Design of a REBCO HTS Superconducting Undulator

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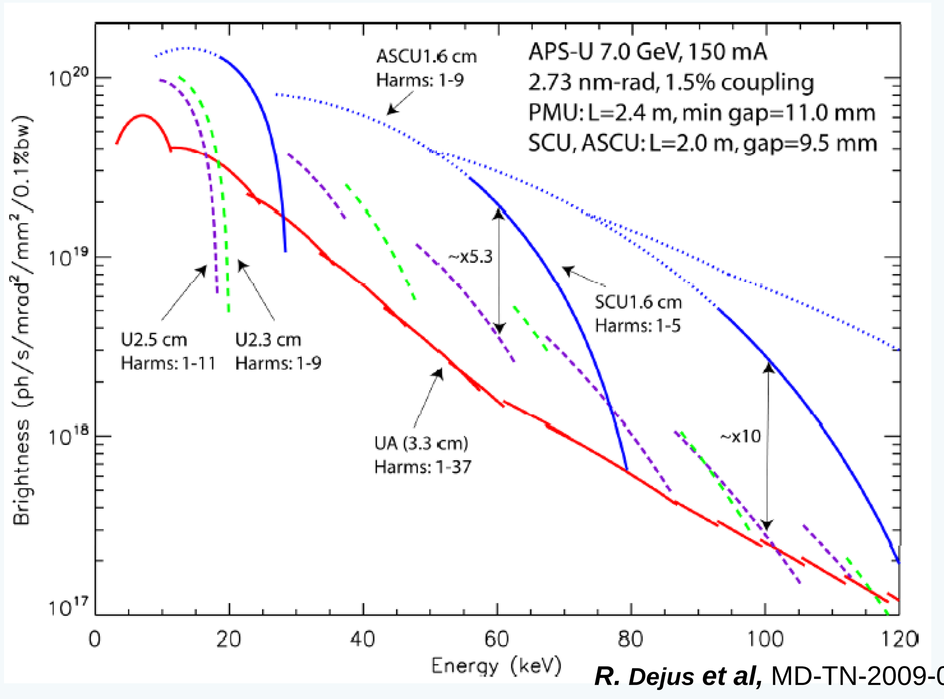
Introduction

Undulators are an important component of storage ring and free electron laser light sources to produce high-brilliance X-ray photon beams. Recent developments have shown that superconducting undulators (SCU), mainly NbTi-based, outperform the existing devices. However, cooling these undulators is a challenge. REBCO (RE = rare earth, barium copper oxide) coated conductors (CCs) have been found to be a promising alternative to these materials due to their larger temperature stability margin; therefore, they can be operated at higher temperatures than NbTi which simplifies the cryogenic design. In addition, the engineering current densities of REBCO CCs have been enhanced drastically during the past years. In this study, we have investigated the feasibility of building an undulator magnetic structure using REBCO coated conductors and carried out experiments to evaluate their performance at 77 K.

$$\text{Brightness} = \frac{7.25x10^6 \gamma^2 N^2 I(A) f(K) K^2}{\sigma_x \sigma_y \left(1+\frac{\sigma_x'^2}{\theta_{cen}^2}\right)^{\frac{1}{2}} \left(1+\frac{\sigma_y'^2}{\theta_{cen}^2}\right)^{\frac{1}{2}} (1+\frac{K^2}{2})^2}$$

