Flux Motion and Screening Current in High-temperature Superconducting Magnets

Yi Li, **Chen Gu, Timing Qu, Zhenghe Han**

ASRC, Tsinghua University

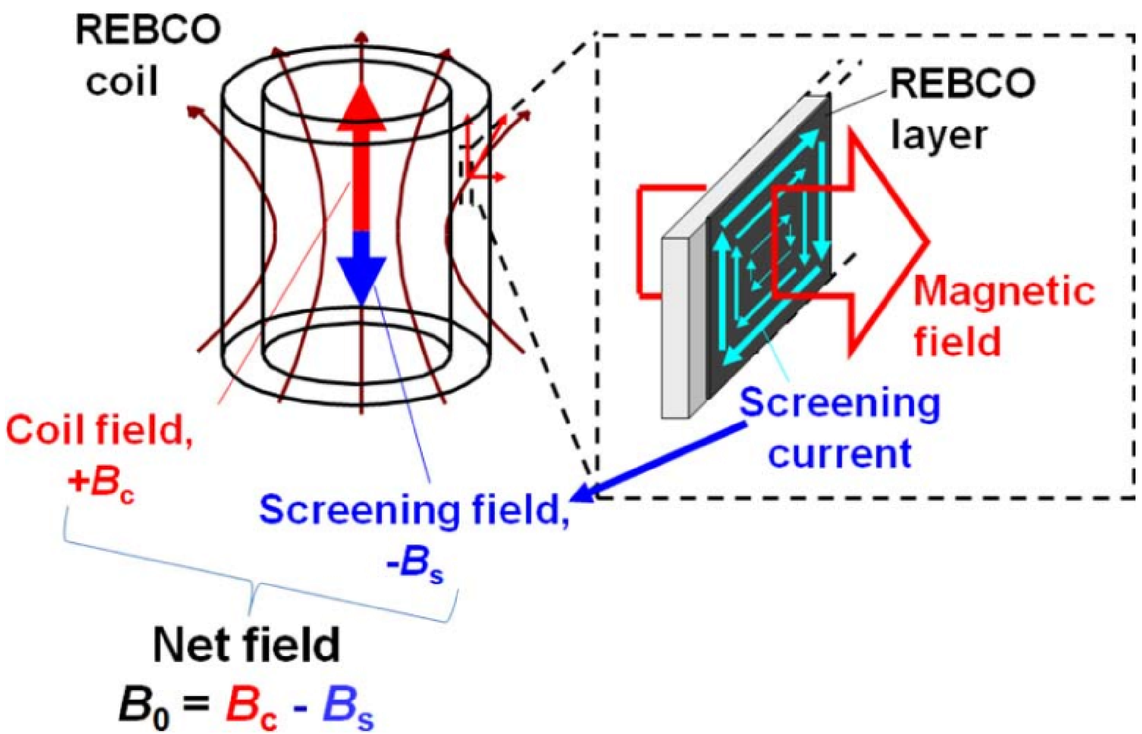
ICFA Mini-workshop on High Field Magnets for pp Colliders

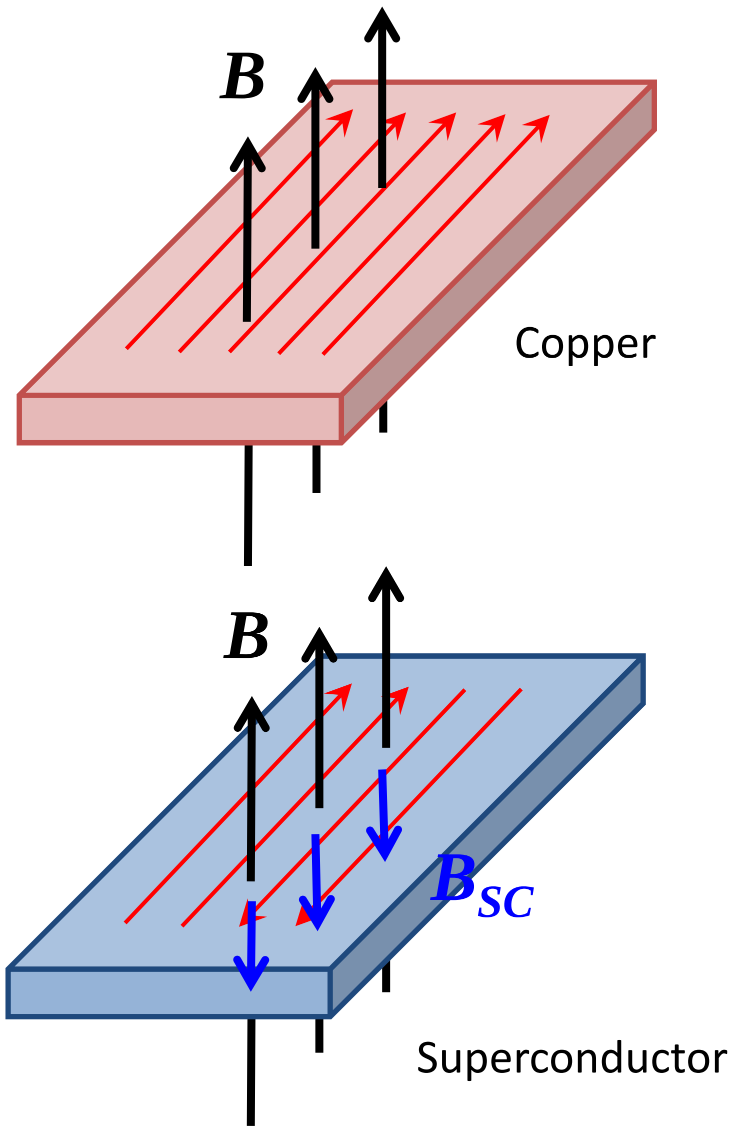
Shanghai Jiao Tong University, Xuhui Campus 20150616

