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ASC 2016 paper 1SPOr1A-03. ASC Best Student Paper Contest (Large Scale) Third Prize Winner.

Screening Current-Induced Magnetic Field in a Non-Insulated GdBCO HTS coil for the 24 T All-Superconducting Magnet

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Outline

- Motivation and Background
- Simulation Model and Method
- Experiment Setup
- Results
- Conclusion

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Motivation and Background

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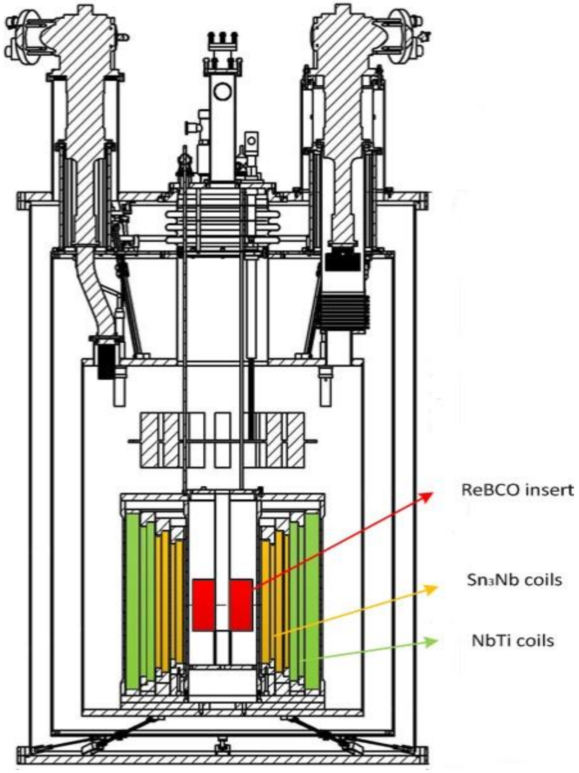
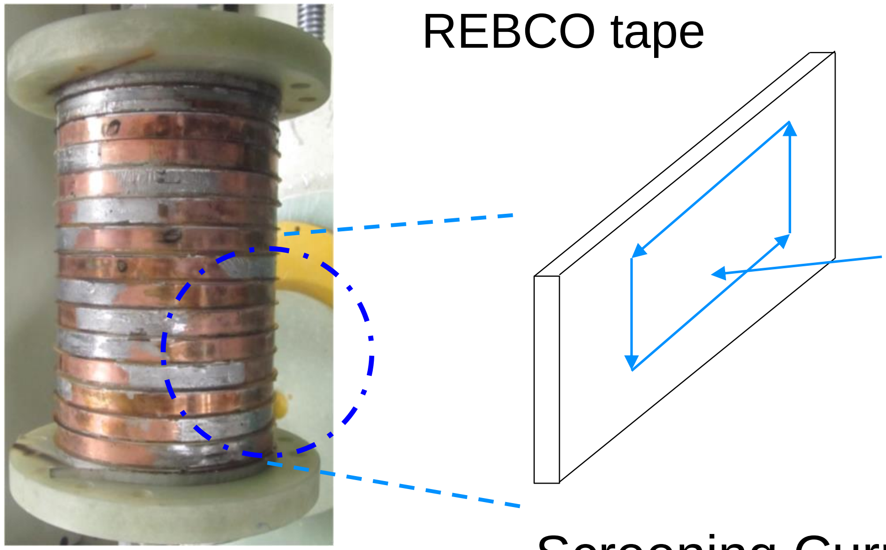


Motivation and Background



REBCO HTS insert

External Magnetic Field:

- LTS Outsert
- Other turns in the HTS Insert

Screening Current Deterioration:

- Field Reduction (central)
- Field Homogeneity
- Field Repeatability : charge and discharge
- Temporal Stability : flux creep motion

