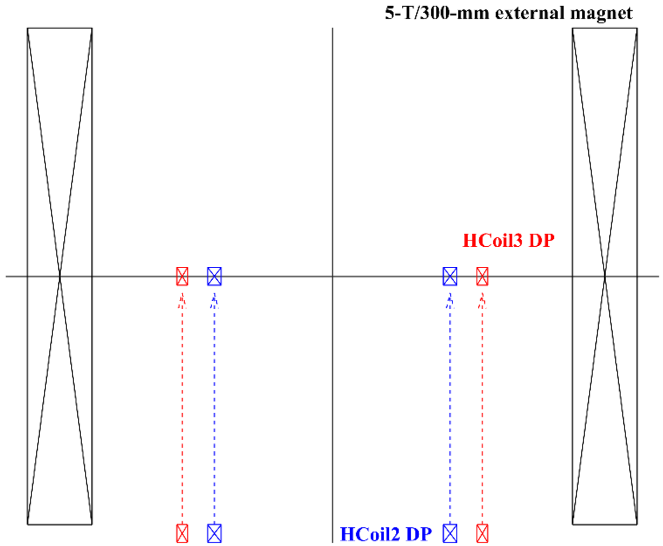
Parameters	Values
Overall i.d.; o.d.; height [mm]	327; 415; 338
Magnet constant [mT/A]	61.52
Center field at I_{op} of 81.268 A [T]	5.0
Self-inductance [H]	143

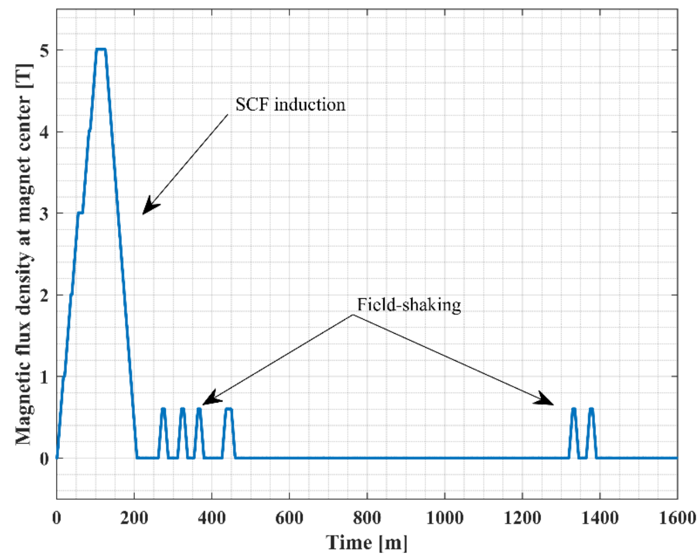


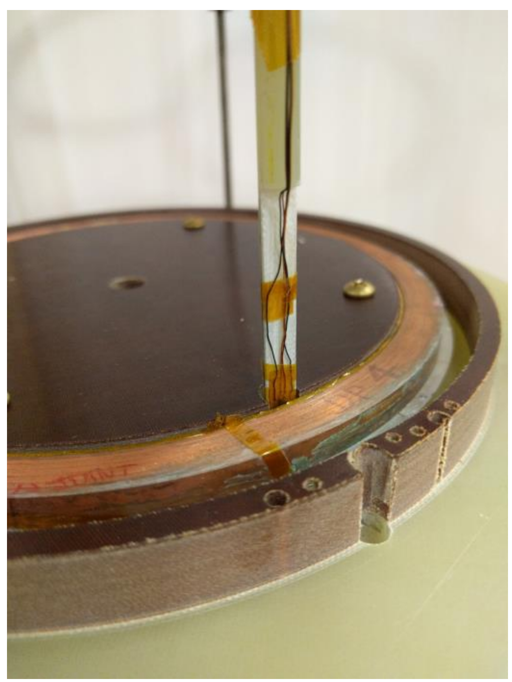
Experiments procedure

1. Place the NI REBCO DP, *at room temperature*, at an axial location, $z = -175\ mm$, below the mid-plane of the external magnet.
2. *Apply the magnetic field* of 5 T to the DP set. Each coil experiences the external radial field, the perpendicular field to the tape surface, at this location.
3. *Turn the DP set into the superconducting state*, by cooling in a bath of liquid nitrogen.
4. *Reduce the magnetic field to zero*, the process of which *induces SCF* in the double-pancake.
5. *Relocate the double-pancake to the mid-plane* of the external magnet.
6. *Apply a shaking field* with the external magnet using the trapezoidal field injection, confirmed as effective for elimination of SCF.
7. *Map the radial field* along the Z-axis at each double-pancake's innermost turn.