BASIC MECHANISM

Screening Current

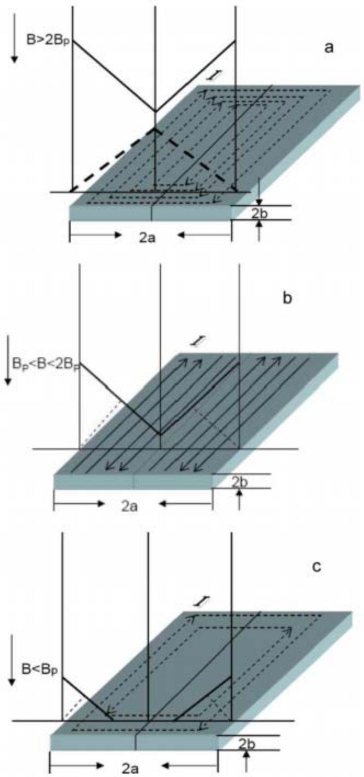
Superconductor tends to screen magnetic field.



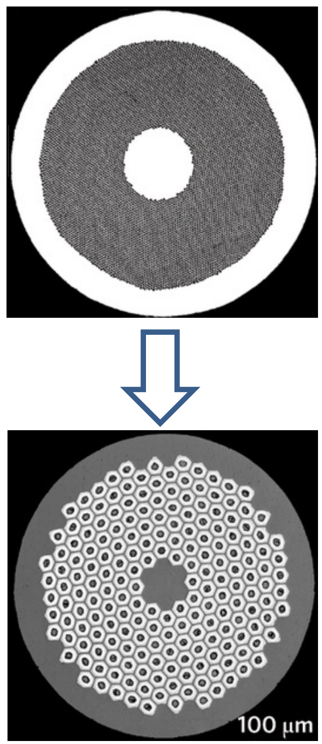


Screening Current (SC) in Superconducting Magnets

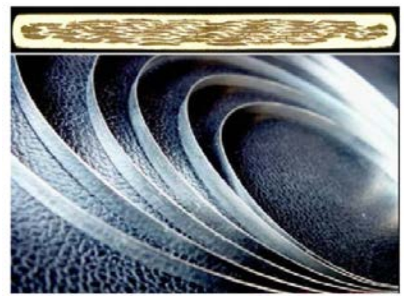
Discovered in 1960s
Critical State Model

