Temperature Effects on High-Temperature Superconducting Flux Conservers for the PFRC Experiment

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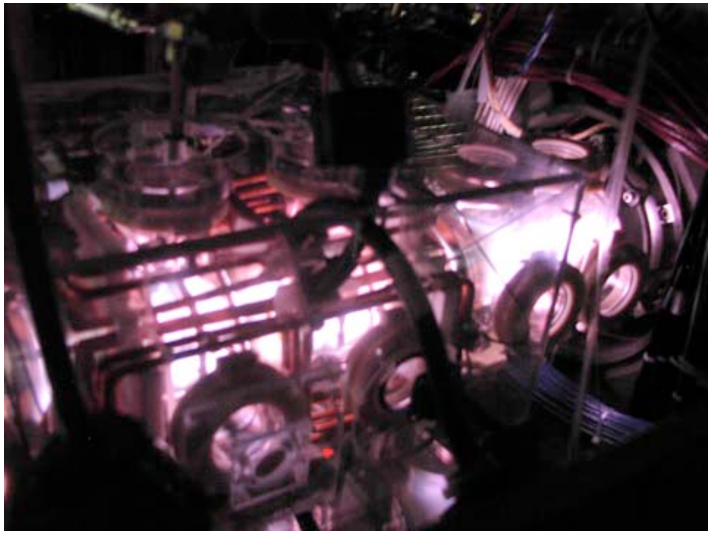
THE PFRC

- The Princeton Field Reversed Configuration (PFRC) experiment is a plasma physics and fusion science research device aimed at developing a van-sized fusion reactor.

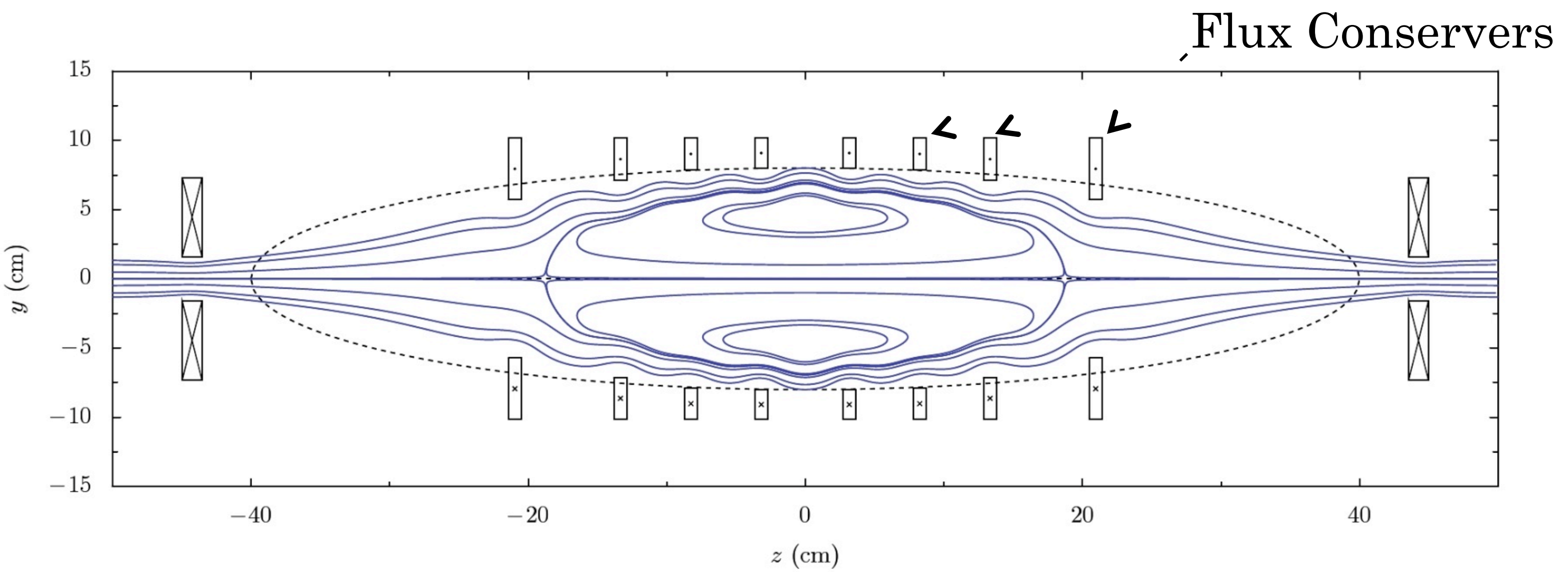
- The PFRC uses rotating magnetic fields induced by radio-frequency antennae to form and heat plasma.

- As the plasma gets hotter and its pressure rises, it tries to push magnetic fields away from it.



Flux Conservers

- The PFRC uses flux conservers (FCs), conducting rings, to magnetically confine plasma.
- The length of time which the flux conservers can contain the plasma after a pulse is governed by the skin time: $\tau = L/R$. In the present PFRC, $\tau = 3$ ms. The goal for the next PFRC is $\tau > .1$ s.
- Low resistance and high inductance are the key components of achieving high skin times.