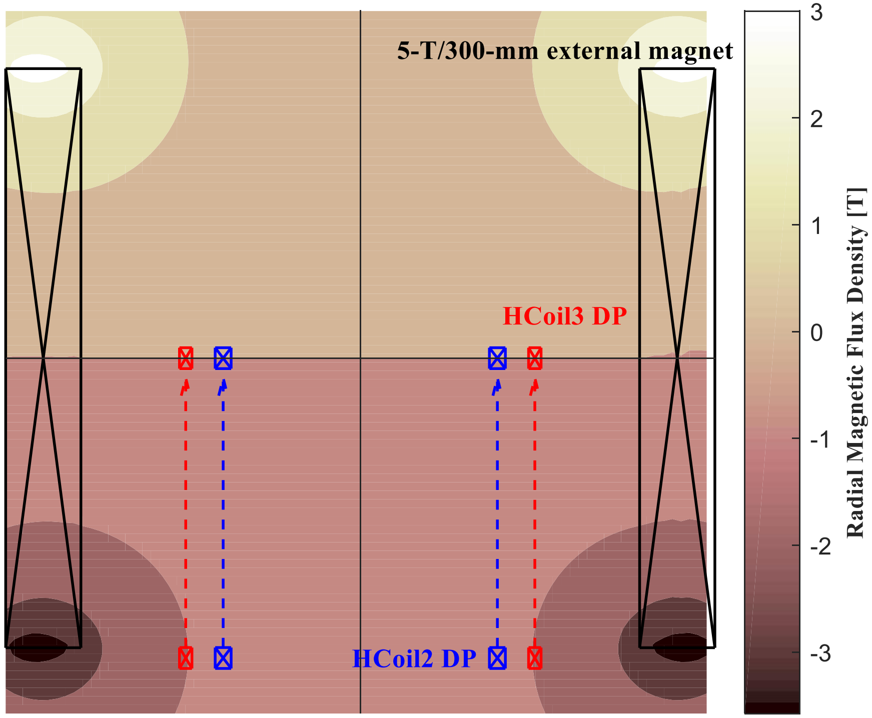
Experiments procedure

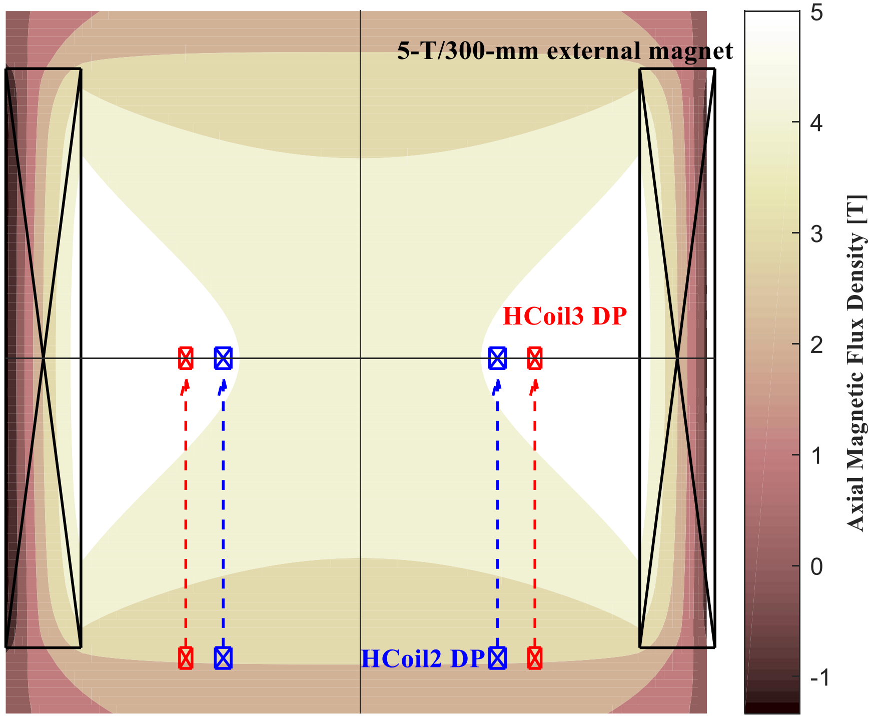






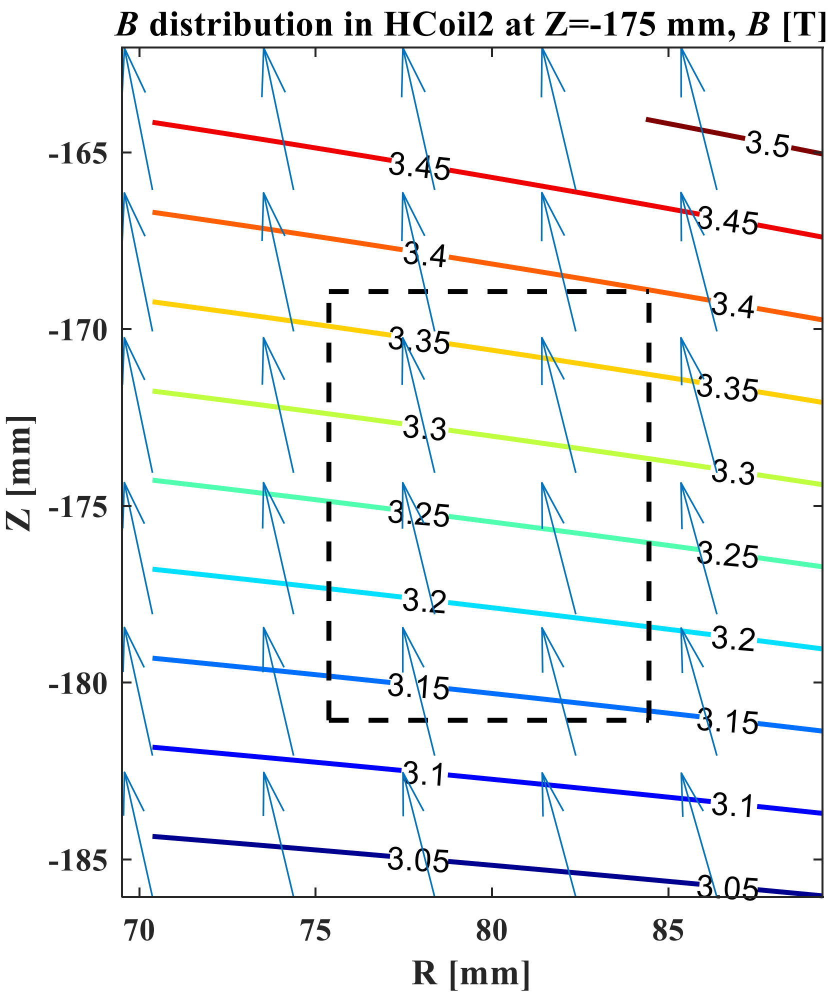
Magnetic flux density of the external magnet

