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Robinson Research Institute

Dynamic resistance measurements in a four-tape YBCO stack

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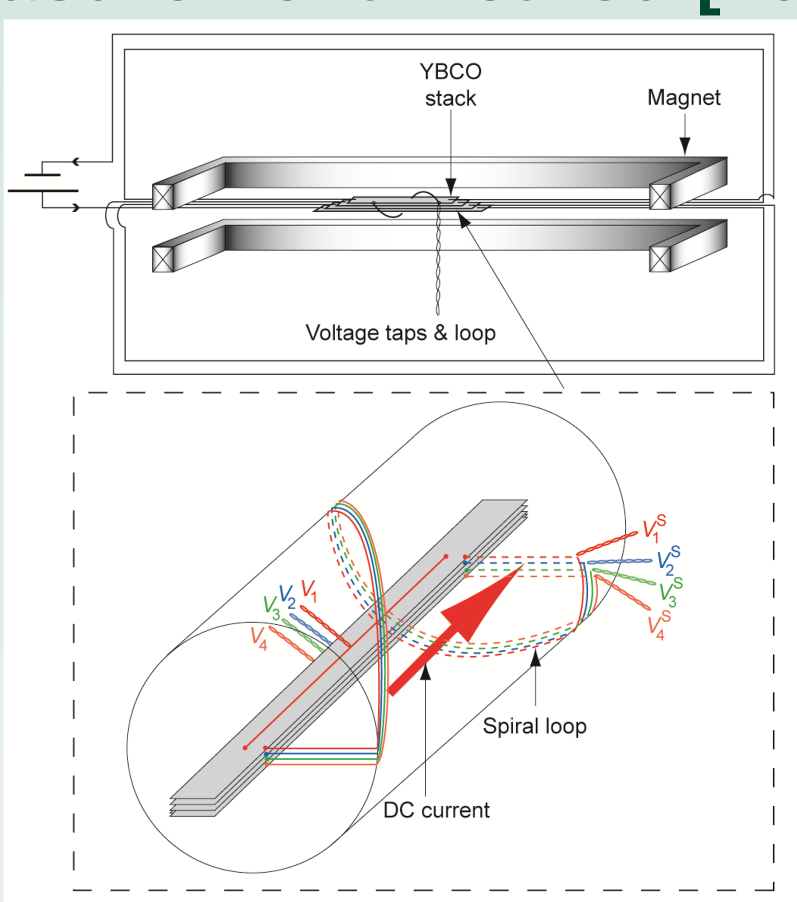
Introduction

- Many HTS applications, such as rotating machines, magnets, flux pumps, and Superconducting Energy Storage Systems (SMES), HTS wires carry DC transport current under external AC magnetic fields [1-4].
- When the amplitude of external magnetic field is larger than a threshold amplitude, dynamic resistance will occur [5-7].
- Dynamic resistance is dissipative and hence plays an important role for many HTS machinery applications [1-4].
- For high current-carrying capacity in these applications, it is essential to assemble the HTS wires by stacking.
- In previous works, we have measured dynamic resistance in coated conductors exposed to perpendicular magnetic fields, and have developed an equation which can predict the dynamic resistance of a single superconducting strip [8, 9].
- However there have been no report on dynamic resistance measurement in parallel connected HTS stacks.
- In this work, we report on dynamic resistance measurements in a four-tape YBCO stack comprising 4 mm-wide coated conductors manufactured by SuperPower Inc.
  – Perpendicular magnetic field
  – Various DC current levels
  – Magnetic field amplitude (up to 100 mT)
  – Two frequencies

Measurement method [10]



Sample specifications

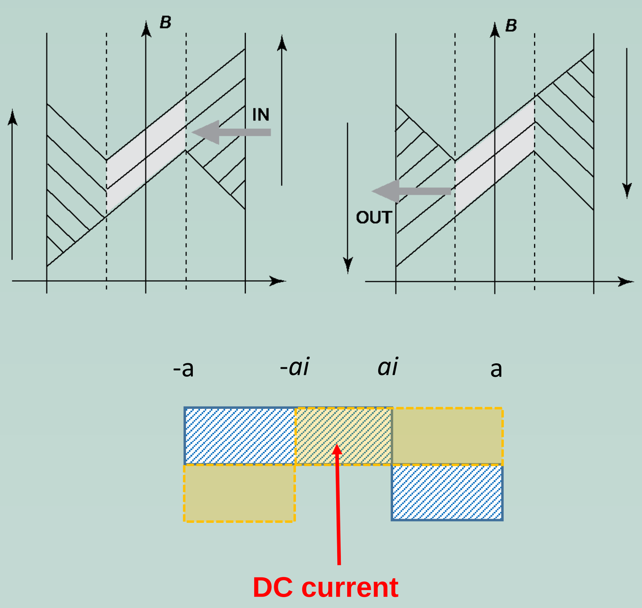
Wire type	YBCO
Manufacturer	SuperPower
Width (mm)	4.0
YBCO layer thickness (μm)	1.0
Substrate thickness (μm)	50.0
Cu stabilizer thickness each side(μm)	20.0