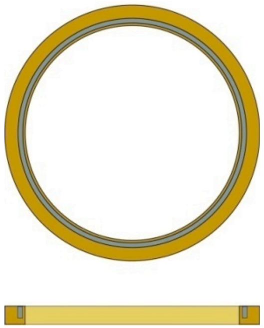
Flux Conservers

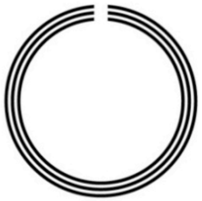
- High temperature superconductors are planned for use in the next PFRC's flux conservers, but their performance, particularly maximum current carried, is strongly dependent on temperature.

- The superconductor (BSCCO) has a critical temperature of 95 K for the 2223 subtype and 105-110 K for the 2212 subtype.

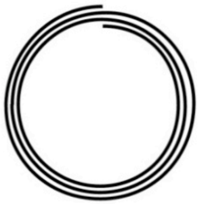
- The critical currents for the tapes used were 62.4 A and 160 A.

- In order to design the next PFRC, we need to know how cold the flux conservers should be in order to operate for the desired length of time; this will give the design parameters for the cooling system.

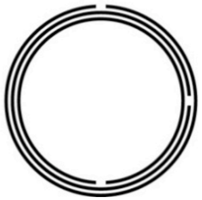




Aligned



Spiral



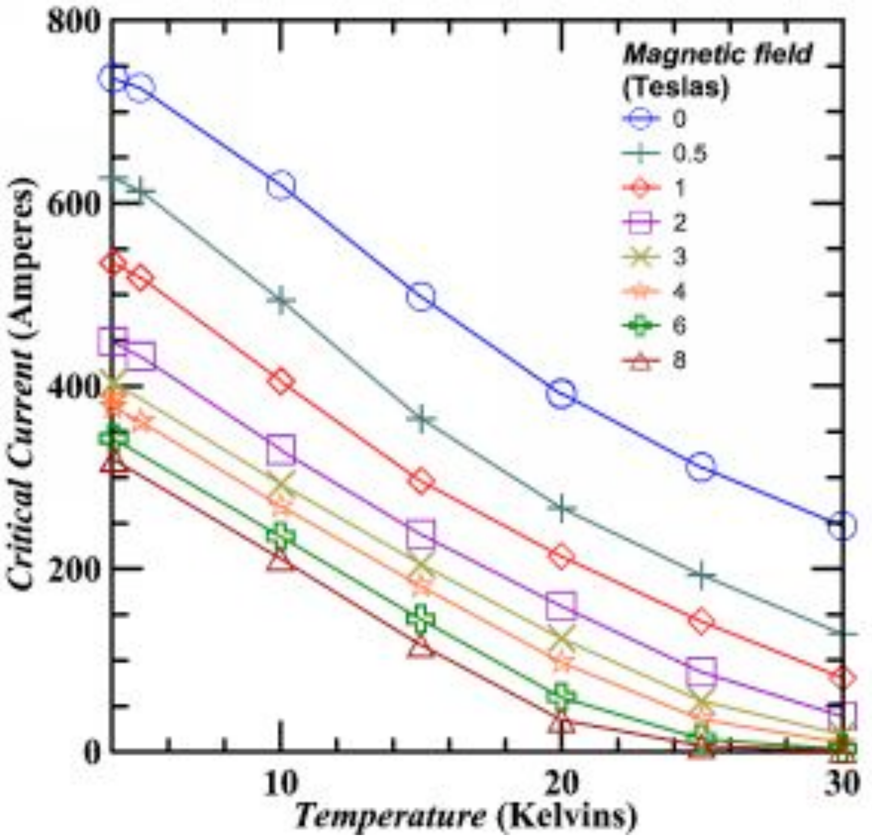
Staggered

Goals of The Project

- Determine critical current and skin time dependence on temperature
- Develop, build, and operate experimental apparatus for testing new, larger flux conservers
- Test larger flux conservers with more turns of tape and different winding patterns
- Determine the physical mechanism for current decay in the flux conservers

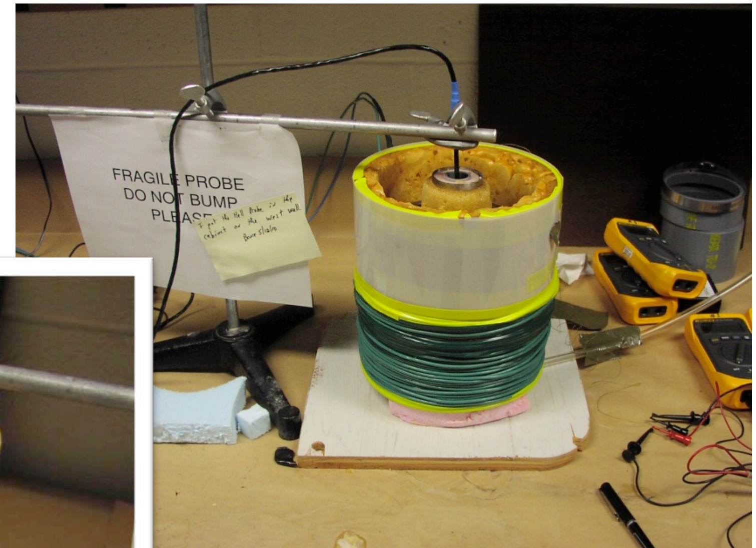
What is the Critical Current?

