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Effect of Dynamic Resistance on AC loss in a multi-superconducting-strip stack

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Abstract—High temperature superconductors (HTS) have become promising candidate conductors for HTS applications, such as superconducting magnets and electric machines. However, these superconductors are faced with significant AC loss under an alternating magnetic field. Dynamic resistance occurs in a superconductor carrying DC current and experienced an AC magnetic field exceeding the threshold value. Here we investigate the dynamic resistance to understand the mechanism and calculate the magnitude of AC loss in this state. We used a critical-state model for a superconducting strip in a perpendicular magnetic field to calculate the dynamic resistance, threshold field and power loss for each strip stacked in arrays. A new external susceptibility was introduced into the analytical expression of threshold field to represent the actual de-magnetization condition in the stack. And we found that the analytical expressions with the Kim model would be more accurate in predictions of dynamic resistance. Our results provide an effective approach to calculating the dynamic resistance of a multi-superconducting-strip stack.

Index Terms—Multi-superconducting-strip stacks, Dynamic resistance, Analytical solutions

1. Calculation of Dynamic Resistance

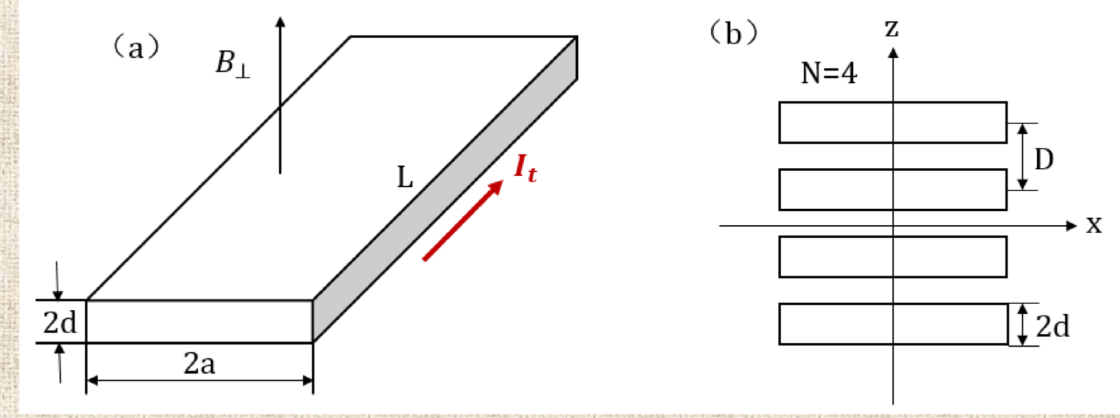

Fig. 1. Geometry and dimensions. (a) A single strip in perpendicular magnetic field, (b) A four-strip stack in perpendicular magnetic field.

TABLE
Analytical expressions for dynamic resistance and threshold field for superconducint strips in a perpendicular field

Item	Analytical expression	
R_{dyn} for a single superconducting strip(1)	$\frac{R_{dyn}}{Lf} = \frac{4a}{I_c}(B_a - B_{th})$	(1)
B_{th} for a single superconducting strip	$B_{th} = \frac{4\mu_0 J_c d(1-i)}{\pi}$	(2)
External susceptibility X_0 for the stack	$X_0(N) = \frac{2D^2 \ln\left[\cosh\left(\frac{\pi a}{D}\right)\right](N^{0.8}-1)+\pi^2 a^2}{4\pi a d N^{0.8}}$	(3)
$B_{th}(N)$ for each strip in a multi-strip stack	$B_{th}(N) = \frac{\mu_0 a \pi N^{0.8}(I_c - I_t)}{2D^2 \ln\left[\cosh\left(\frac{\pi a}{D}\right)\right](N^{0.8}-1)+\pi^2 a^2}$	(4)
$R_{dyn}(N)$ for each strip in a multi-strip stack	$\frac{R_{dyn}(N)}{Lf} = \frac{4a}{I_c}(B_a - B_{th}(N))$	(5)
$R_{dyn}(N)$ for each strip in a multi-strip stack with Kim model	$\frac{R_{dyn}(N)}{Lf} = \frac{4a(1+B_a/B_0)}{I_{c0}}(B_a - B_r(N))$	(6)
Critical value $B_r(N)$	$B_r(N) = \frac{\mu_0[I_{c0} - I_t(1+B_a/B_0)]}{4d(1+B_a/B_0)X_0(N)}$	(7)

TABLE I
Specification of the Strip for Stack Array

Item	value
Self-field critical current	104 A
Width (2a)	4 mm
Thickness of superconducting layer (2d)	1 μm
Length (L)	15 cm
Distance between neighboring superconducting strips (D-2d)	295μm