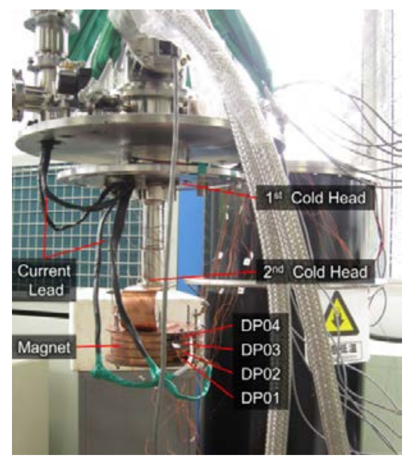


"Solved" in 1970s
Twisted Multifilamentary Wire

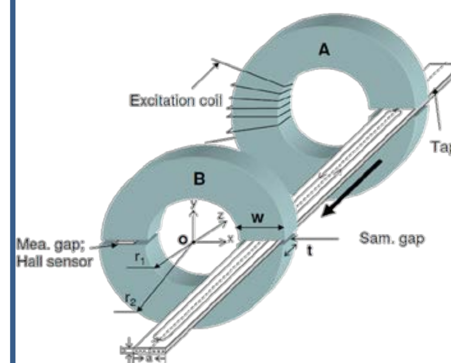


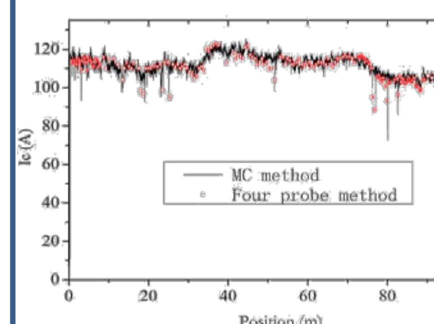
Emerged in 2000s
HTS Wide Tape



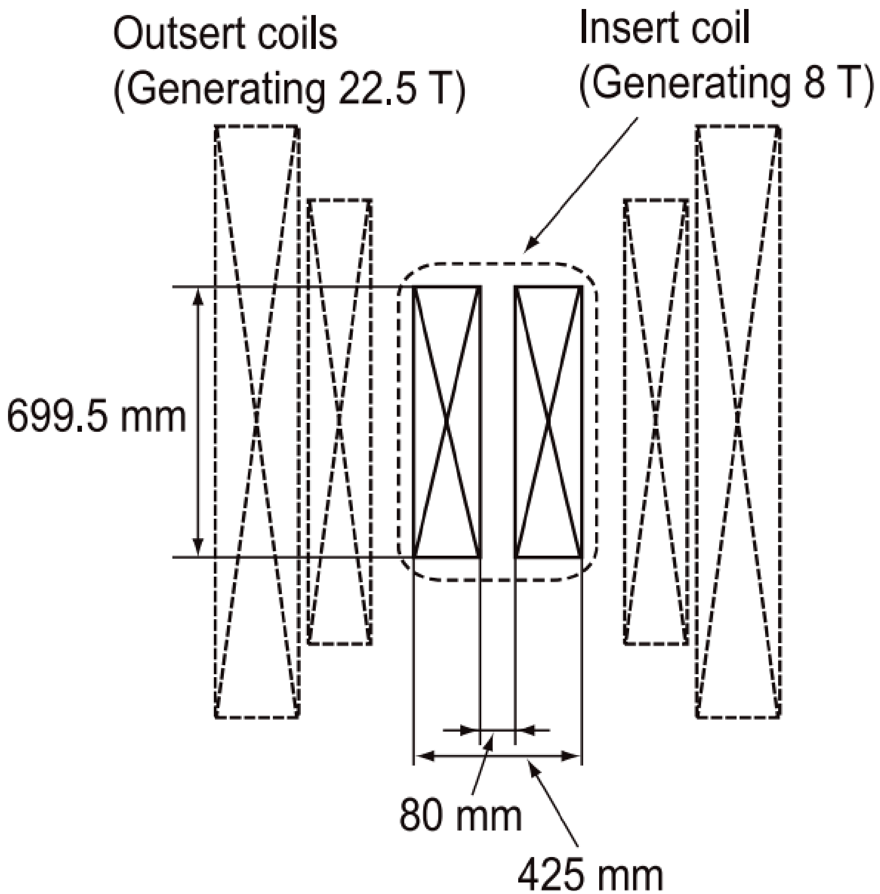


Used in 2010s
Continuous Noncontact I_c Measurement





NMR MAGNETS



Amemiya-2008-SUST-Magnetic field generated by shielding current in high Tc superconducting coils for NMR magnets

8 T ReBCO Insert Coil for a 30 T (1.3 GHz) NMR Magnet

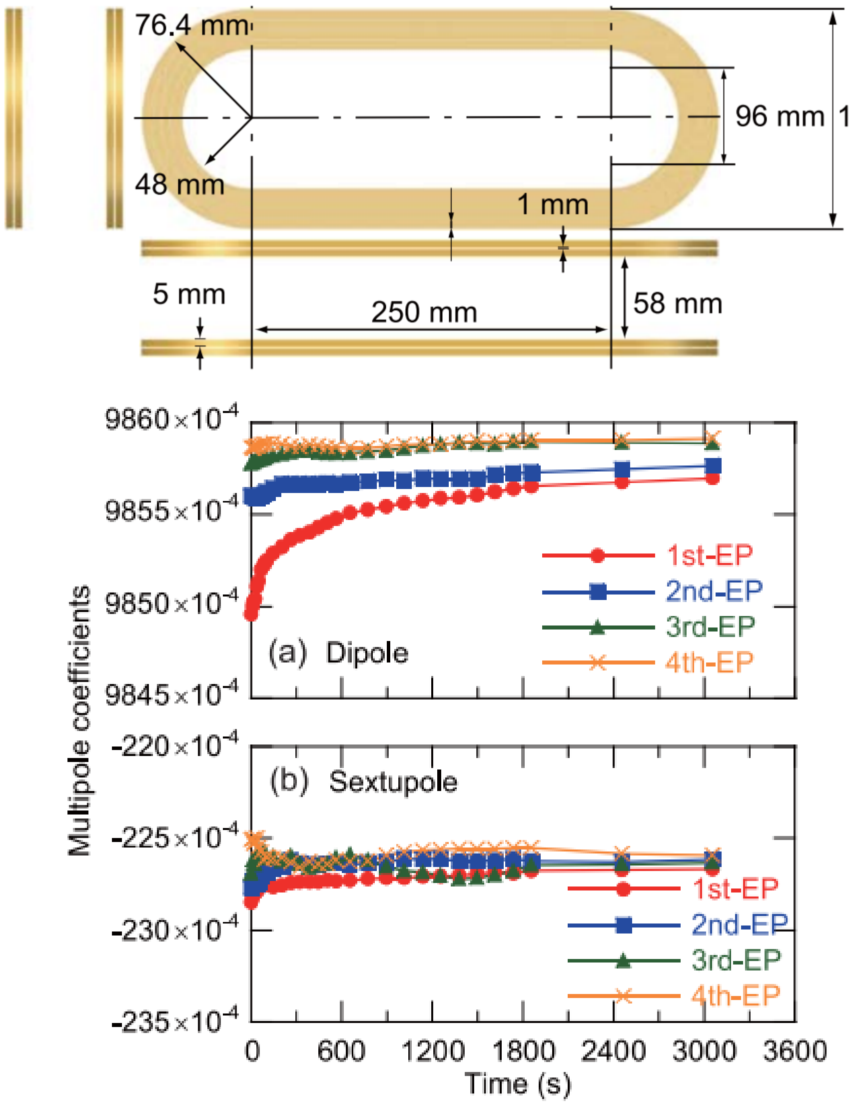
Conclusion:

- The error field caused by SC is **5.55×10^{-2} T**;
- The relative error is **0.182 %**.

The field decay is **3 orders** of magnitude larger than the requirement of NMR.