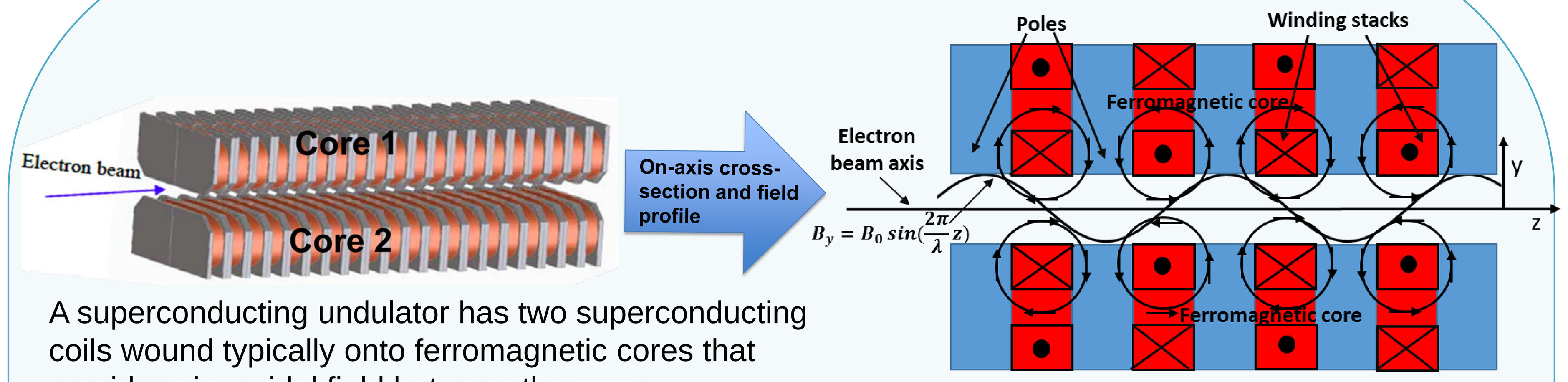
Only two parameters (red colored) can be controlled by an undulator and the rest are related to the electron beam. N is the number of periods and K is the deflection parameter.



R. Dejus et al, MD-TN-2009-004

Brightness or brilliance curves versus photon energy for different undulators. SCUs offer huge enhancements!

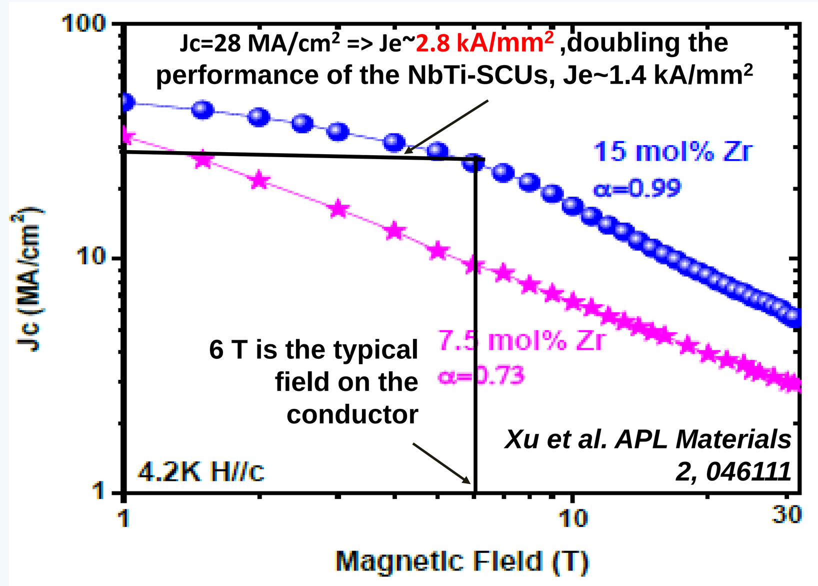
Undulators and Motivation



A superconducting undulator has two superconducting coils wound typically onto ferromagnetic cores that provides sinusoidal field between the cores.

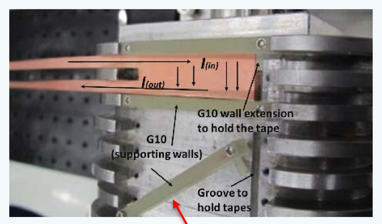
Deflection Parameter $K = 0.934\ \lambda_u$ [cm] B_0 [T] ≈1

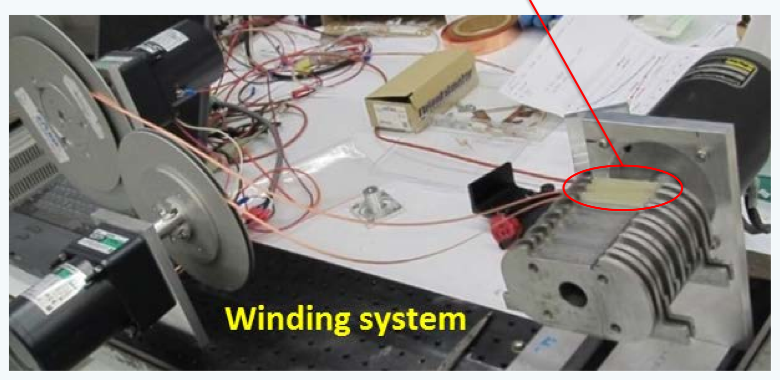
The goal is to achieve higher on-axis magnetic field in short period undulators, thus, enhance the brilliance and tunability.
REBCO conductors almost **doubles** the **performance of the existing devices** due to the higher engineering current densities.