- Current above which superconductor loses superconductivity
- The critical current is dependent on temperature: higher temperatures mean a lower critical current.
- If we go above the critical current, we lose some of the benefits of having superconductor embedded in the flux conserver.

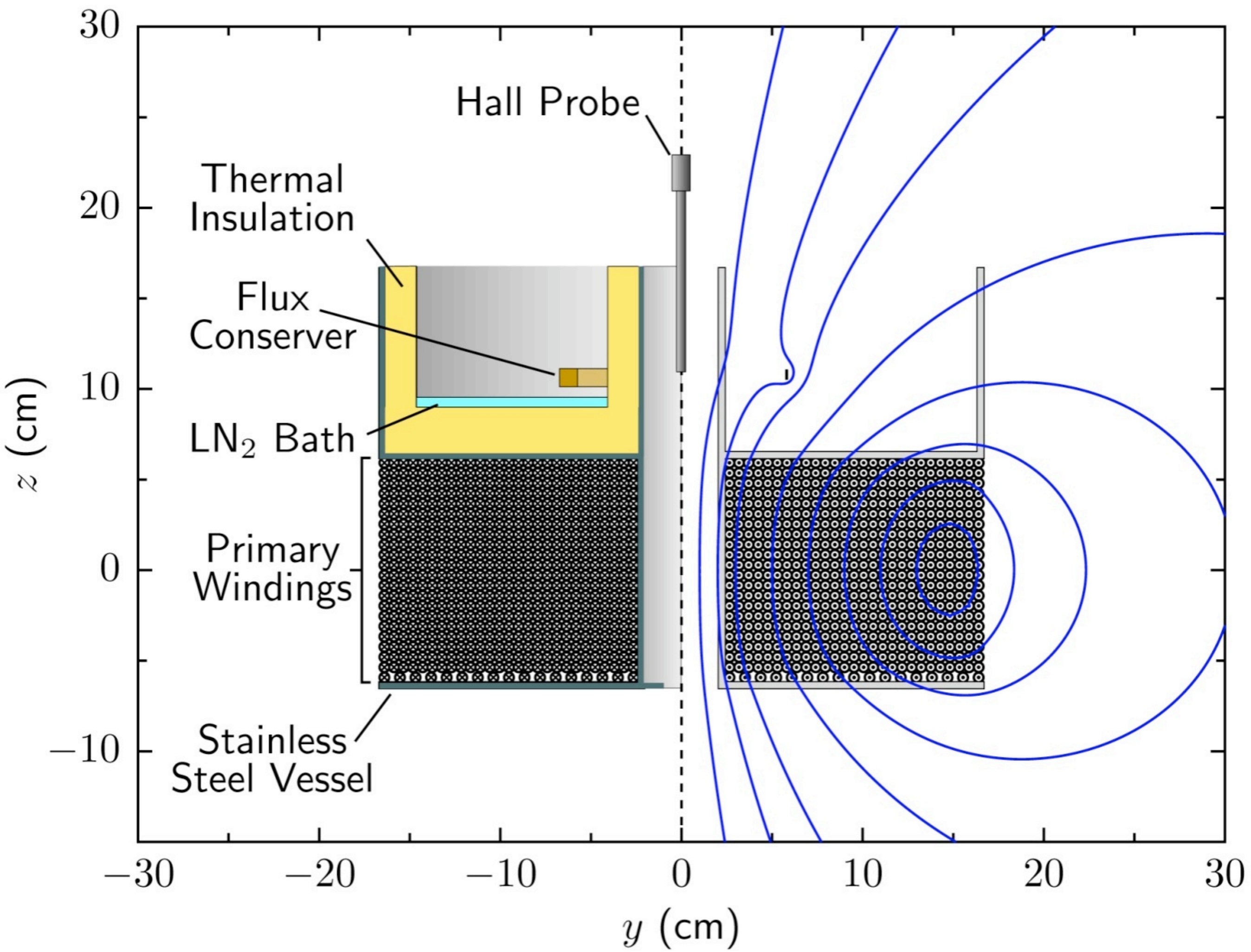


National Institute of Standards and Technology. http://www.nist.gov/eeel/electromagnetics/magnetics