Ugliette-2010-SST-Measurements of magnetic field induced by screening currents in YBCO solenoid coils

DIPOLE MAGNETS



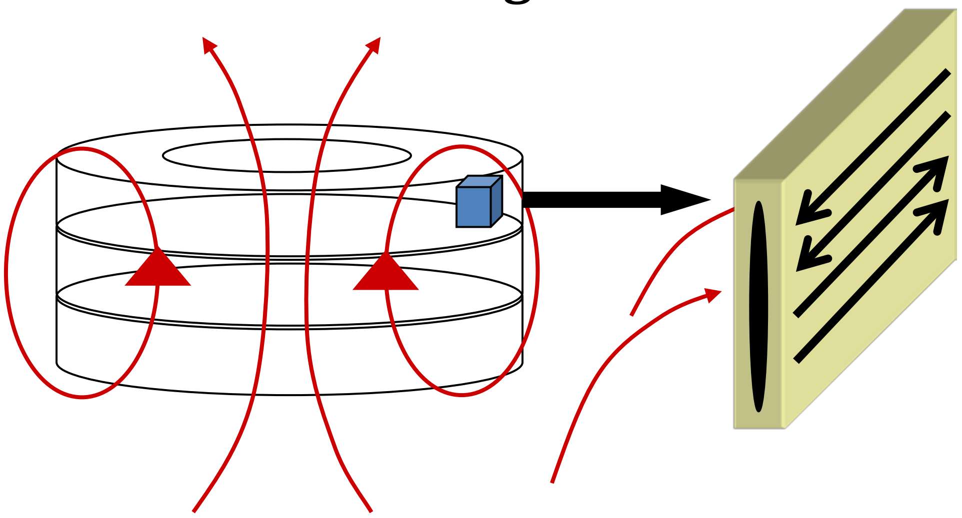
Dipole Magnet Made of ReBCO Coated Conductor

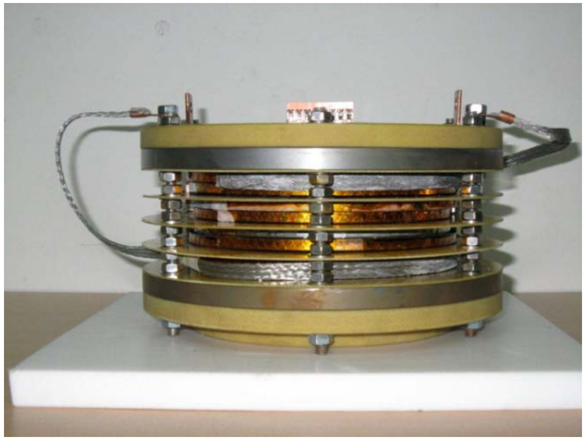
Conclusion:

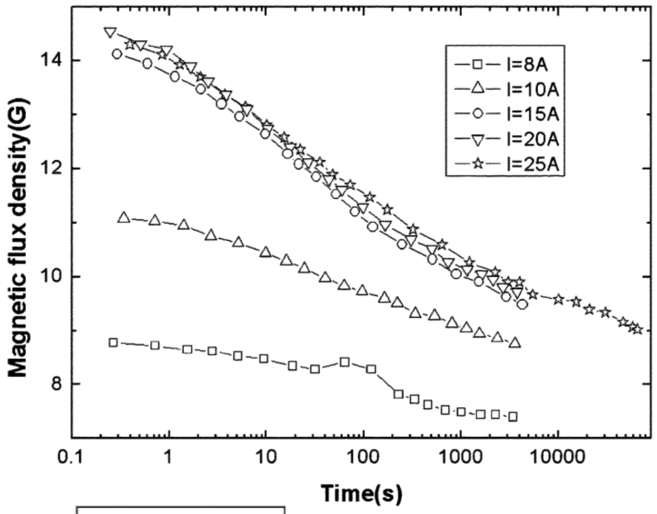
- Different temporal behaviour in **dipole** and **sextupole** components.
- An excitation with a **larger** current substantially influences multipole components in **later, smaller**-current excitations.

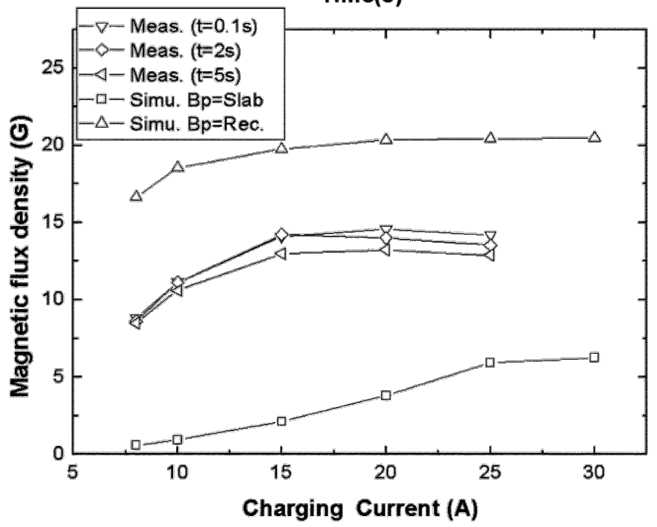
Amemiya-2015-SuST-Temporal behaviour of multi-pole components of the magnetic field in a small dipole magnet wound with coated conductors

Residual Field Caused by Screening Current in HTS Magnets



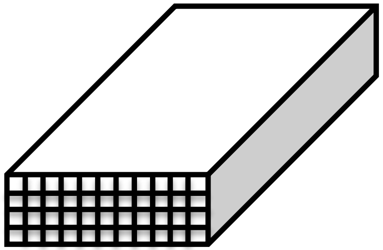






ChenGu-2007-IEEE-Measurement and Calculation of Residual Magnetic Field in a Bi2223/Ag Magnet