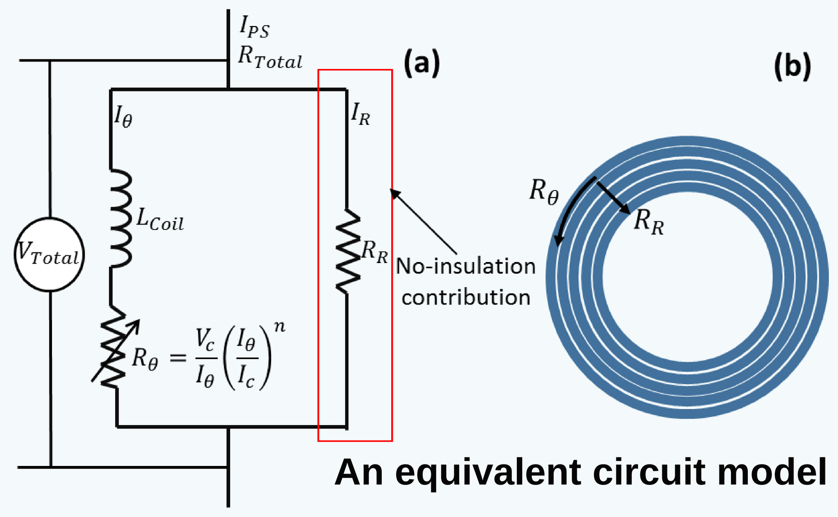
Winding of the Undulator Coils

Winding stacks are confined with G10 supporters on the side





Undulator core and REBCO tapes during windings

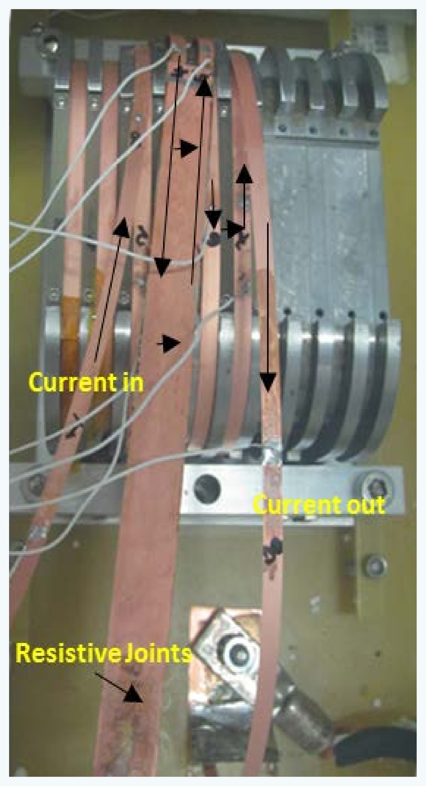


An equivalent circuit model

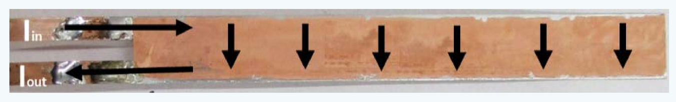
$$V_{Total} = \begin{cases} L_{Coil}\dfrac{dI_\theta}{dt} + \dfrac{V_c}{I_\theta}\left(\dfrac{I_\theta}{I_C}\right)^n = I_R R_R & I_\theta > I_C \\ L_{Coil}\dfrac{dI_\theta}{dt} & I_\theta < I_C \end{cases}$$