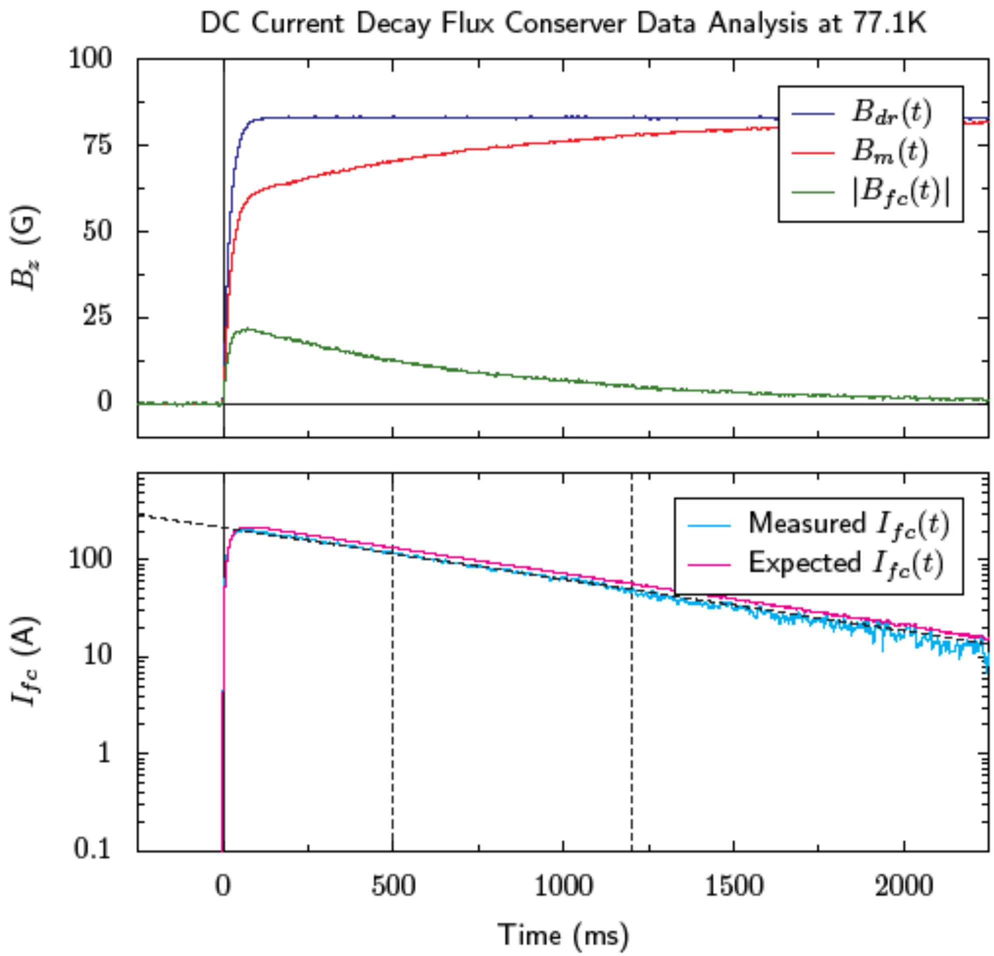
THE EXPERIMENTAL APPARATUS



The Experimental Apparatus



Aligned Superconducting FC Below its Critical Current



$$t_{fit,1} = 500.0 \text{ ms}$$
$$t_{fit,2} = 1200.0 \text{ ms}$$

$$M_{dr,fc} = 1.0776 \times 10^{-5} \text{ H}$$
$$L_{fc} = 3.0080 \times 10^{-7} \text{ H}$$

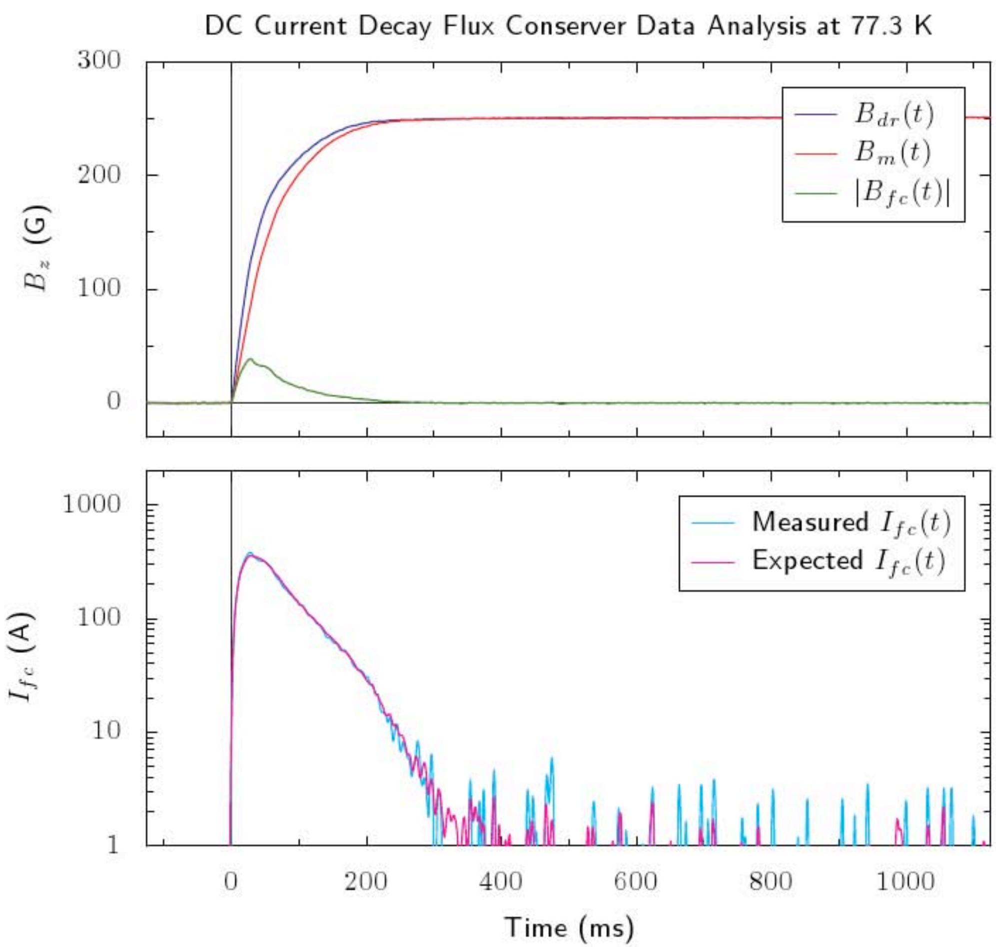
$$c_{dr} = 8.0963 \times 10^{-2} \text{ A/G}$$
$$c_{fc} = 0.9339 \times 10^{1} \text{ A/G}$$