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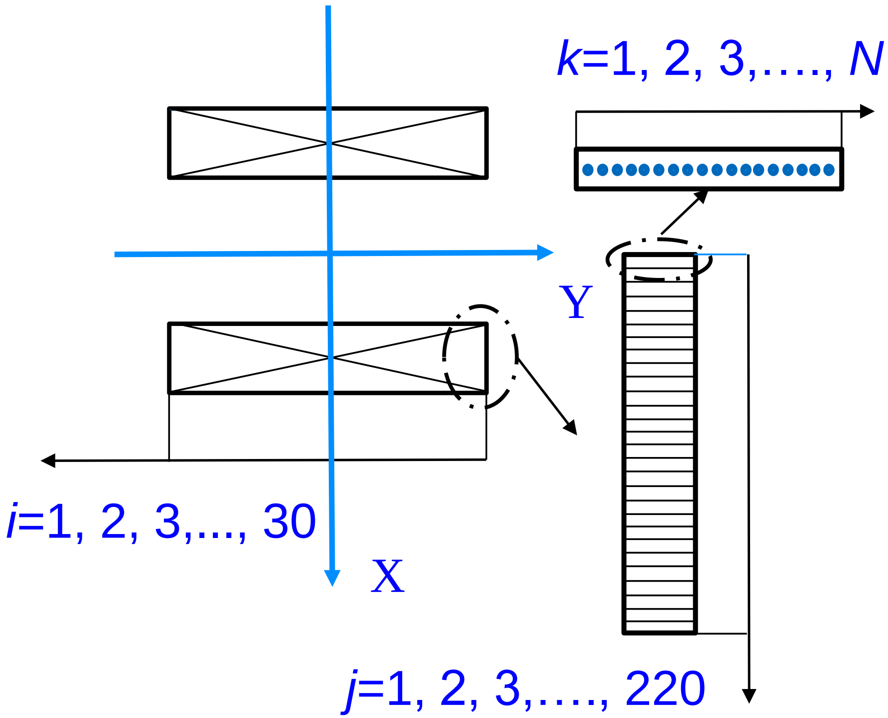
Simulation Model and Method



Simulation Model of HTS insert

Specifications of HTS insert

Parameter	Value
Inner Diameter	32 mm
Outer Diameter	104 mm
Coil Height	150 mm
Turns per DP	220*2
Number of DP	15
B_0 per Ampere	0.055 T
Max Br	3.72

Simulation Model and Method

Only charging I_t in the HTS (I_t and $B_r(i,j)$)

$$J(i,j,k) = \frac{J_c(i,j)}{\pi}[H - L + \pi] \qquad |y_0(i,j,k) - p| < a$$

$$J(i,j,k) = J_c(i,j) \qquad a < |y_0(i,j,k) - p| < w_0$$

$$H = \arcsin\left(\frac{(y(i,j,k)-p)\cdot(w_0 - p) - a^2}{a\cdot(w_0 - y(i,j,k))}\right)$$

$$L = \arcsin\left(\frac{(y(i,j,k)-p)\cdot(w_0 + p) + a^2}{a\cdot(w_0 + y(i,j,k))}\right)$$

$$J(i,j,k) = \frac{J_c(i,j)}{\pi}[H + L] \qquad |y_0(i,j,k) - p| < a$$

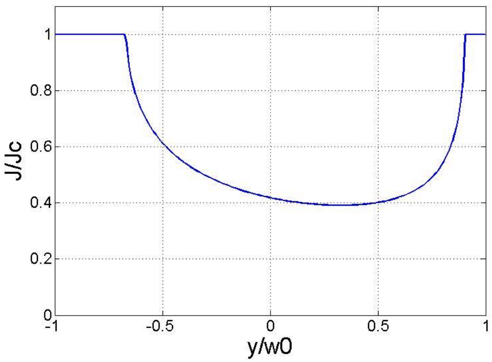
$$J(i,j,k) = J_c(i,j) \qquad -w_0 < y_0(i,j,k) < p - a$$

$$J(i,j,k) = -J_c(i,j) \qquad p + a < y_0(i,j,k) < w_0$$

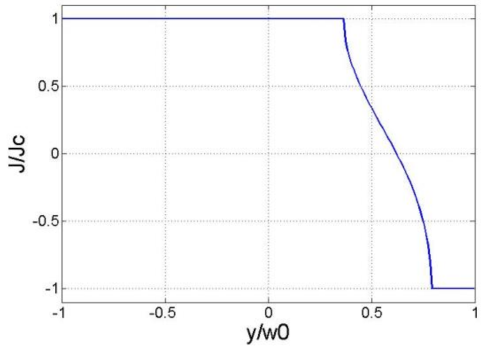
$$p = w_0(I_t / I_c(i,j))\tanh(B_r(i,j)/B_p(i,j))$$

$$a = (w_0 / \cosh(B_r(i,j)/B_p(i,j)))\sqrt{1 - (I_t / I_c(i,j))}$$

Criterion $m(i,j) = \dfrac{I_t}{I_c(i,j)} - \tanh\left(\dfrac{B_r(i,j)}{B_p(i,j)}\right)$