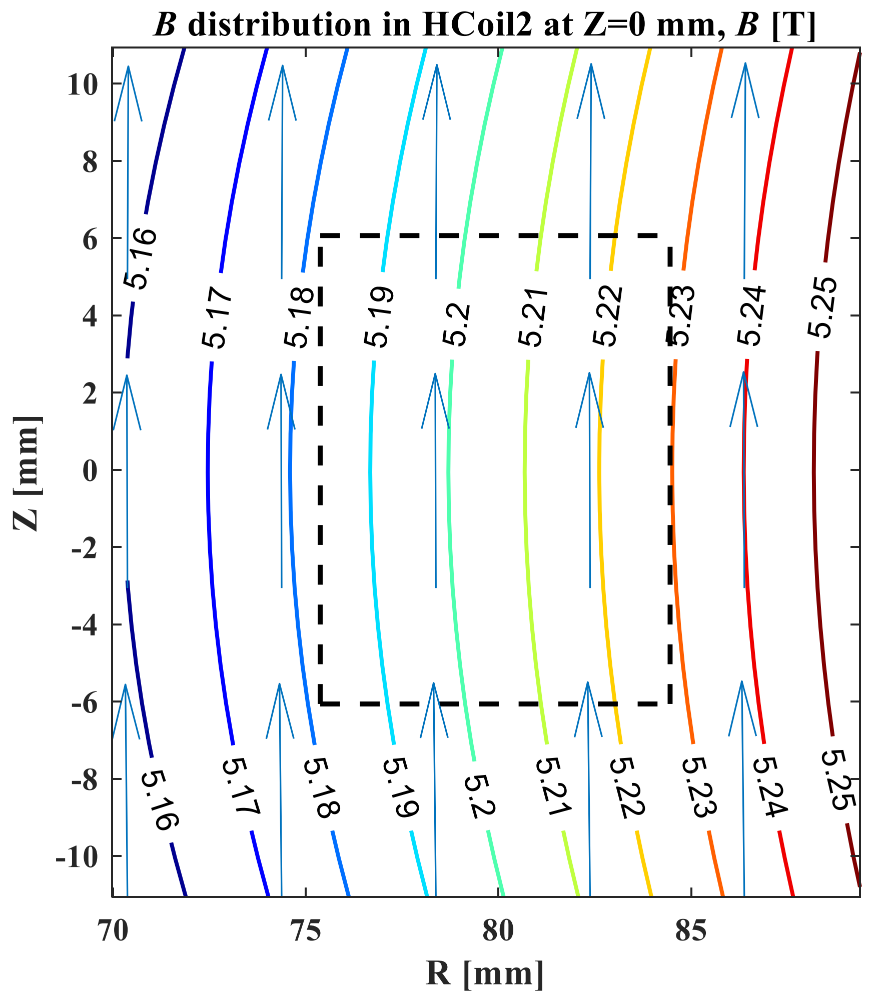




When *B* at magnet center is 5 T, …

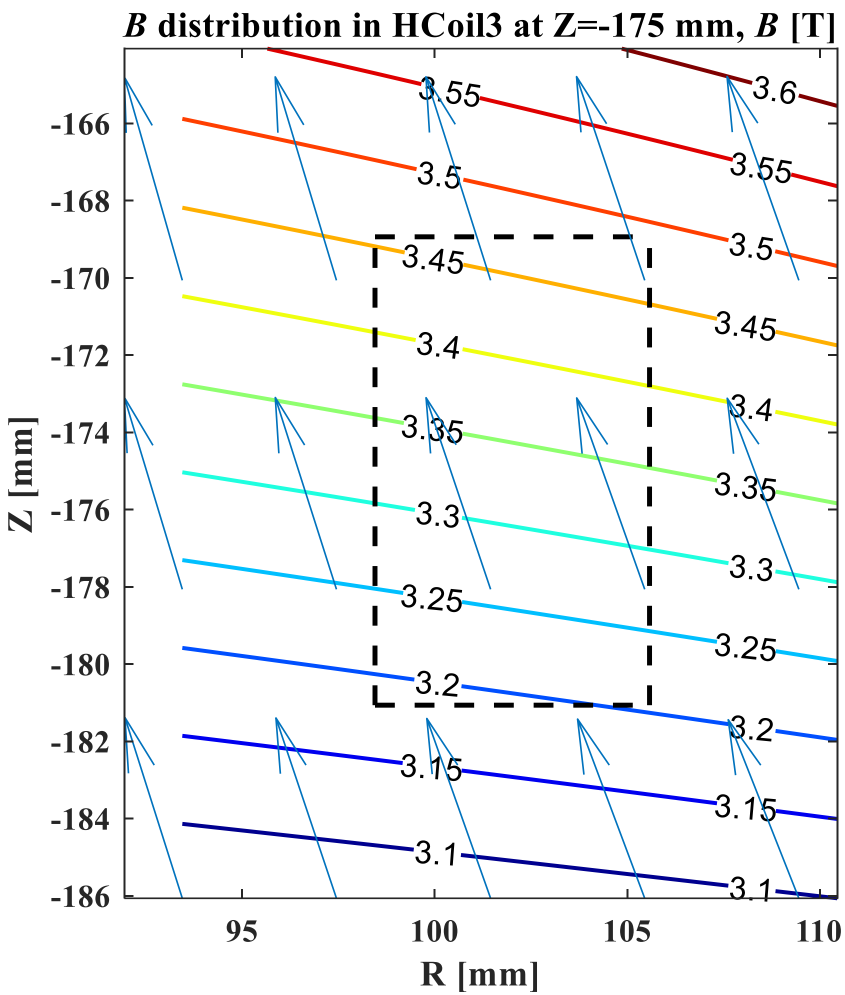
- Magnetic flux density in HCoil2 DP winding