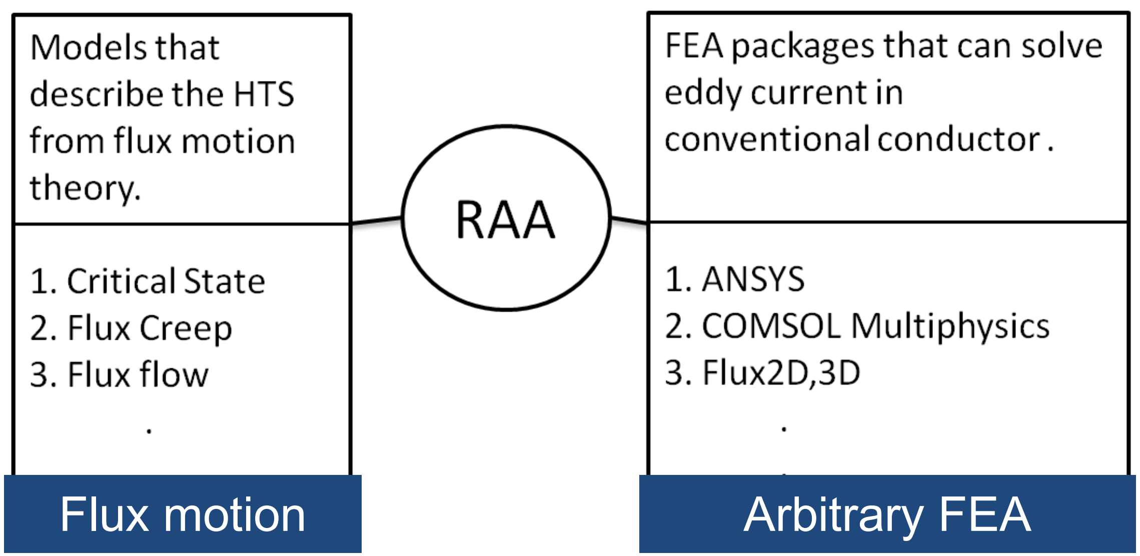
RESISTIVITY ADAPTION ALGORITHM

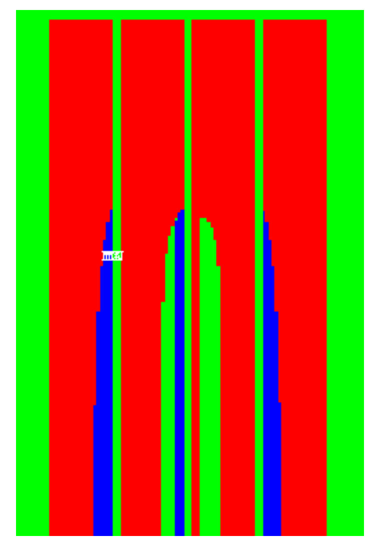


"Resistivity Adaption" Algorithm: The superconductor is simulated by using a field diffusion process in a conventional conductor, which is divided into elements that have local resistivity.

HISTORY

- Chen Gu *et al*, *IEEE Trans. Appl. Supercond.*, vol.15, 2005. （First proposed in 2004）
- S. Farinon *et al*, *Supercond. Sci. Technol.* vol. 23, 2010. (Improve calculation efficiency greatly)
- Chen Gu *et al*, *IEEE Trans. Appl. Supercond.*, vol.23, 2013. （Theoretical difficulty of the RAA was solved ）





WIDE TAPE VS ROUND WIRE

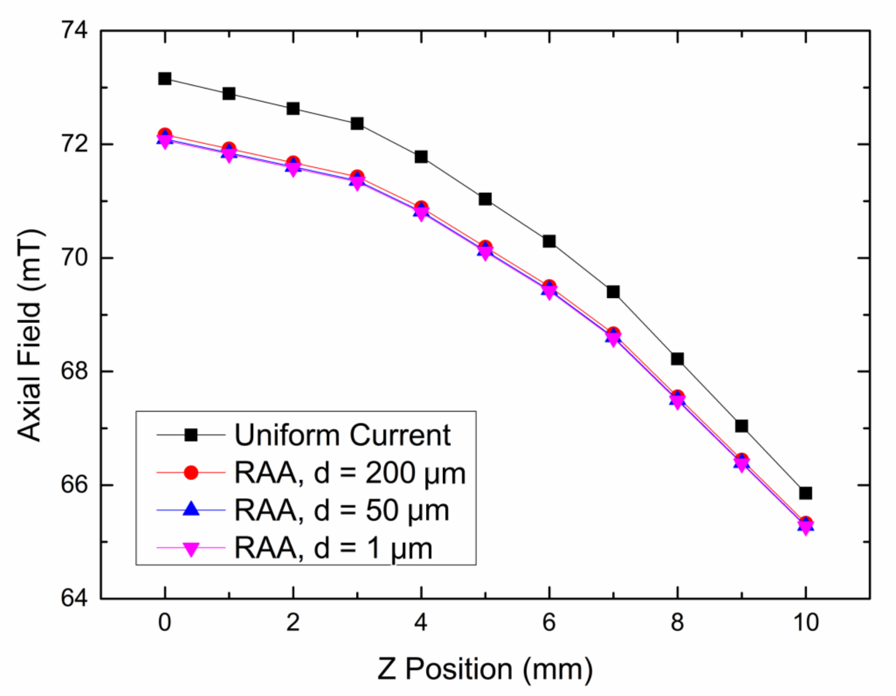
	Rectangular Tape	Round Wire
Example	YBCO Tape	MgB_2 Wire
SC Filament	Width: 4 mm	Φ 0.39 mm
Supposed I_c	200 A	200 A
Operating I_{op}	100 A	100 A
Inner R of coil	30 mm	30 mm
Turn Number	10×4	8×6
Central Field	~ 72.1 mT	~ 92.7 mT