$m(i,j)>0$



$m(i,j)<0$

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Simulation Model and Method

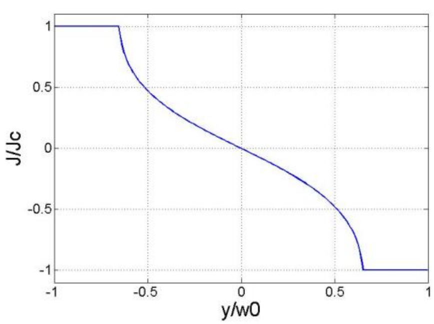
First, Charging the LTS Outsert ($B_1(i,j)$)

$$J_1(i,j,k) = \frac{-2J_{c(i,j)}}{\pi} \cdot \arctan\left(\frac{y(i,j,k)}{w_0}\sqrt{\frac{w_0^2 - a_1^2}{a_1^2 - y(i,j,k)^2}}\right) \quad -a < y(i,j,k) < a$$

$$J_1(i,j,k) = -J_{c(i,j)} \qquad a_1 < y(i,j,k) < w_0$$

$$J_1(i,j,k) = J_{c(i,j)} \qquad -w_0 < y(i,j,k) < -a_1$$

$$a_1 = w_0 / \cosh(B_1(i,j)/B_p(i,j))$$



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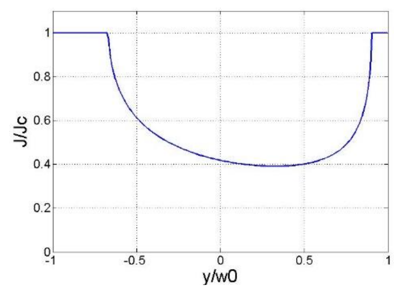

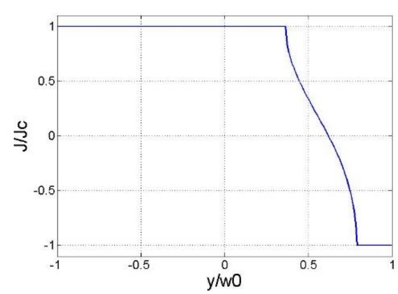

Second, Charging the HTS Insert:

$J = J_{LTS} + J_{HTS}$?

NO! The conductor is not from a virgin state

Simulation Model and Method

LTS First, HTS Second ($I_2(i,j)$ and $B_2(i,j)$, $m_2(i,j)>0$)

$-a<y(k_1)<p_2-a_2$ $p_2-a_2<y(k_2)<p_2+a_2$, $p_2+a_2<y(k_3)<w_0$

$$J_2(k_1)=J_c(i)-J_1(k_1) \qquad -a<y(k_1)<p_2-a_2$$

$$J_2(k_3)=J_c(i)-J_1(k_3) \qquad p_2+a_2<y(k_3)<w_0$$

$$J_2(k_2)=\int_A \frac{-J_2(k_1)}{\pi}\left[\arcsin\left(\frac{\alpha(\beta+\kappa)+2Ma_2}{\gamma+\kappa}\right)-\arcsin\left(\frac{\alpha(\beta-\kappa)+2Ma_2}{\gamma-\kappa}\right)\right]$$

$$+\int_C \frac{J_2(k_3)}{\pi}\left[\arcsin\left(\frac{\alpha(\beta_1+\kappa_1)-2Ma_2}{\gamma_1+\kappa_1}\right)-\arcsin\left(\frac{\alpha(\beta_1-\kappa_1)-2Ma_2}{\gamma_1-\kappa_1}\right)\right]$$