I_c values in the four conductor comprising the YBCO stack

	T-1	T-2	T-3	T-4	Average
Self-field I_c (A)	96.6	96.6	96.0	96.5	96.4
I_c after assembling (A)	82.3	83.8	83.0	85.1	83.6

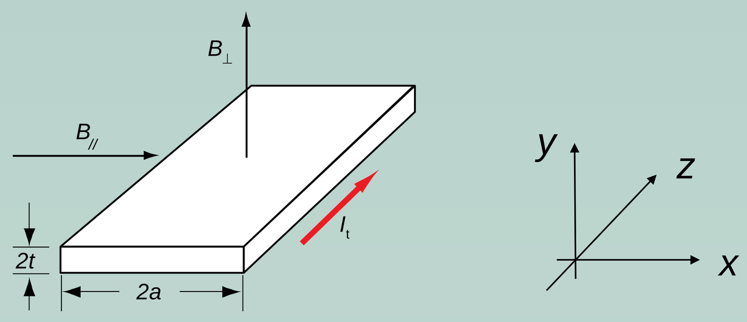
Equations

Slab [6]



$$\frac{R_{\mathrm{dyn},\,//}}{L}=\frac{4tf}{I_{c0}}\left(B_{a,\,//}-B_{\mathrm{th},\,//}\right)$$

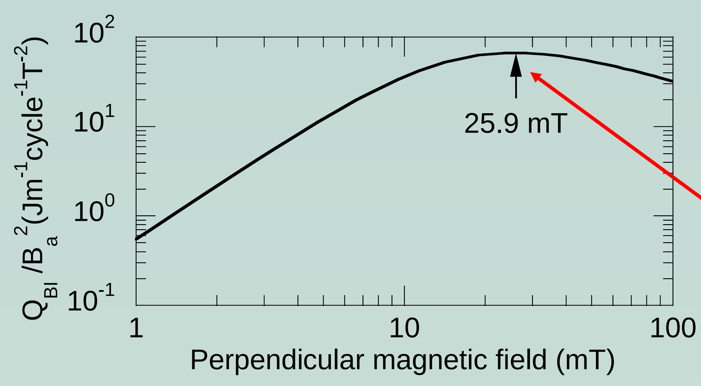
$$B_{\mathrm{th},\,//}=t\mu_0 J_{c0}\left(1-\frac{I_t}{I_{c0}}\right)=B_{p,\,//}\left(1-\frac{I_t}{I_{c0}}\right)$$



$$B(y)\approx\frac{\mu_0 t}{2\pi}\int_{-a}^{a}\frac{J_{th}(u)}{y-u}du+B_{a,th}+(B_a-B_{th})\ \ for\,B_a>\ B_{th}$$

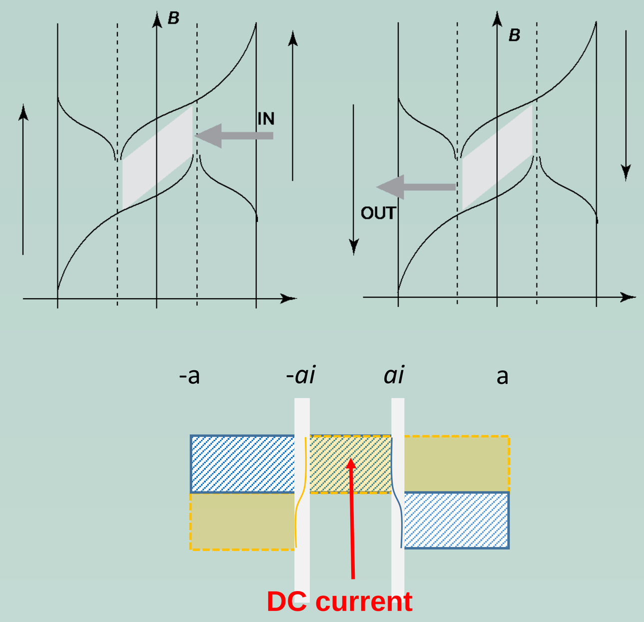
$$P=Qf=\Delta\Phi.I_T.f=L.2ai.2t.J_c.2aif\Delta B=\frac{4afLI_T{}^2}{I_{c0}}(B_a-B_{th})$$

$$\frac{R_{dyn}}{L}=\frac{4af}{I_{c0}}(B_a-B_{th})$$



$$0=\frac{d}{dx}\left(\frac{Q_{BI}}{H^2}\right)=\frac{3\tan h(x)}{x^2}-\frac{4\ln(\cosh(x))}{x^3}-\frac{1-(\tan h(x))^2}{x}$$