$$\tau_{dr} \simeq 19.3 \text{ ms}$$
$$\tau_{fc} \simeq 817.9 \text{ ms}$$
$$t_{cr} \simeq 120.0 \text{ ms}$$

$$I_{dr,0} \simeq 6.7 \text{ A}$$
$$I_{fc,0} \simeq 215.3 \text{ A}$$
$$I_{cr} \simeq 185.9 \text{ A}$$
$$I_{tape} = 64.2 \text{ A}$$

$$\frac{I_{cr}}{I_{tape}} \simeq 2.896$$

Solid Copper FC



$t_{fit,1} = 200.0$ ms
$t_{fit,2} = 280.0$ ms

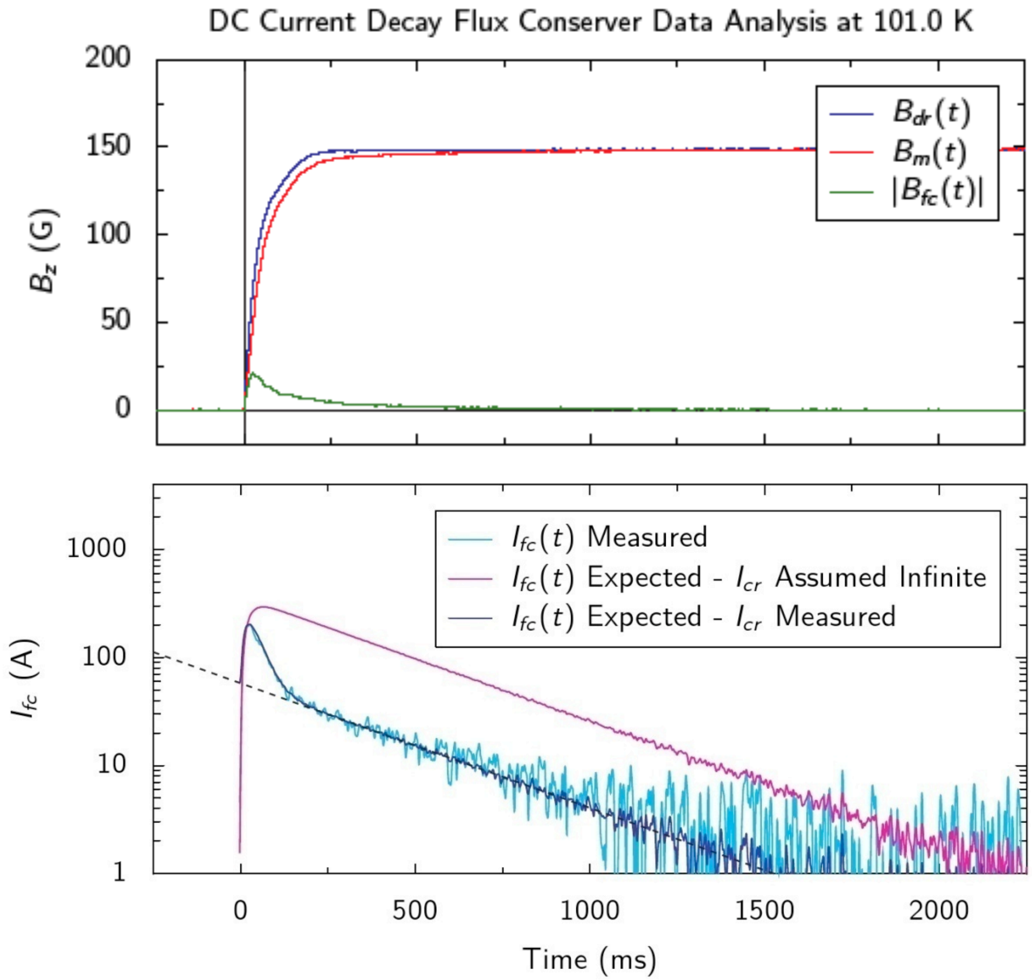
$M_{dr,fc} = 1.1972 \times 10^{-5}$ H
$L_{fc} = 2.0740 \times 10^{-7}$ H

$c_{dr} = 8.1889 \times 10^{-2}$ A/G
$c_{fc} = 0.9859 \times 10^{1}$ A/G

$\tau_{dr} \simeq 40.9$ ms
$\tau_{fc} \simeq 42.9$ ms
$\tau_{fit} = 28.0$ ms <

$I_{dr,0} \simeq 20.6$ A
$I_{cr} \simeq 182.4$ A
$I_{max} = 382.1$ A

Aligned Superconducting FC Above Critical Current



$$t_{fit,1} = 500.0 \text{ ms}$$
$$t_{fit,2} = 1200.0 \text{ ms}$$

$$M_{dr,fc} = 1.0542 \times 10^{-5} \text{ H}$$
$$L_{fc} = 3.0080 \times 10^{-7} \text{ H}$$

$$c_{dr} = 8.0963 \times 10^{-2} \text{ A/G}$$
$$c_{fc} = 0.9339 \times 10^{1} \text{ A/G}$$