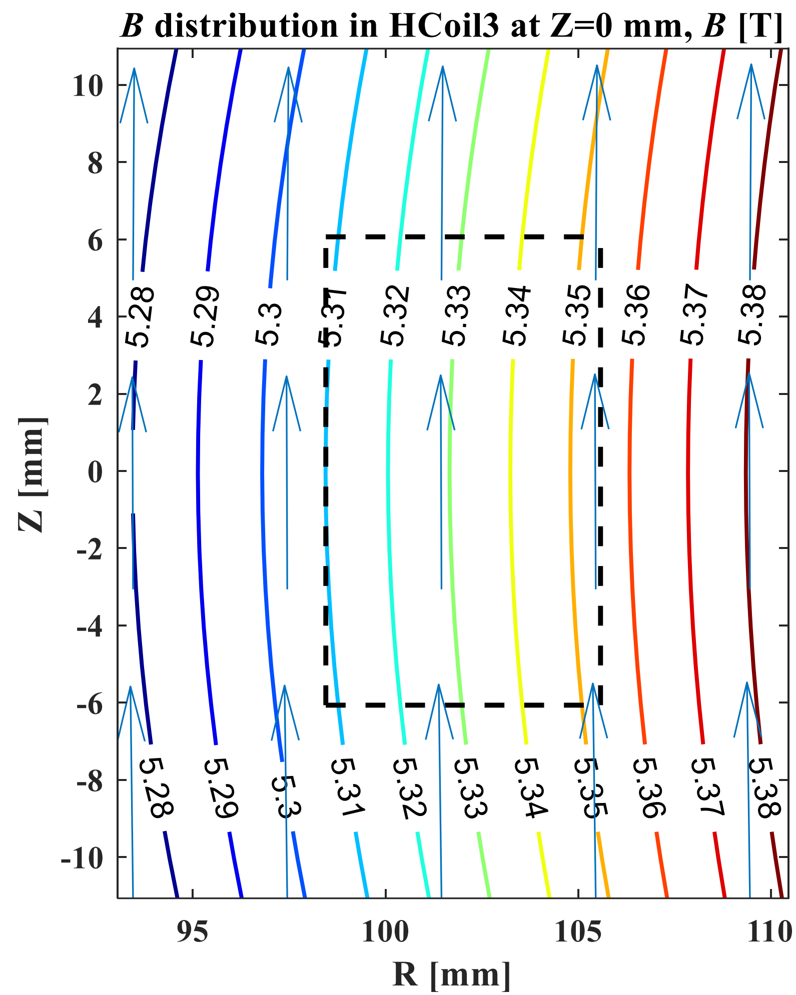




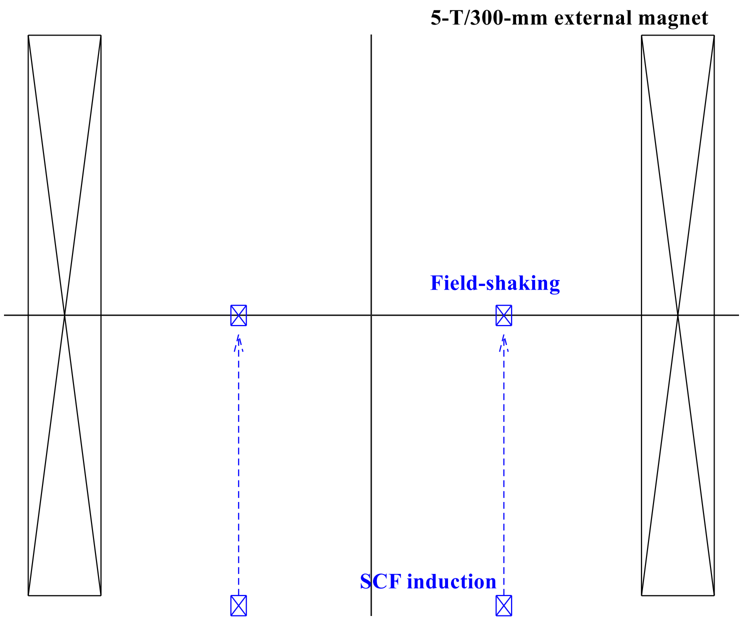
When *B* at magnet center is 5 T, …

- Magnetic flux density in HCoil3 DP winding

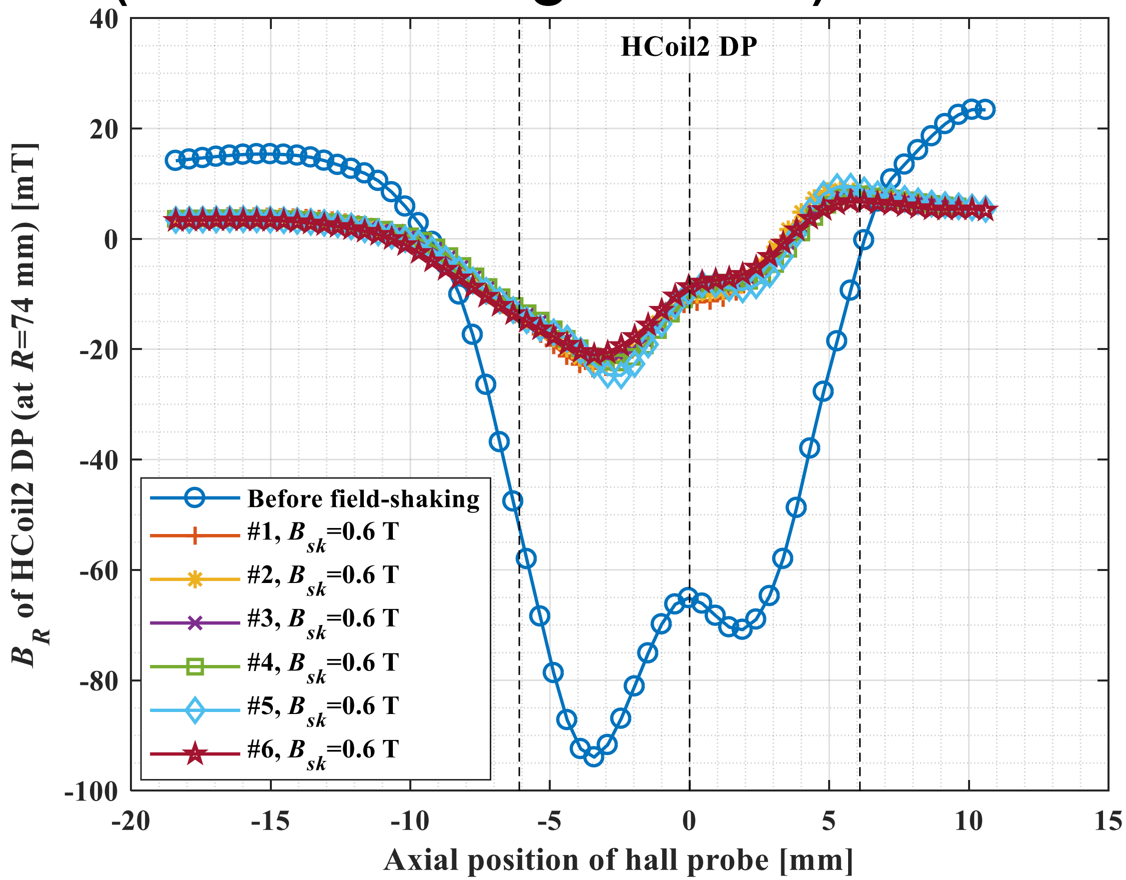




Test results1: HCoil2 DP (field-shaking at z=0)