Voltage equation

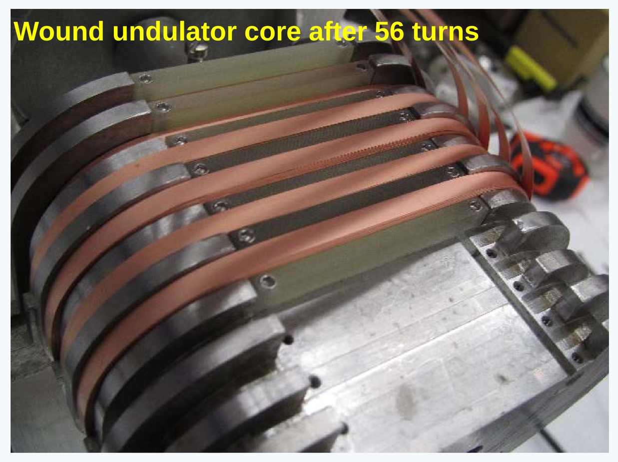
Undulator Core After Winding



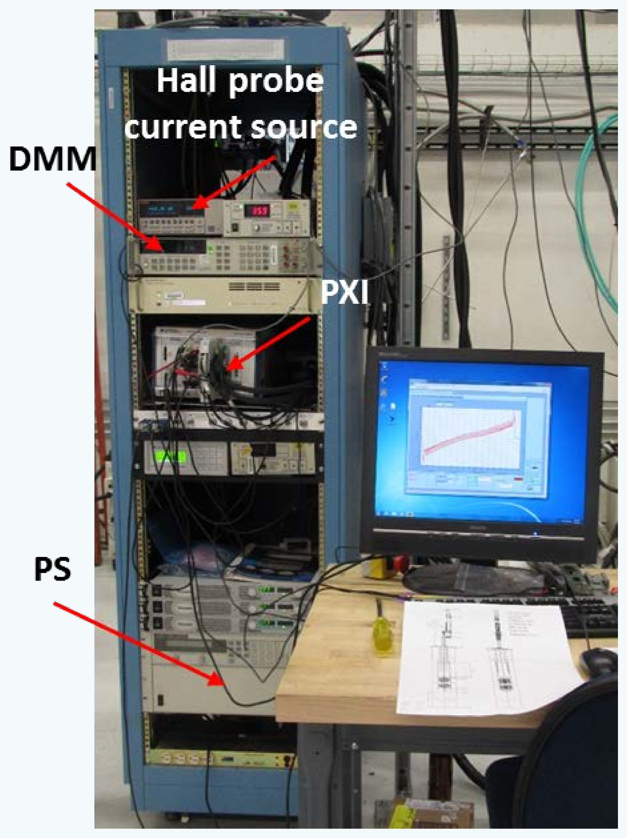
Undulator core with winding stacks and the current flow directions



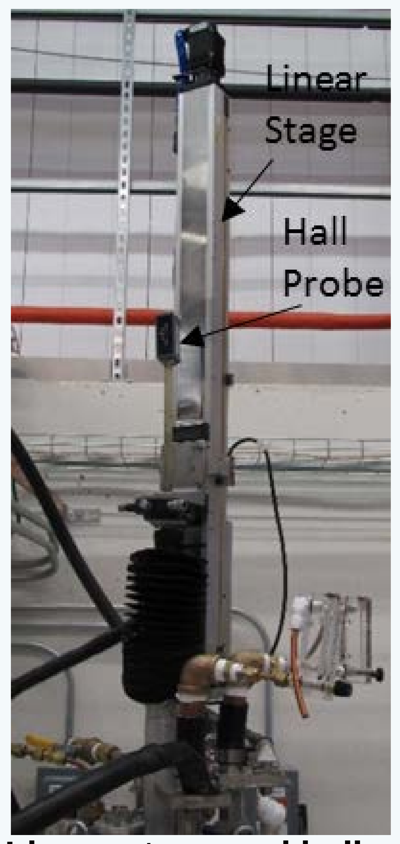
Resistive joint for 360 degree current reversal. R=~6 nΩ per joint