Strip [8, 11]



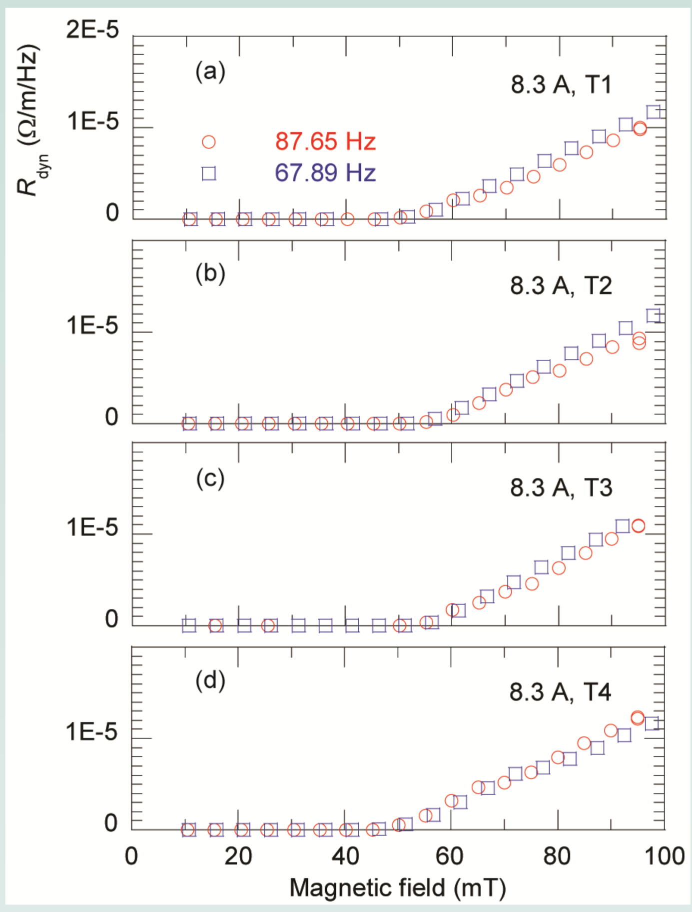
$$\boxed{\frac{R_{\mathrm{dyn},\,\perp}}{L}=\frac{4af}{I_{c0}}\left(B_{a,\,\perp}-B_{\mathrm{th},\,\perp}\right)}$$

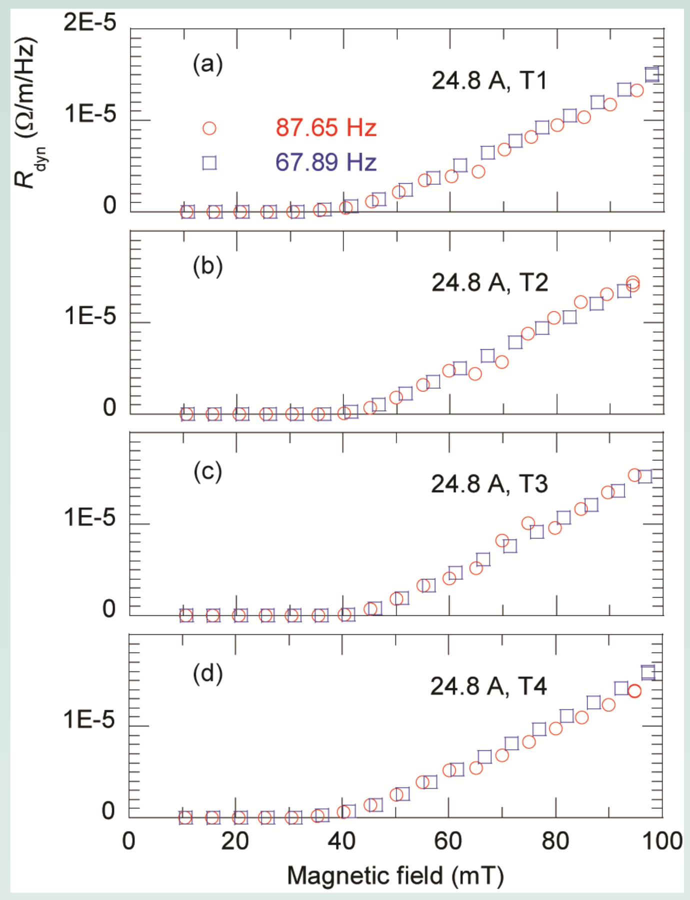
$$B_{\mathrm{th},\,\perp}=B_{p,\,\perp}\left(1-\frac{I_t}{I_{c0}}\right)$$