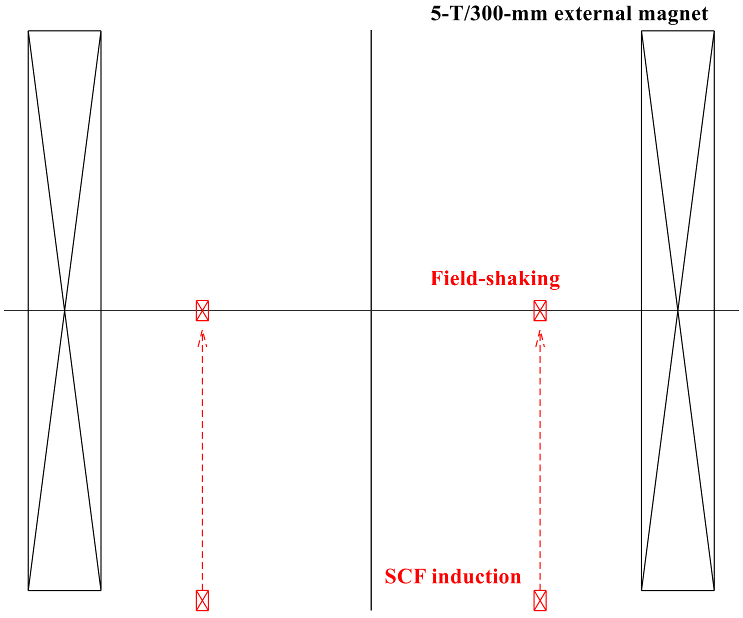


HCoil2 DP test (field-shaking without B_R)

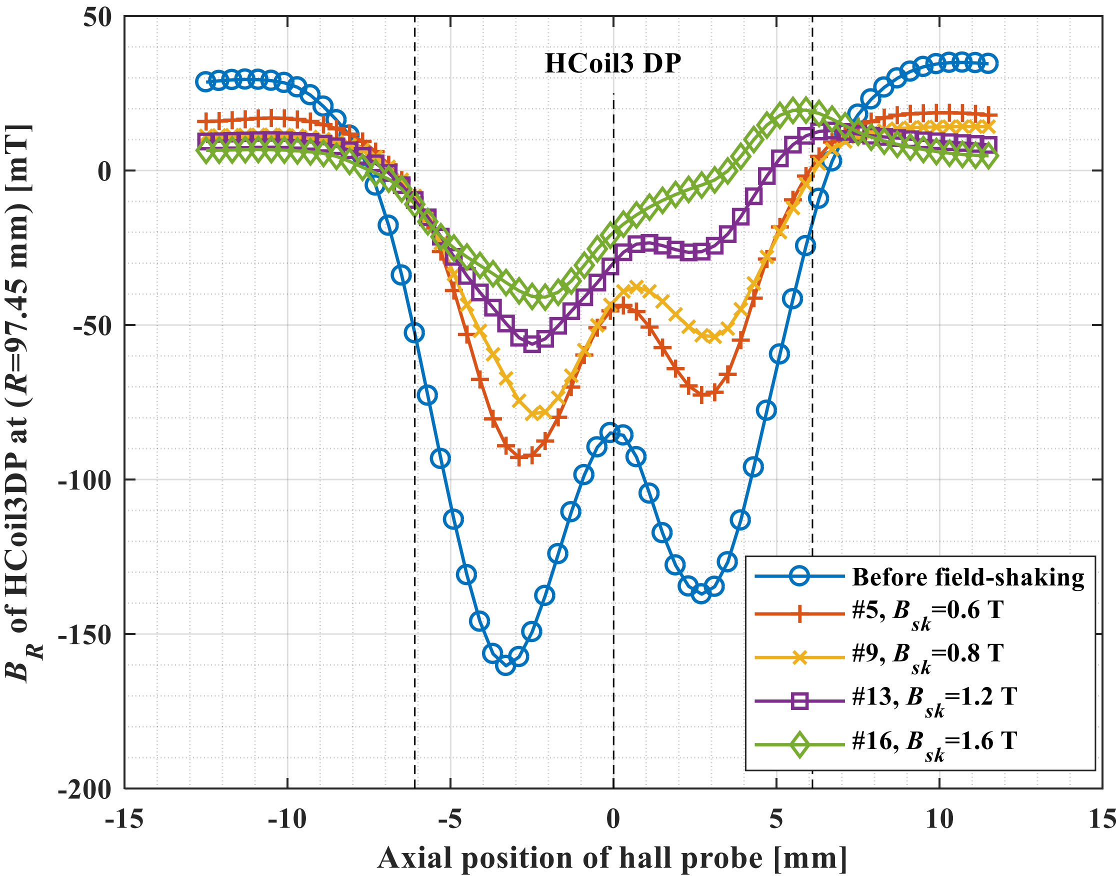


- SCF induction at z=-175 mm which is the location with maximum B_R
- Field-shaking at z=0 mm which is the location with almost zero B_R
- From the first attempt of field-shaking of 0.6 T based on the magnet flux density at magnet ce nter, the considerable SCF was decreased to 20% of its originally induced one.
- However, after then, even with the multiple attempts, same field-shakings of 0.6 T didn't show the notable effect on the elimination of SCF.