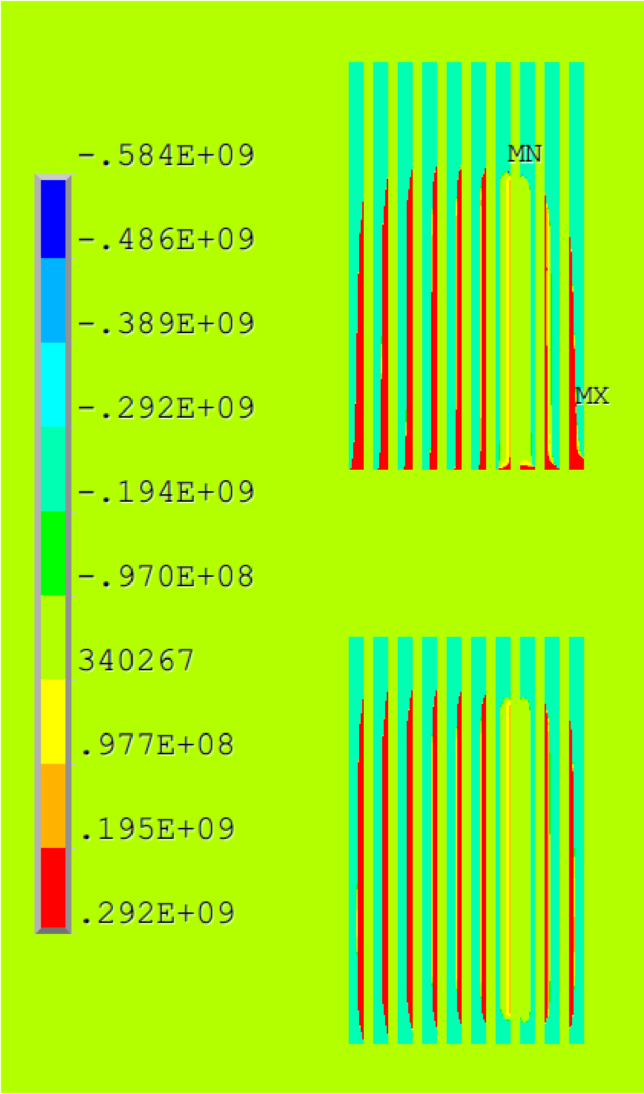
The calculation was based on **Bean model**. Flux creep is ignored, and decay of screening current is not considered.

MAGNET MADE OF HTS TAPE

Preliminary Conclusions:

- The relative error caused by SCF is **1.35% (13,500ppm)**.
- Current distribution in the tape width is the main factor that cause the difference of the field.