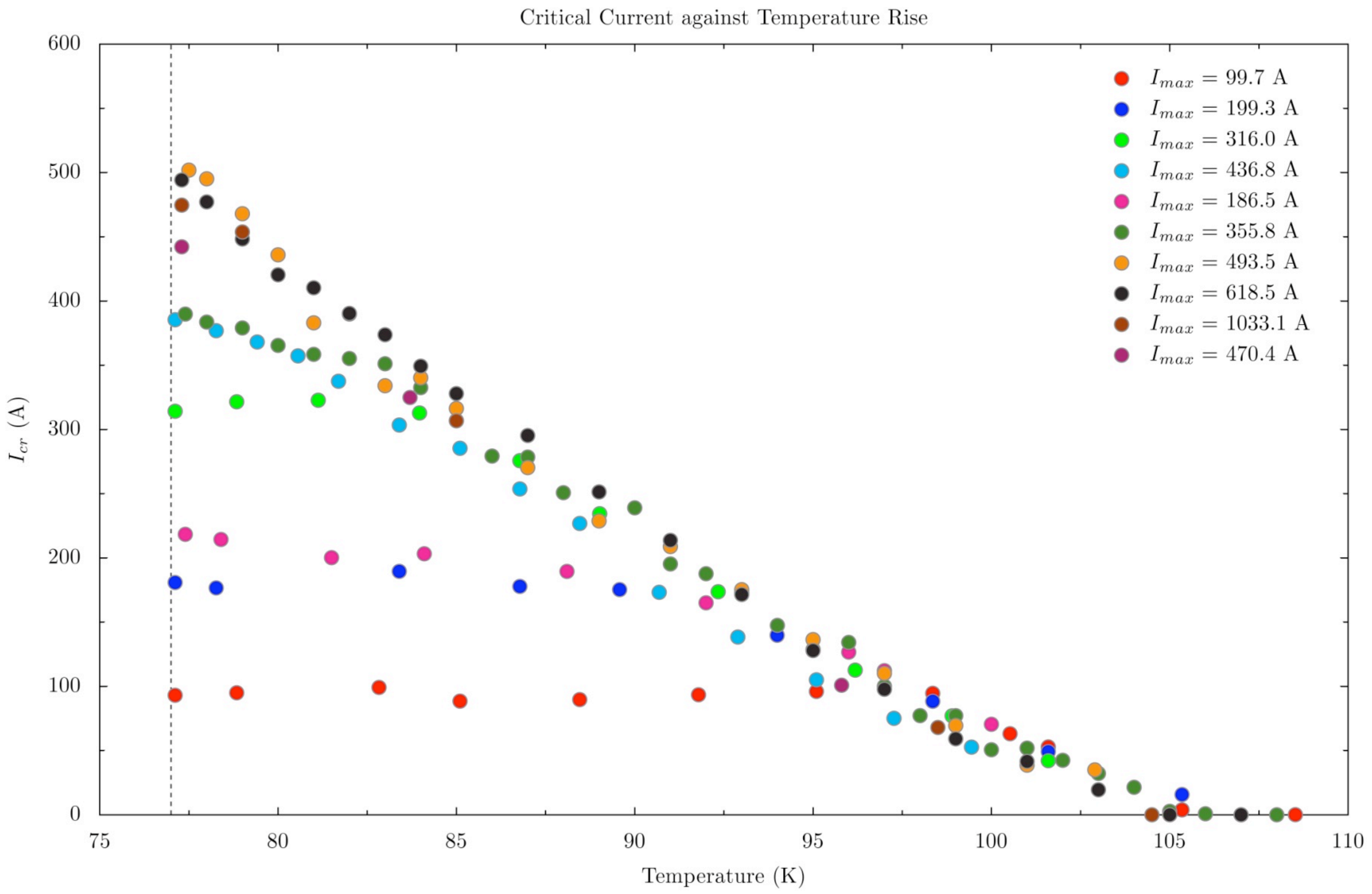
$$\tau_{dr} \simeq 39.6 \text{ ms}$$
$$\tau_{fc} \simeq 418.8 \text{ ms}$$
$$\tau_{Cu} \simeq 28.0 \text{ ms}$$
$$t_{cr} \simeq 120.0 \text{ ms}$$

$$I_{dr,0} \simeq 12.0 \text{ A}$$
$$I_{fc,0} \simeq 70.7 \text{ A}$$
$$I_{cr} \simeq 53.1 \text{ A}$$
$$I_{tape} = 64.2 \text{ A}$$