2. Model Verification

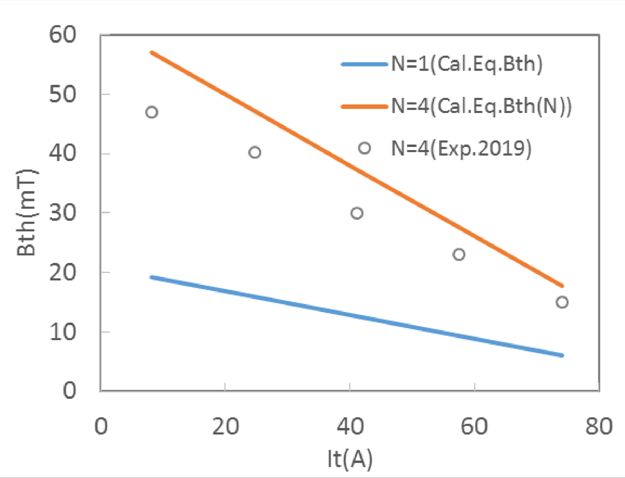

Fig. 2. Comparison of the B_{th} measurements and the analytical solutions from equation (2) and (4)

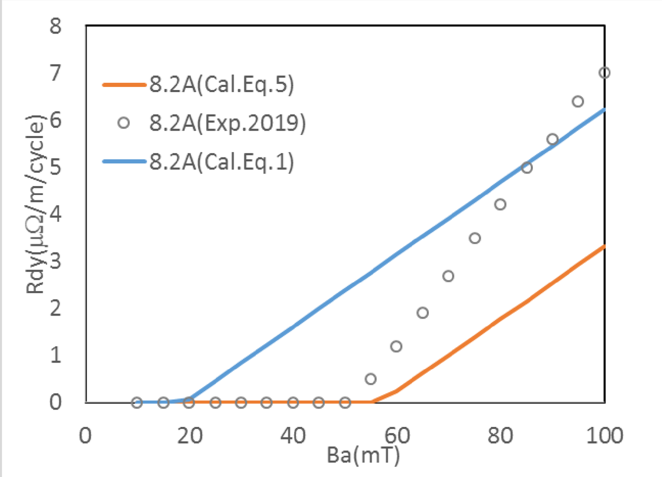

Fig. 3. Comparison of the R_{dyn} measurements and the analytical solutions from equation (1) and (6)

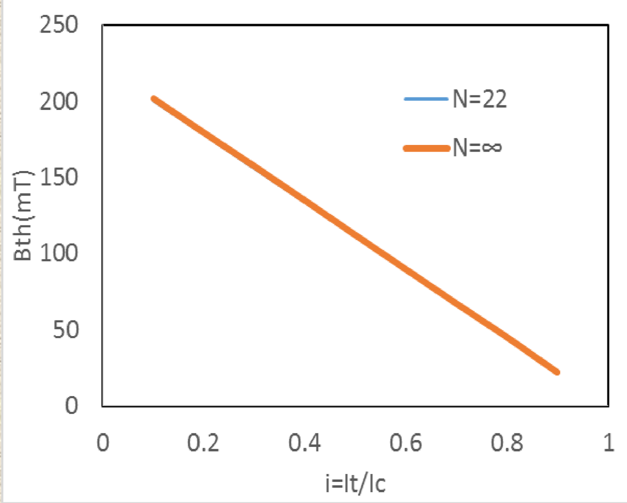

Fig. 4. Research on application scope of equation (4).

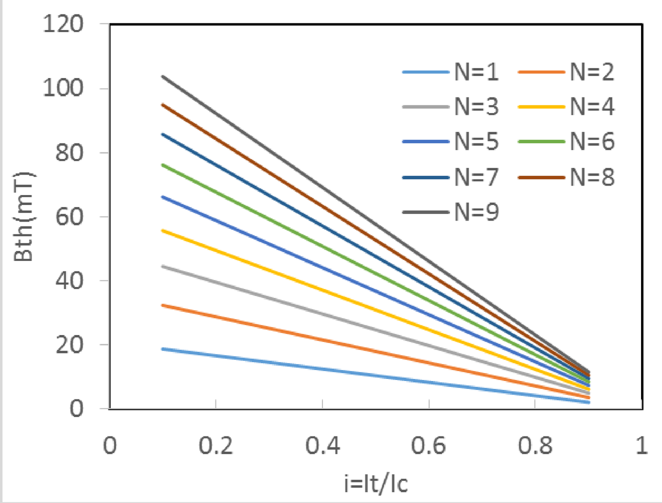

Fig. 5. Analytical predictions of B_{th} in multi-strip stacks obtained by equation (4).

The equation (4) can only be applied for stacks with less than nine strips, which means $1 < N \le 22$.