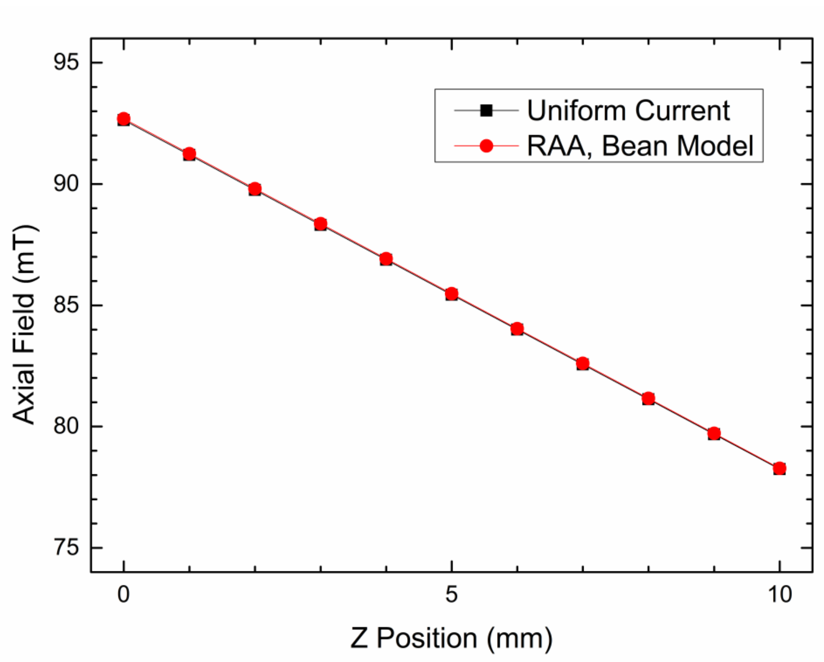


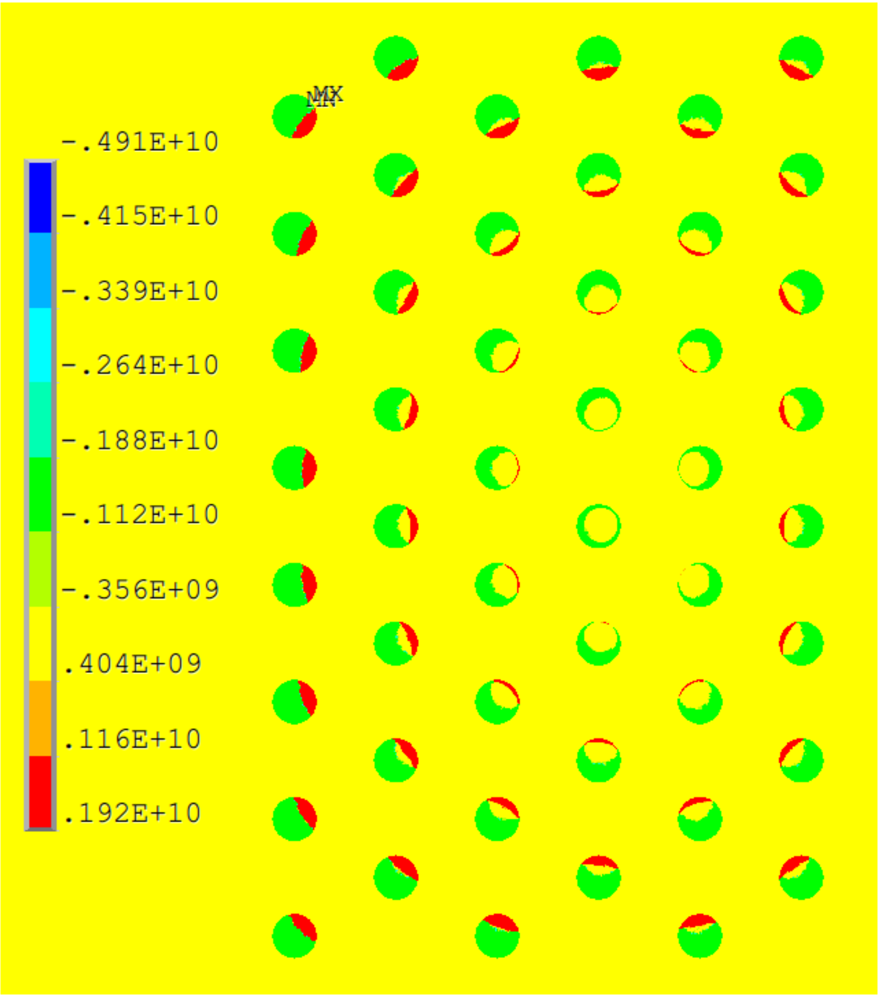


MAGNET MADE OF ROUND WIRE

Preliminary Conclusions:

- The relative error caused by SC is **0.059% (590ppm)**.