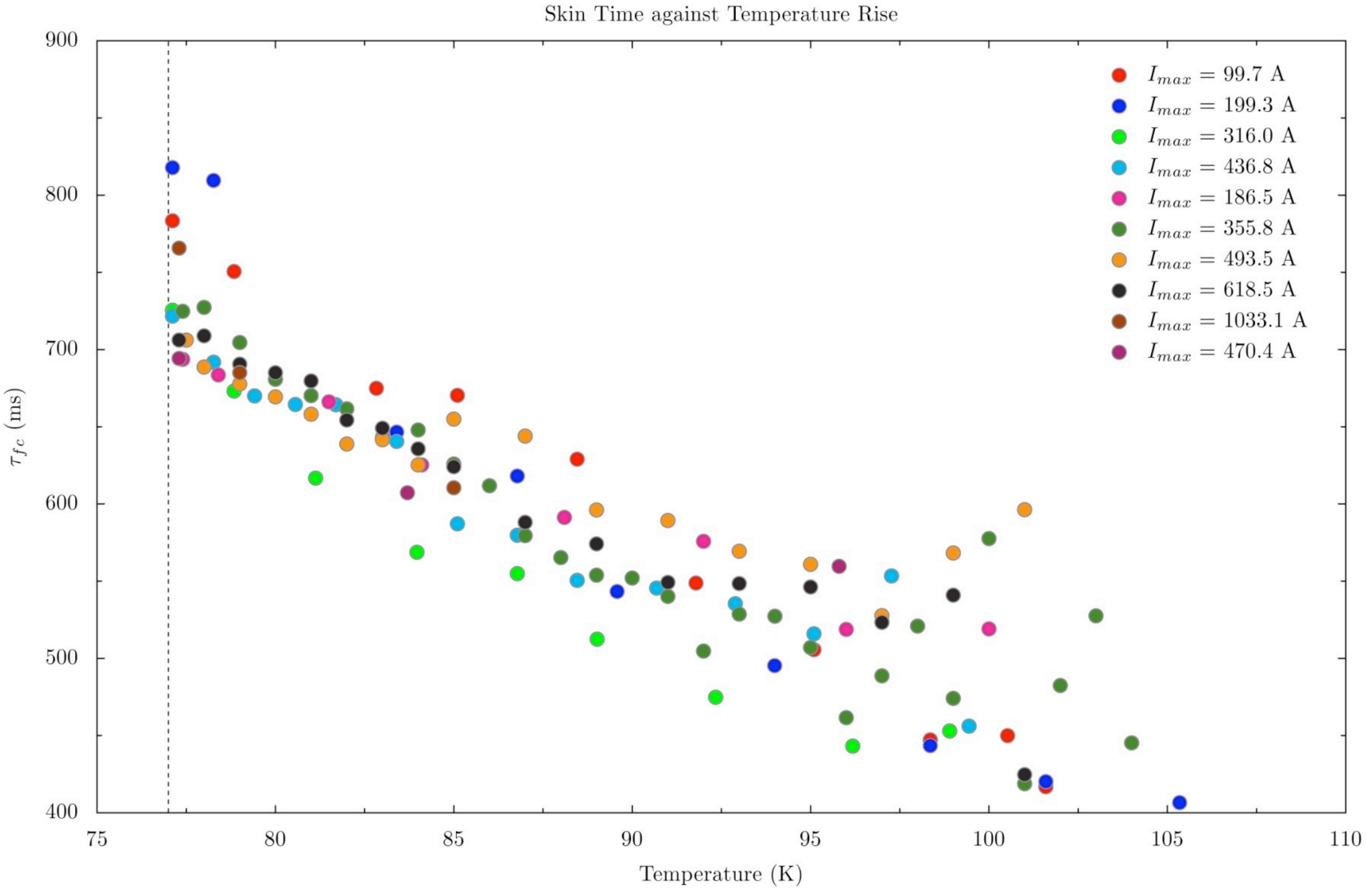
$$\frac{I_{cr}}{I_{tape}} \simeq 0.827$$

Assumption of decay in copper followed by decay in superconductor accounts well for observed behavior

Critical Current for Aligned Superconducting FC



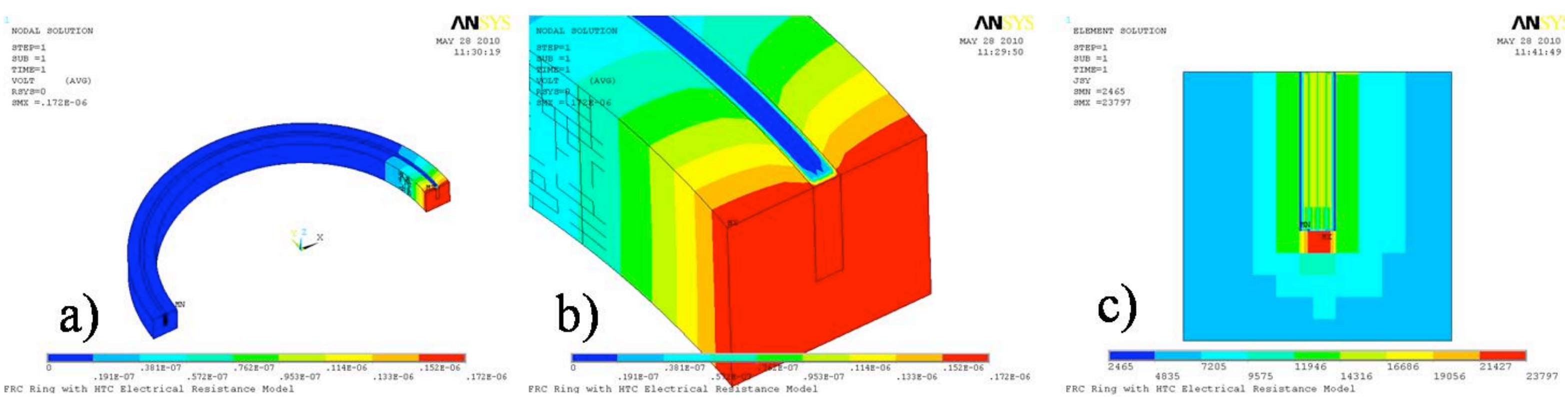
Skin Time for Aligned Superconducting FC