Test results2: HCoil3 DP (field-shaking at z=0)

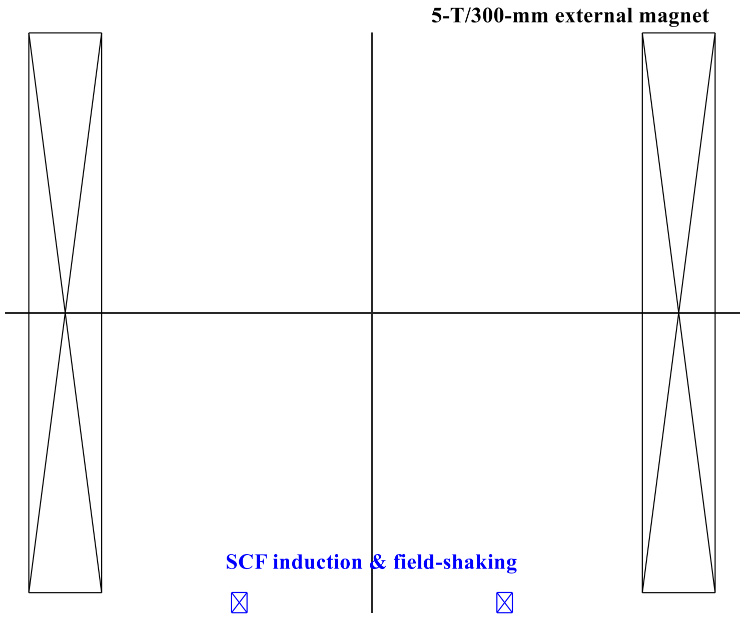


HCoil3 DP test (field-shaking without B_R)

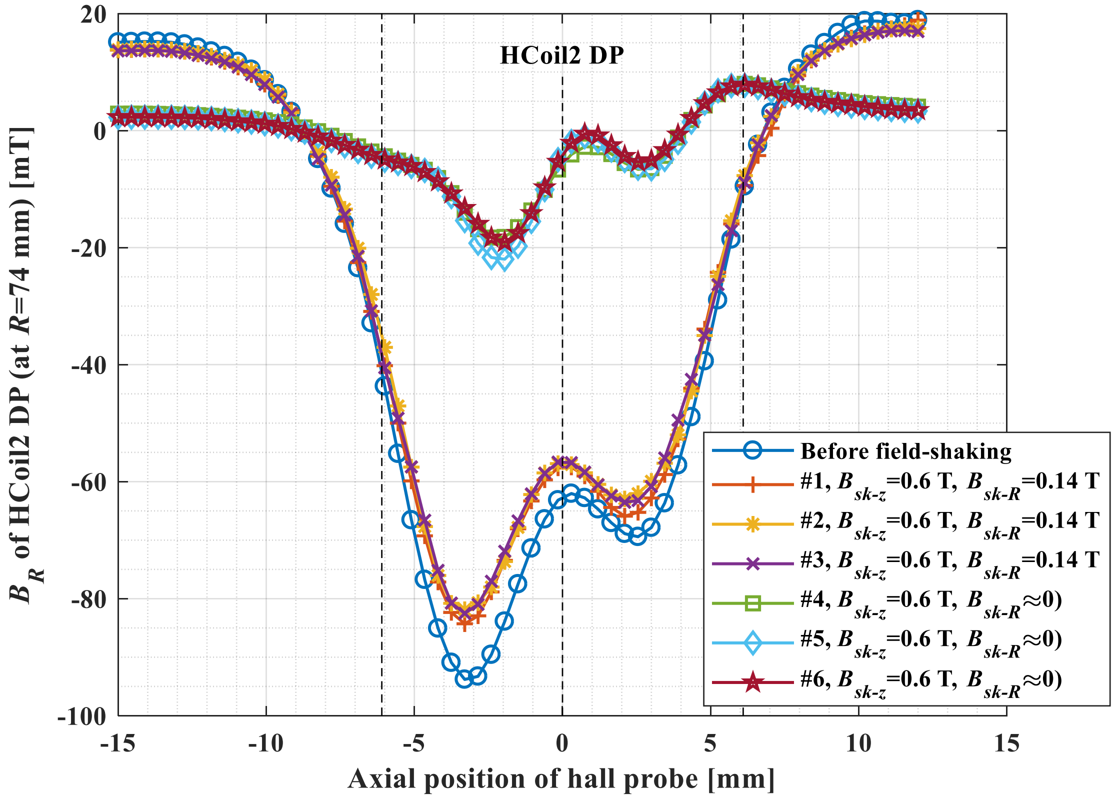


- SCF induction at z=-175 mm which is the location with maximum B_R
- Field-shaking at z=0 mm which is the location with almost zero B_R
- From five field-shaking of 0.6 T lowered SCF to 55-50% of its originally induced one. And then four more field-shaking of 0.8 T and 1.2 T lowered the SCF to 44-48% of the original magnitude. To eliminate SCF to ~20% of the originally induced one same as the HCoil2 DP test result, three field-shaking of 1.6 T was needed.

Test results3: HCoil2 DP (field-shaking at z=-175 mm)

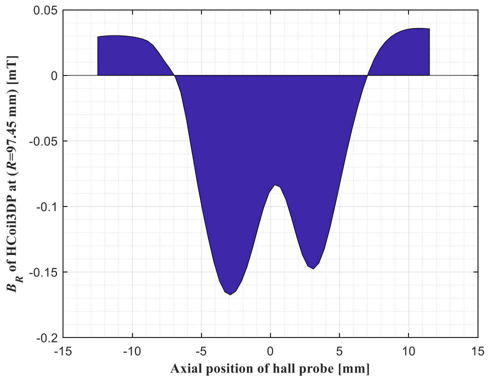


HCoil3 DP test (field-shaking with B_R)