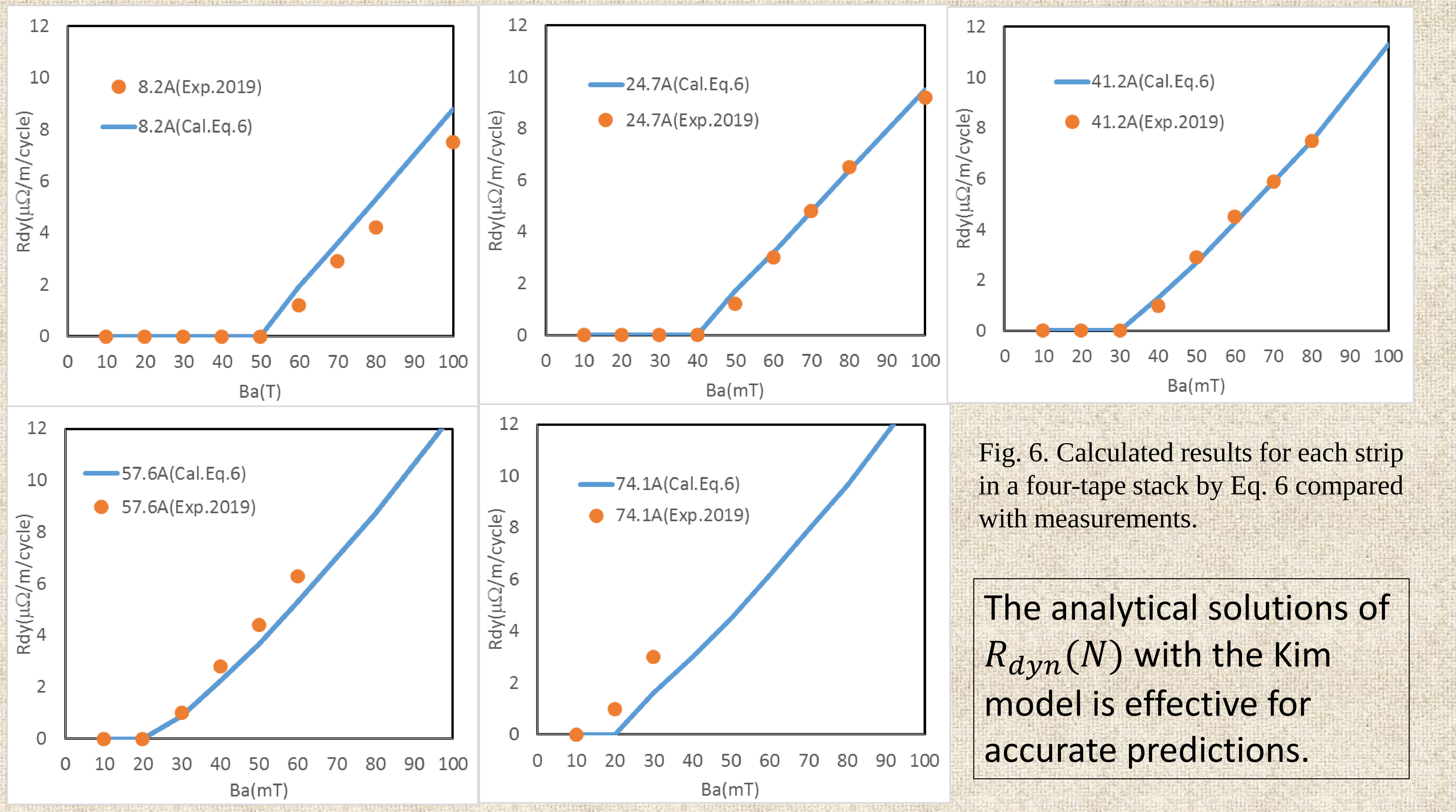

Fig. 6. Calculated results for each strip in a four-tape stack by Eq. 6 compared with measurements.

The analytical solutions of $R_{dyn}(N)$ with the Kim model is effective for accurate predictions.

3、Conclusion

Fig. 2 shows that the analytical solutions of B_{th} derived from the Eq. (4) could predict B_{th} for stacks relatively accurate. Although the predictions from Eq. (4) are higher than the measurements, we considered that the actual thickness of YBCO tape attributes the deviation.

Fig. 3 shows that neither Eq. (1) nor Eq. (5) could predict R_{dyn} in stacks. Therefore the dynamic resistance for superconducting strips in the stack need more accurate analytical expressions.

Fig. 4 shows the threshold field $B_{th}(N)$ can be applied for stacks with $1 < N \le 22$. The external susceptibility X_0 will not affect by dimensions of the stack when the number of stacked strip exceeds 22. For stacks with $N \ge 22$, the demagnetization effects and shielding effects on the threshold field are invalid.

Fig. 5 shows the slope dB_{th}/dI_t is increasing with the number of strip in the stack. That is because the shielding effects in strips increasing with the N.

Fig. 6 shows the analytical solutions of $R_{dyn}(N)$ with Kim model agreed well with the measurements reported by Yanchao Liu et al.