REBCO tapes and G10 supports

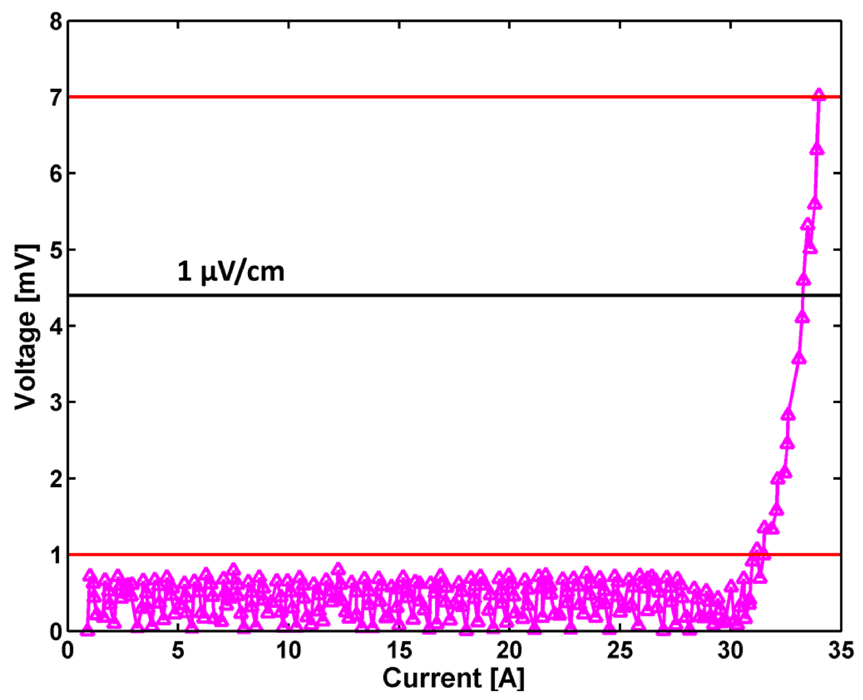


Measurement system

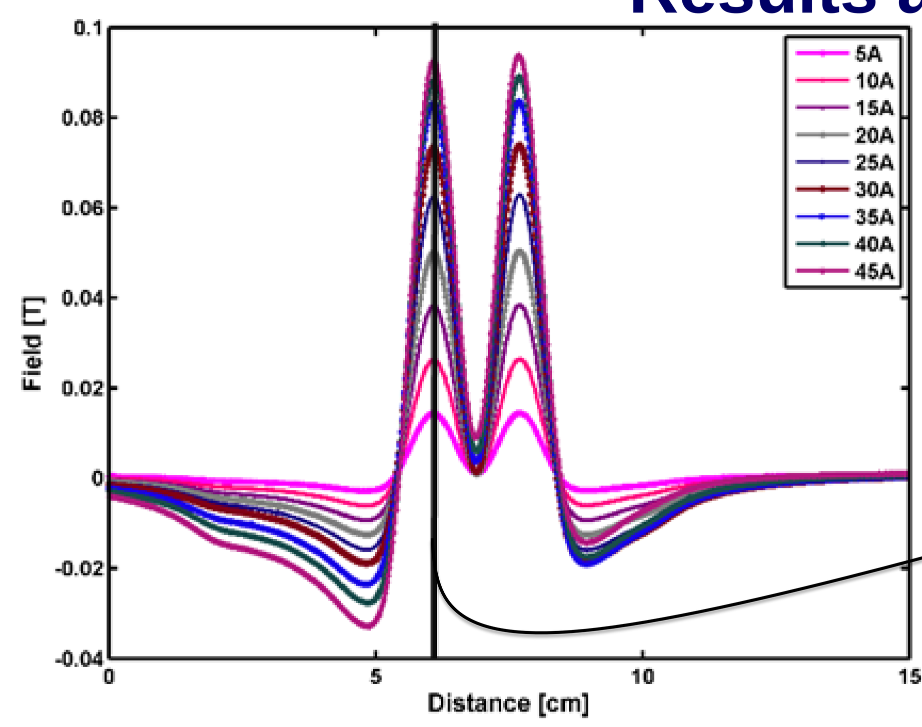


Linear stage and hall probe tube

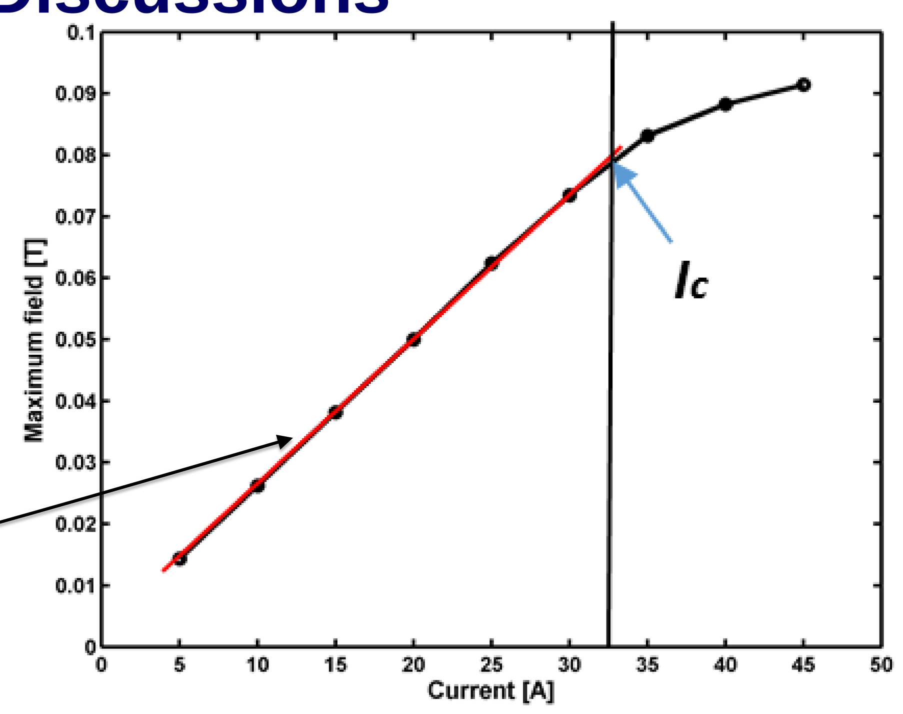
Results and Discussions



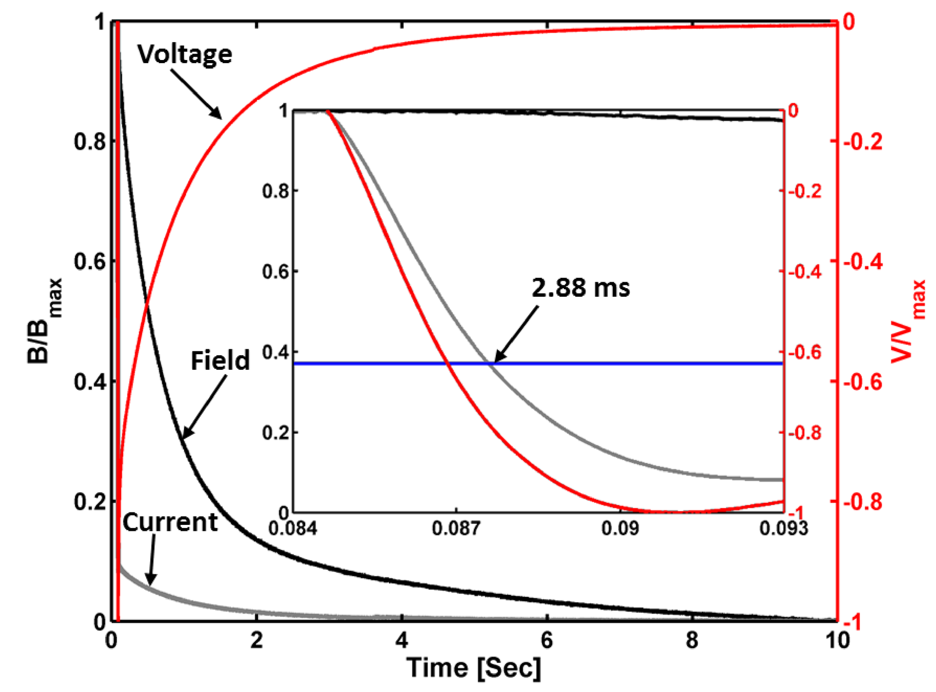
I-V characteristic of the undulator coil. ***Ic*=34.5A** and ***n*=21**. The *Ic* retention is at the expected level after winding!



Magnetic field scans along the z direction at different currents at a distance of 7.4 mm from the magnet pole.



Field versus current that was obtained form the left figure. Saturation starts beyond Ic. Current sharing arises deviation from the linearity of B (I) curve.



Sudden discharging test from 28 A steady-state operation showing voltage (across the undulator coil), current and field profiles. Inset shows magnified initial current decay portion of the overall performance. Time constants for the field and current are ~0.7s and ~2.88 ms respectively.

Conclusions

- We have investigated feasibility of using REBCO coated conductors in planar undulator applications and shown that an undulator magnetic structure can actually be built using RECO coated conductors with no significant degradation in the performance of the REBCO CCs.
- The I_c retention has been found to be reasonable after the undulator core winding indicating that the undulator winding and cooling cycles do not deteriorate the performance of the undulator significantly.
- Dynamic behaviour of the undulator core has been found to be not appealing since the field lags considerably due to the lack of insulation between the winding layers(~2.88 ms compared to ~0.7s).
- Steady-state mode performances have been found to be suitable for most of the undulator applications. The generated field is very stable. This would suggest that NI windings are perfect for most of the undulators.

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