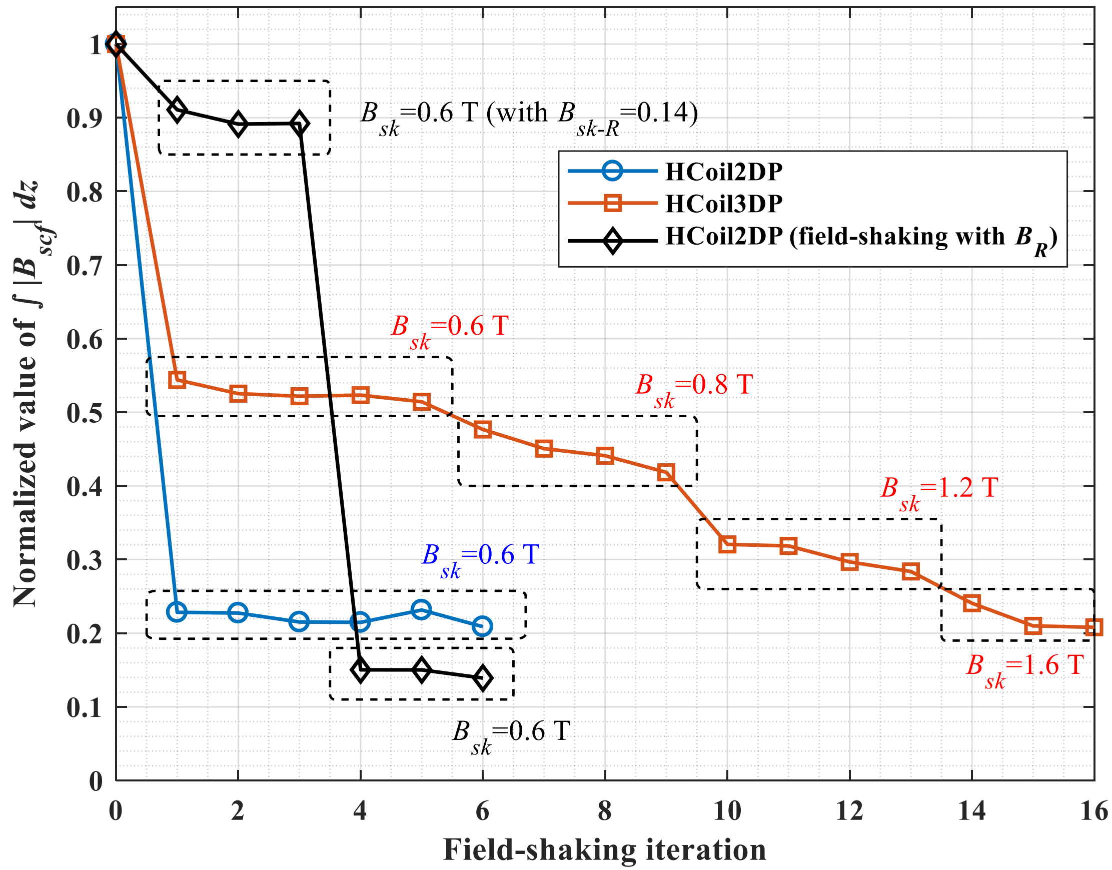


- To simulate the conditions of the end-plane of H800 which has the maximum external radial field, another field-shaking test about HCoil2 DP was performed without changi ng its axial location.
- $B_{Z=-175\ mm}$ =0.6 T, $B_{R=-175\ mm}$=-0.14 T where $B_{Z=0}$=0.98 T
- With the radial field of 0.14 T, 0.6 T field-shaking didn't show the effective reduction/e limination of SCF comparable than the test result shown in Fig. 3 which is the results of field-shaking without the radial field.