$$\alpha=2M(y(k_2)-p_2)$$

$$\beta=2M(y(k_1)-p_2) \qquad \beta_1=2M(y(k_3)-p_2)$$

$$\kappa=w_0+p_2-a_2 \qquad \kappa_1=w_0-p_2-a_2$$

$$\gamma=2M(y(k_1)+y(k_2)) \qquad \gamma_1=2M(y(k_3)-y(k_2))$$

$$I_t=\frac{2w_0d_0}{N}\int_{-w_0}^{w_0} J_2(k)$$

$$-B_2(i,j)=\frac{\mu_0 d_0}{2\pi}\int_{-w_0}^{w_0}\frac{J_2(k)}{y(k)-p_2}$$

p_2 and a_2

$$J_3(i,j,k)=J_1(i,j,k)+J_2(i,j,k)$$

Simulation Model and Method

Central Field Reduction

$$B_c = \sum B_c(i,j,k) = \sum_{\substack{i=1:1:30 \\ j=1:1:220}} \frac{\mu_0 J(i,j,k) w_0 d_0 x(i,j,k)^2}{N(x(i,j,k)^2 + y(i,j,k)^2)^{3/2}}$$

$$B_i = I_t * B_0$$

$$B_{fr} = B_c - B_i$$

B_0- axial filed per ampere at center 0.055 T/A

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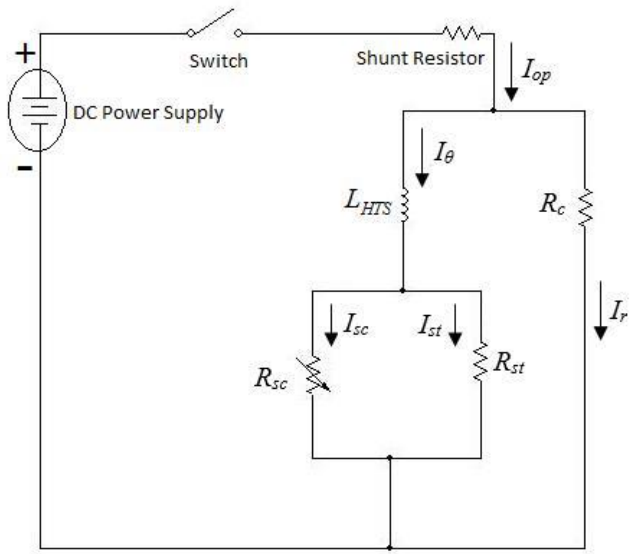
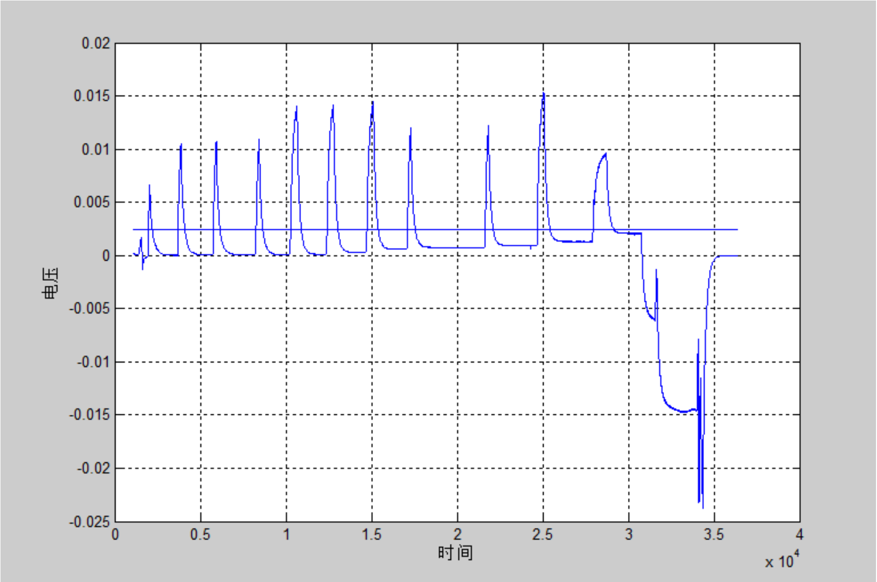
Experiment Setup