$$B_{p,\,\perp}=4.9284\mu_0 J_c t/\pi$$

Results

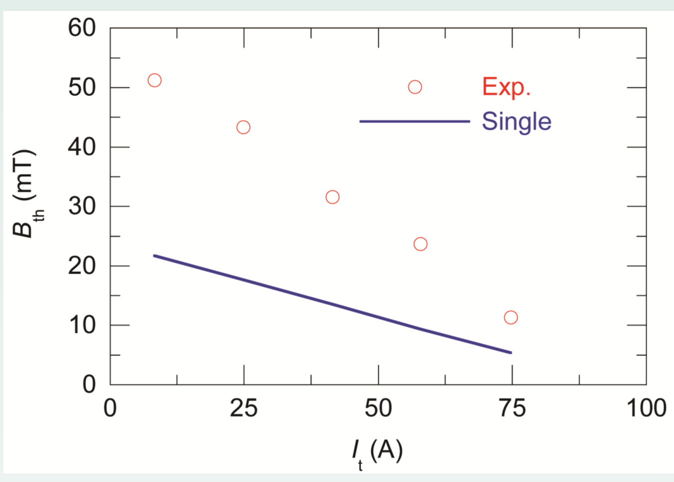
Frequency dependence





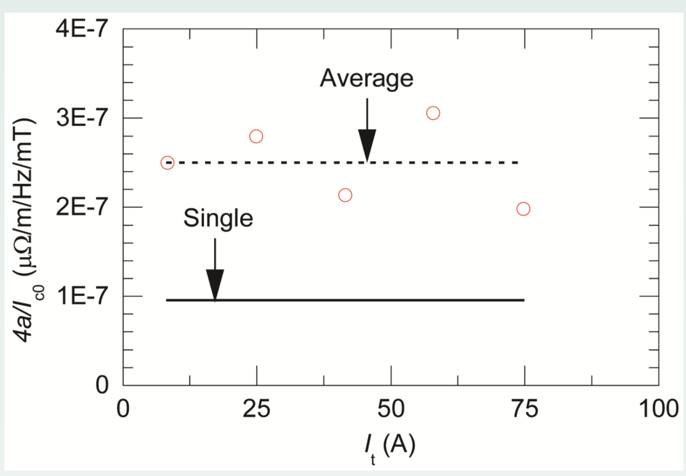
- There is no obvious difference between the results at 67.89 Hz and 87.65 Hz.
- The result suggests the hysteretic nature of dynamic resistance in the stack..