Results summary

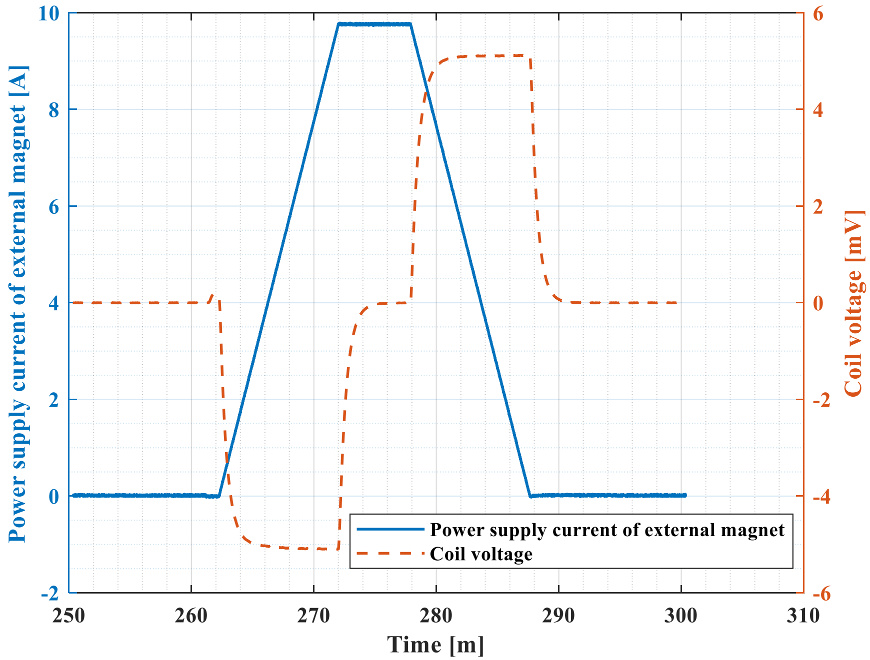


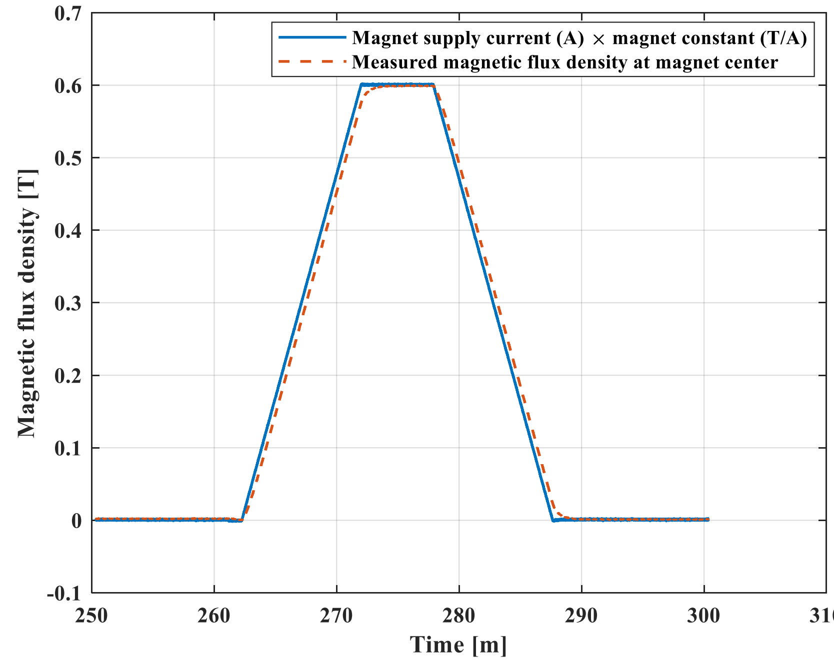
$\int |B_{scf}| dz$ [Wb/m]→Normalization →



- Three tests successfully eliminated the SCF to approximately 20% of their initially induced values.
- Once the degradation of SCF shows the tendency of saturation, unless B_{sk} was increased, th e repetition of the field-shaking didn't make the elimination of SCF much.
- The field-shaking with the radial field of 0.14 T which shows 9% reduction (100→89%) make s the field-shaking of 0.6 T which shows 80% reduction (100→20%) significantly less effectiv e.

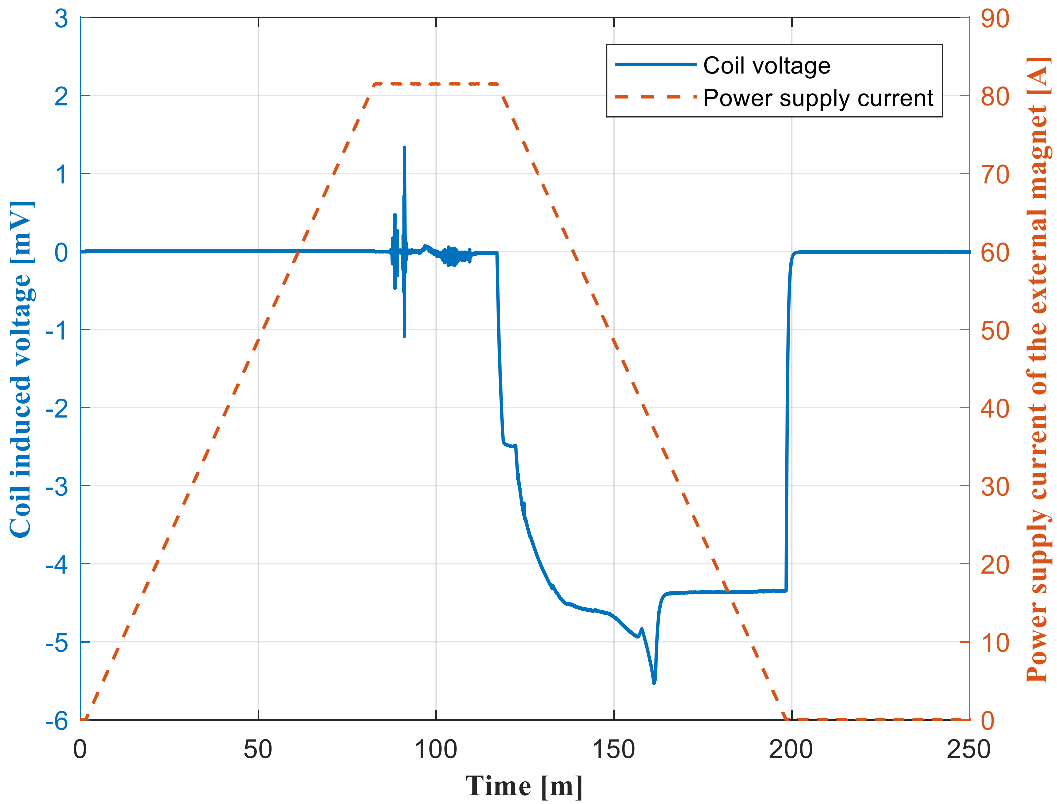
Issues





- During the induction of SCF to each NI double-pancake and the field-shaking, the electromotive force developed by the external magnet caused the azimuthally induced current due to its NI winding technique which makes the closed loop inside the coil.
- Therefore, the trace of the coil terminal voltage of each double-pancake during the field-shaking is almost same as the trace during the operation of each DP powered by power supply.
- Most of NI HTS double-pancakes are used for high-field magnets themselves or their insert to elevate the magnetic flux density at magnet center.

Issue



- Electromotive force is proportional to the change rate of the external magnetic field, which is proportional to the ramp rate of the power supply current for the external magnet.
- During the induction of SCF for HCoil3 DP, the trace of the coil voltage shows superconducting-to-normal transition. HCoil3 DP which has the bigger inner/outer radius than HCoil2 DP should experience the higher radial field. Therefore, its critical current at 3-4 T could be high enough to make the superconducting-to-normal transition.

Conclusion

- Field-shaking method was successfully applied to eliminate the considerable amount of SCF in a couple of attempts. The higher shaking field is more effec tive on the elimination of SCF.
- Presence of the radial field during field-shaking made field-shaking significant ly less effective than absence of one. Though with the same z-axial shaking fi eld of 0.6 T, the presence of the radial field, 0.14 T makes the field-shaking al most ineffective.
- Double-pancakes applying NI winding have the azimuthally induced current d ue to the electromotive force which is proportional to the ramping-rate of field-shaking magnet. In case of operating condition, this azimuthally induced curr ent could be helpful to eliminate SCF similar to the current sweep reversal (C SR) method or make the HTS coils closer to their operating current margin.