Equivalent Circuit Model





$$L_{HTS}\frac{dI_\theta}{dt} = I_r R_c$$

$$I_\theta + I_r = I_{op}$$

τ =69 s

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Experiment Setup

Charging Test

- Charging HTS insert only: series I (0 A -160 A)
- Charging HTS insert only: series II (0 A - 200 A)
- Charging the LTS outsert with central field of 10.72 T, and then the HTS insert
- Charging the LTS outsert with central field of 15 T, and then the HTS insert

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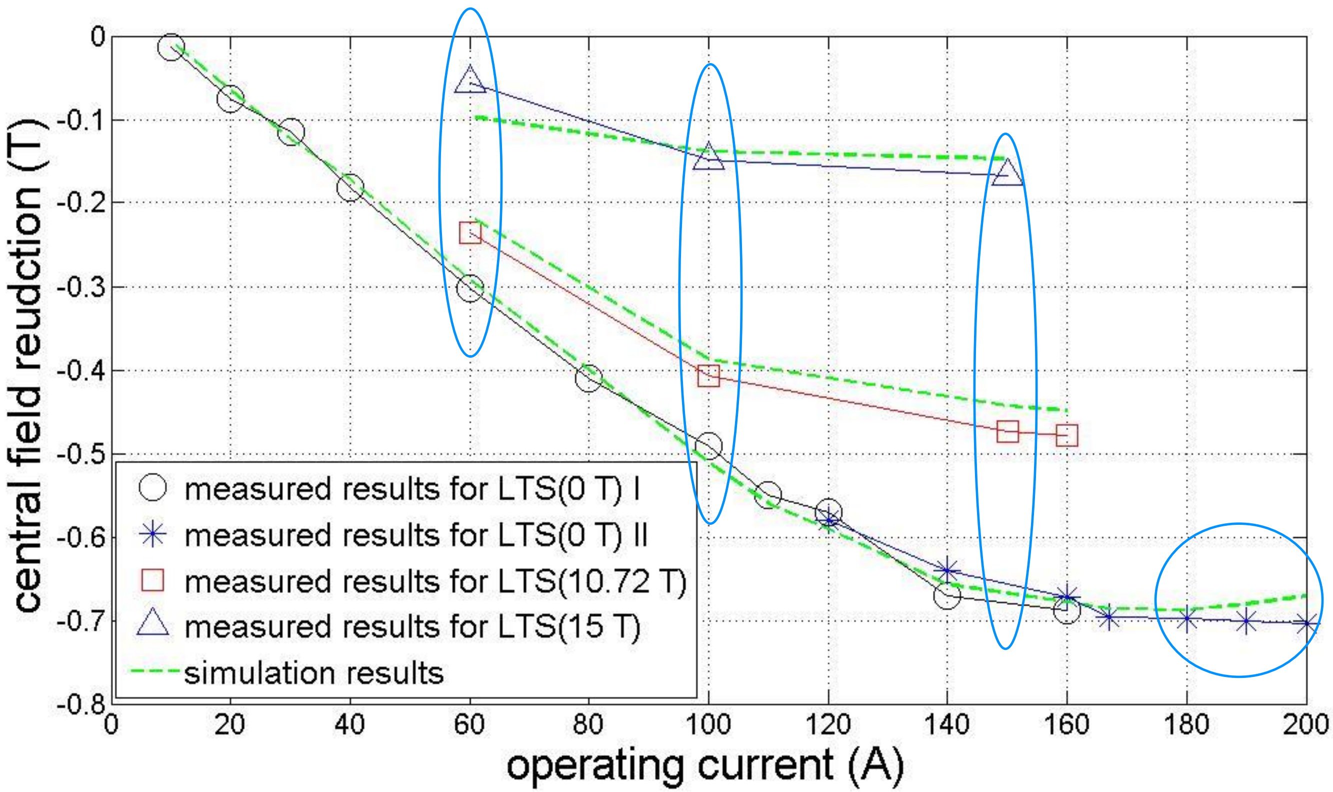