Stack vs single tape



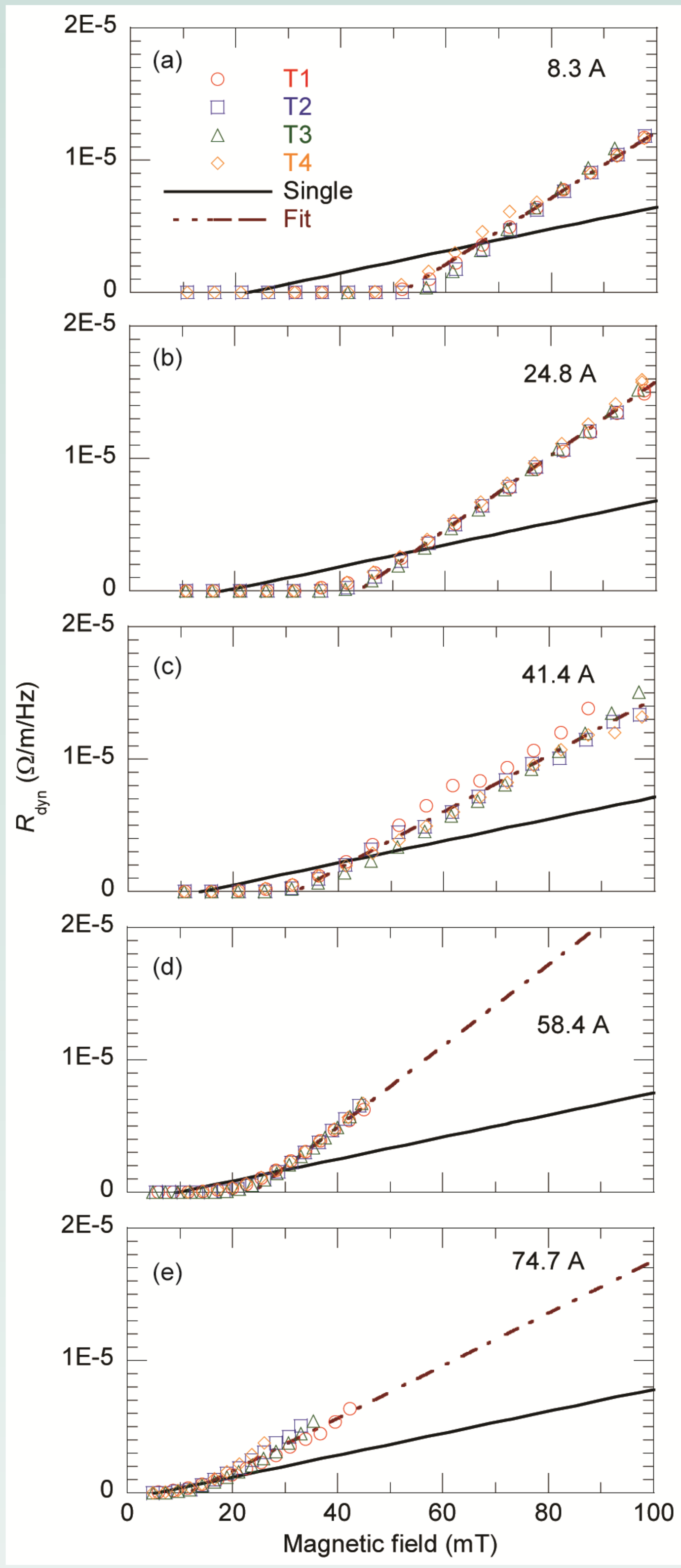
- At I_t = 8.4 A, the B_{th} value for the stack is approximately 2.5 times those in the single conductors.
- The B_{th} values in the stack decrease in faster rate than those for the single conductor.

Stack vs single tape



- The averaged gradient value in the figure is more than 2.5 times the theoretical value for the single conductor.
- A detailed electromagnetic field analysis will be desired to investigate the magnetic flux movement and understand the cause of the gradient increase in the stack

Stack vs single tape



- B_{th} values for the stack are bigger than those in the single conductor at each DC current value → Shielding effect from circulating current present in each wire in the stack
- The effect is more remarkable when the DC current value is small and the effect becomes weaker with increasing DC current values.
- The gradient values of the linear fits (dR_{dyn}/dB_a) for each tape of the stack are much bigger those for the single conductor

References

[1] E. Pardo *et al., IEEE Trans. Appl. Supercond.* **24**, 4700105 (2013).
[2] P. J. Masson *et al., IEEE Trans. Appl. Supercond.* **15**, 2218-2221 (2005).
[3] Z. Jiang *et al., Appl. Phys. Lett.* **105**, 112601 (2014).
[4] C. Bumby *et al., Supercond. Sci. Technol.* **29**, 024008 (2016).
[5] K. Ogasawara *et al., Cryogenics* **16**, 33-38 (1976).
[6] M. P. Oomen *et al., Supercond. Sci. Technol.* **12**, 382-387 (1999).
[7] M. Ciszek *et al., Supercond. Sci. Technol.*, **15**, 1275-1280 (2002).
[8] Z. Jiang *et al., Supercond. Sci. Technol.* **30**, 03LT01 (2017).
[9] Z. Jiang *et al., IEEE Trans. Appl. Supercond.* **27**, 5900205 (2017).
[10] S. Fukui *et al.,* Advances in Cryogenic Engineering. **44**, 723-730 (1998).
[11] E. H. Brandt and M. Indenbom, *Phys. Rev. B*, **43**, 12893-12906 (1993).

Summary

- We have measured dynamic resistance in a four−tape YBCO stack comprising 4 mm−wide YBCO coated conductors carrying same current in each conductor under an AC perpendicular magnetic field.
- Threshold field values in the stack are much bigger than those for a single coated conductor due shielding effect from circulating current present in each wire in the stack, and the effect becomes weaker with increasing DC current value in each conductor.
- The gradient values (dR_{dyn}/dB_a) from the linear fit of the composite data for the stack are more than twice those for the single conductor. This might be due to I_c (B) dependence of the conductors in the stack. A numerical electromagnetic analysis is needed to better understand the experimental result.