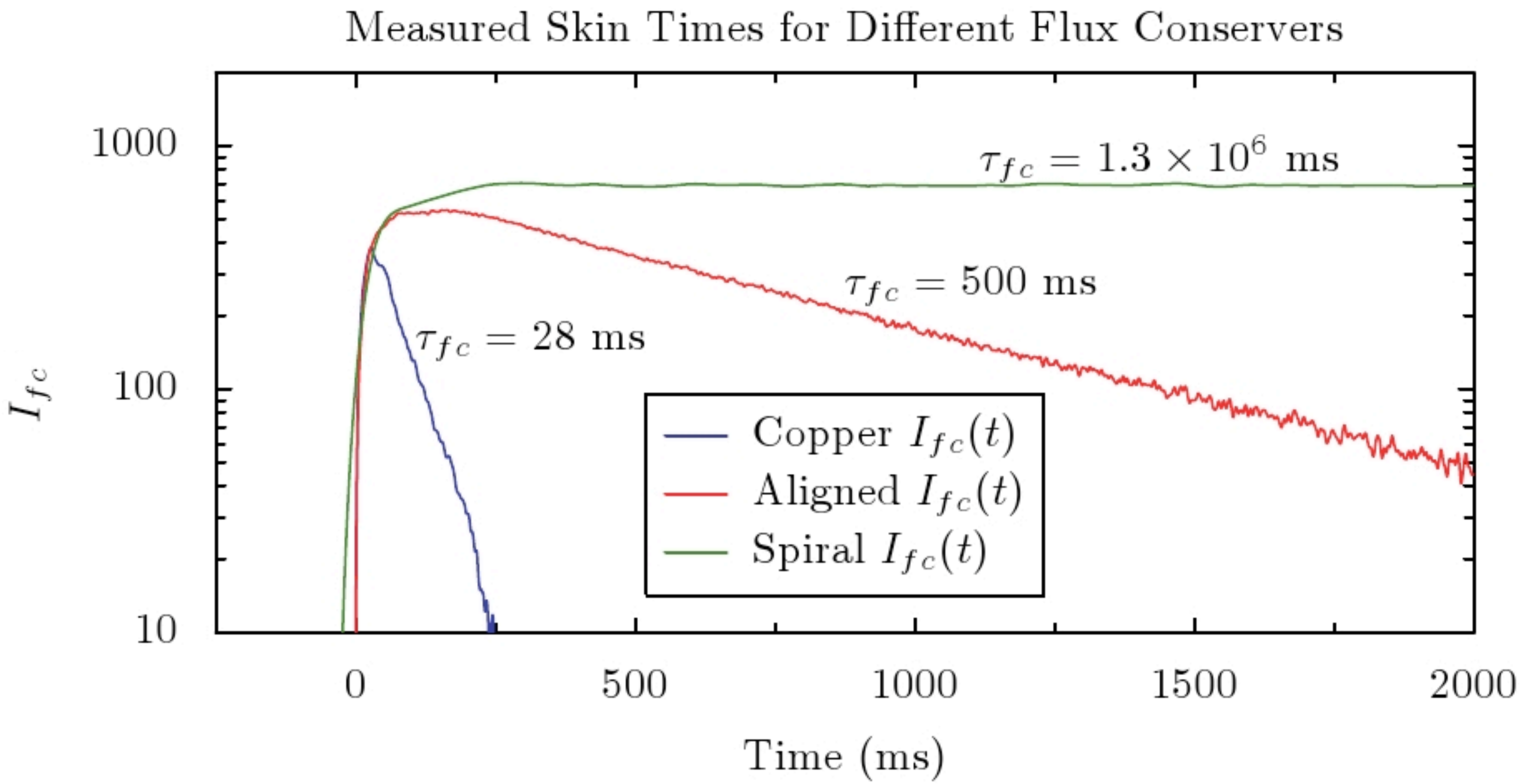
Current Flow in Aligned HTS FC

- Current flow across gap in aligned case is concentrated in the section of copper below the gap

- Simulated results explain experimental observation of lower skin times at higher temperatures.



Effect of Design on Skin Time



Summary and Conclusions

- The skin time and critical current dependence on temperature are now better understood.
- We know how the copper casing and its temperature affect the HTS-FC skin time.
- Skin times in the range of .5 – 1300 seconds have been achieved, which are sufficient for this and the next generation of PFRC device.
- An induced current of 1200 A has been achieved in the ten turn aligned HTS-FC, which is 75% of critical current expected for ten tapes. The PFRC-2 experiment will use FCs with 25-turns of HTS tape, in the aligned gap configuration.