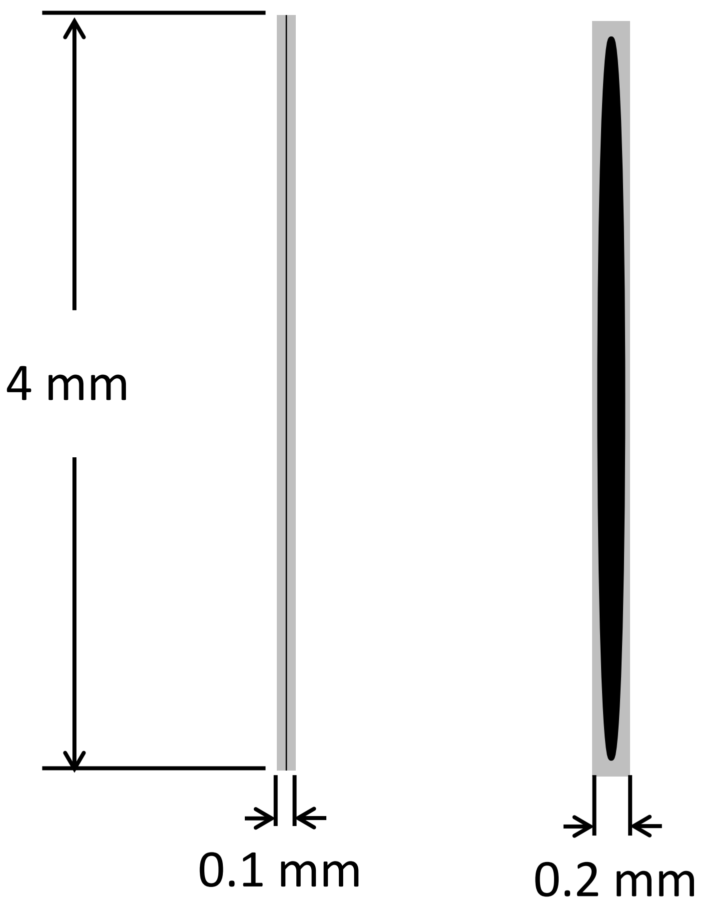




WIDE TAPE VS ROUND WIRE

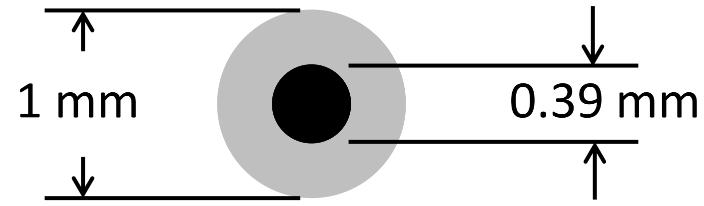
Rectangular Tape

YBCO Tape BSCCO Tape

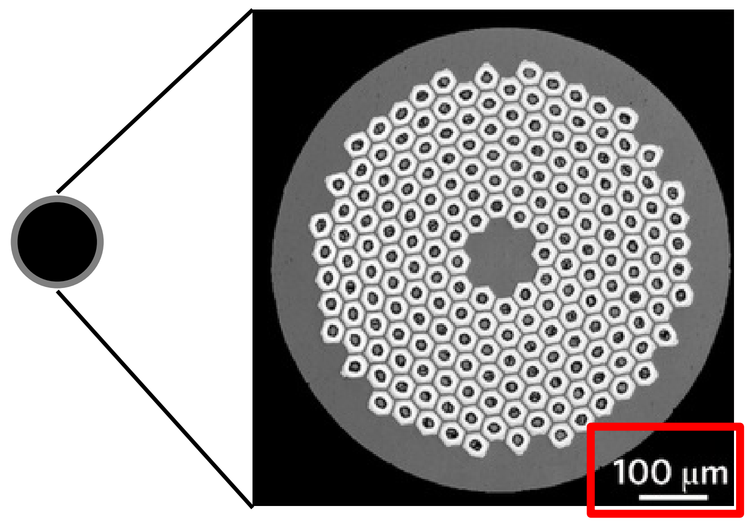


Round Wire

MgB_2 Wire

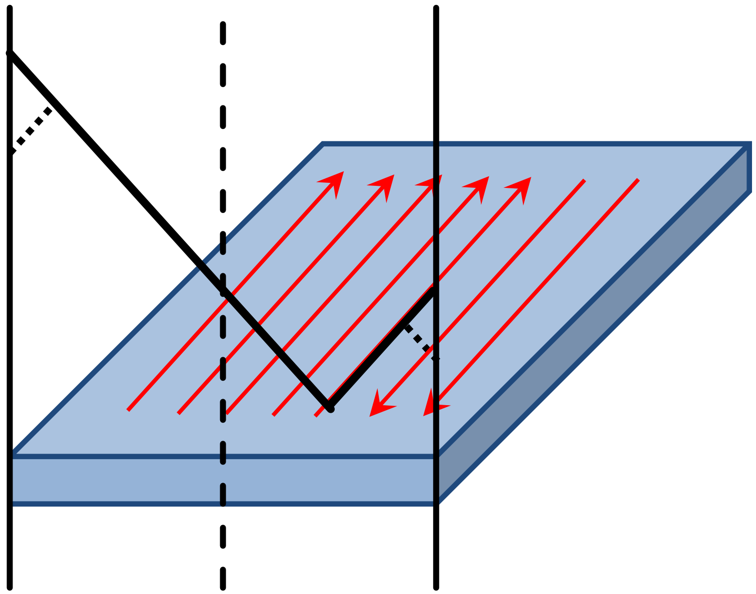


Nb_3Sn Wire



Methods to Help Reducing the Screening Current Field

Ramp up the magnet current to a higher level and then reduce it to the operating current.



Methods to reduce AC loss may also be helpful to reduce the SCF.

SUMMARY

- Screening current affects the magnetic field in both stability and uniformity; For magnets need high stability and uniform field, the influence of screening current in HTS may be a serious issue;
- Screening current field dependents on the scale of the cross section of superconducting wire;
- Screening current may cause a field drift of over **1 %** in magnets made of coated conductor;
- It is possible to control or reduce screen current field;
- In Tsinghua University, **Resistivity Adaption Algorithm** is developed as a powerful tool to simulate the screening current.

REFERENCES

[1] **Maeda**-2014-IEEE-Recent Developments in High-Temperature Superconducting Magnet Technology

[2] **GuChen**-2007-IEEE-Measurement and Calculation of Residual Magnetic Field in a Bi2223/Ag Magnet

[3] **Miyazoe**-2012-IEEE-Magnetic Field Distribution Generated by Screening Current Flowing in Coated Conductor Arranged Edge-By-Edge and/or Face-To-Back

[4] **Yanagizawa**-2011-IEEE-Magnitude of the Screening Field for YBCO Coils

[5] **Yang**-2013-SUST-Screening current-induced field in non-insulated GdBCO pancake coil

[6] **Ueda**-2014-IEEE-Measurement and Simulation of Magnetic Field Generated by Screening Currents in HTS Coil

[7] **Amemiya**-2008-SUST-Magnetic field generated by shielding current in high Tc superconducting coils for NMR magnets

[8] **Ugliette**-2010-SST-Measurements of magnetic field induced by screening currents in YBCO solenoid coils

[9] **Yanagisawa**-2010-IEEE-Effect of YBCO-Coil Shape on the Screening Current-Induced Magnetic Field Intensity

[10] **Otsuka**-2011-IEEE-Evaluation of the Screening Current in a 1.3 GHz NMR Magnet Using ReBCO

[11] **Amemiya**-2015-SUST-Temporal behaviour of multi-pole components of the magnetic field in a small dipole magnet wound with coated conductors

[12] **GuChen**-2004-IEEE-Calculation of AC Losses in HTS Tape With FEA Program ANSYS

[13] **GuChen**-2013-IEEE-AC Losses in HTS Tapes and Devices With Transport Current Solved Through the Resistivity-Adaption Algorithm

[14] **GuChen**-2014-IEEE-Simulation of Current Profile and AC Loss of HTS Winding Wound by Parallel-Connected Tapes

THANKS

For Your Attention