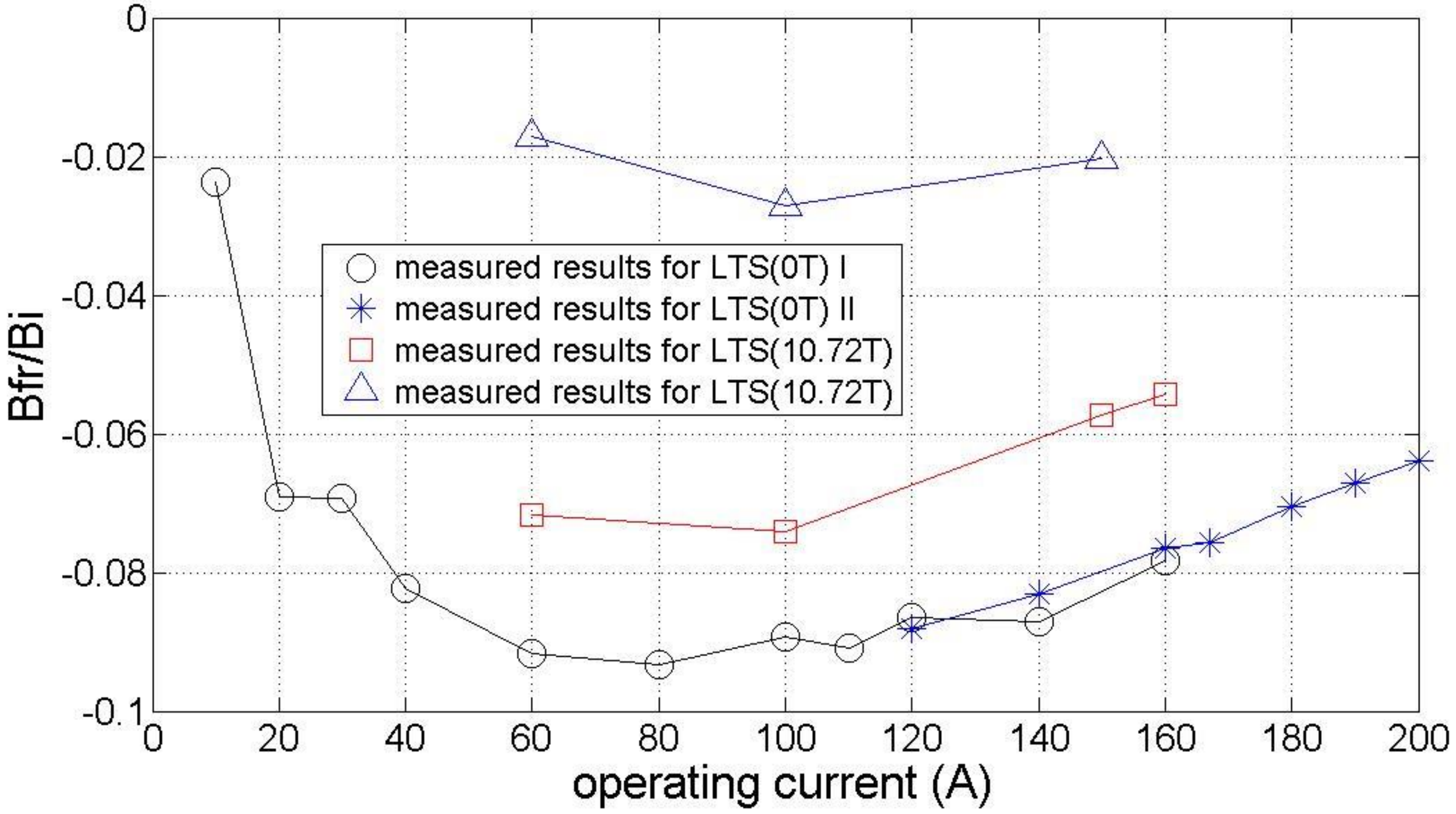
Results



Results


0
-0.02
-0.04
-0.06
-0.08
-0.1
Bfr/Bi
0
20
40
60
80
100
120
140
160
180
200
operating current (A)
measured results for LTS(0T) I
measured results for LTS(0T) II
measured results for LTS(10.72T)
measured results for LTS(10.72T)

Conclusions

- B_{fr} is studied by the simulation results and experimental data, which show a good agreement.
- B_{fr} is not affected by the ramping rate of the operation current.
- The reduction of B_{fr} is as large as 75% when the central field of LTS outsert increases to 15 T.

Thank you