Contribution to the modeling of eddy current losses in HTS tapes

H. Menana , W. Dirahoui, Y. Statra, M. Hinaje, B. Douine

University of Lorraine, Research Group in Electric Engineering of Nancy (GREEN), France

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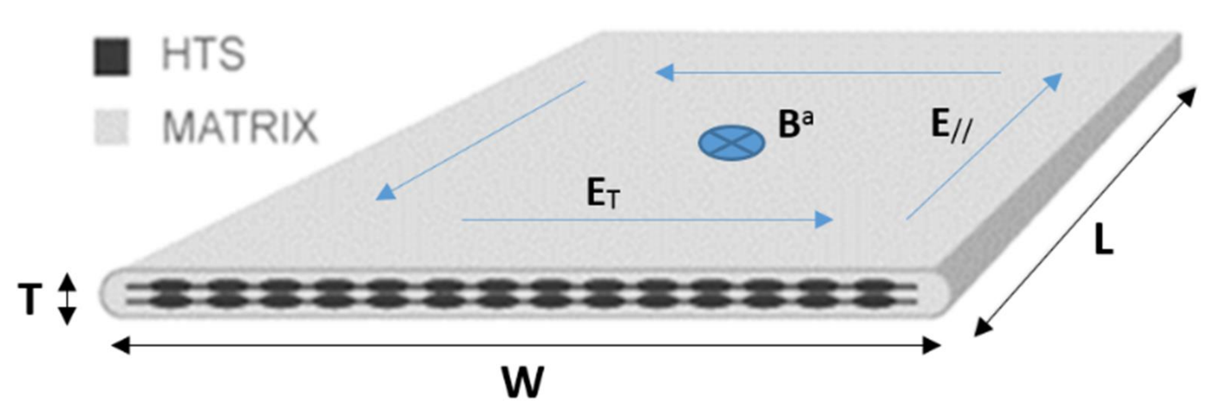
Abstract

This paper presents a simple semi-analytical modeling to evaluate the eddy current losses development in multifilamentary high temperature superconductors (HTS) tapes submitted to external time varying magnetic fields.

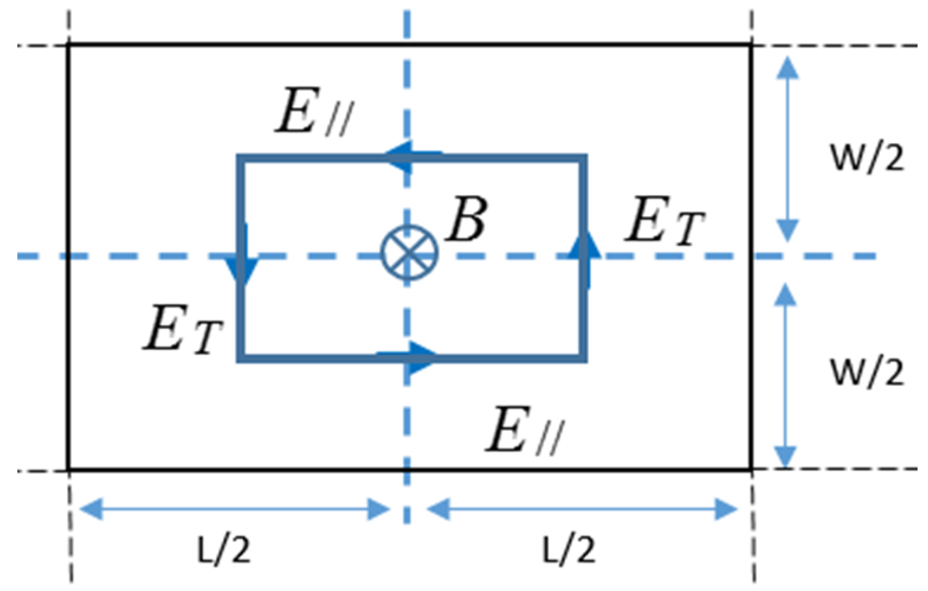
The modeling approach

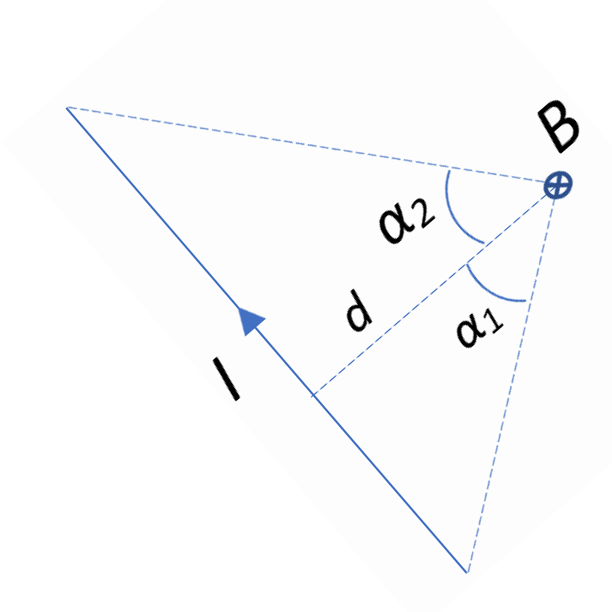


Modelled system (1G untwisted HTS tape)

$$\bar{\bar{\sigma}}(J)=\begin{bmatrix}\eta_s\frac{J_{//}}{E_{//}}+(1-\eta_s)\sigma_m & 0 & 0\\ 0 & \frac{(1+\eta_s)}{(1-\eta_s)}\sigma_m & 0\\ 0 & 0 & \frac{(1+\eta_s)}{(1-\eta_s)}\sigma_m\end{bmatrix}$$

$$E_{//}=E_c\left(\frac{J_{//}}{J_{c0}(1+\frac{|B|}{B_0})^{-\beta}}\right)^n$$





$$B=\frac{\mu_0 I}{4\pi d}\left[\sin(\alpha)\right]_{\alpha_1}^{\alpha_2}$$

$$B=B^a+\frac{4\mu_0 I}{\pi}\frac{L+W}{LW}$$

Algorithm

Input: L, W, T, B^a, σ_m, η_s, B_0, n, β, ω

$\sigma_T=(1+\eta_s)(1-\eta_s)^{-1}\sigma_m$

Initialization: $E_{//}^0=0$, $E_T^0=-\omega B^a\frac{L}{4}$,

$$J_c^0=\frac{J_{c0}}{\left(1+B^aB_0^{-1}\right)^{\beta}},\quad I^0=\frac{TL}{2}\sigma_T E_T^0$$

Do for i=1, 2 …

$$E_{//}^i=E_c\left[\frac{2\,|\,I^{i-1}\,|}{WTJ_c^{i-1}}\right]^n$$

$$B^i=B^a+\frac{4\mu_0}{\pi}\frac{L+W}{LW}I^{i-1}$$

$$J_c^i=\frac{J_{c0}}{\left(1+B^iB_0^{-1}\right)^{\beta}}$$

$$E_T^i=-\omega B^i\frac{L}{4}-\frac{L}{W}E_{//}^i$$

$$I^i=\frac{TL}{2}\sigma_T E_T^i$$

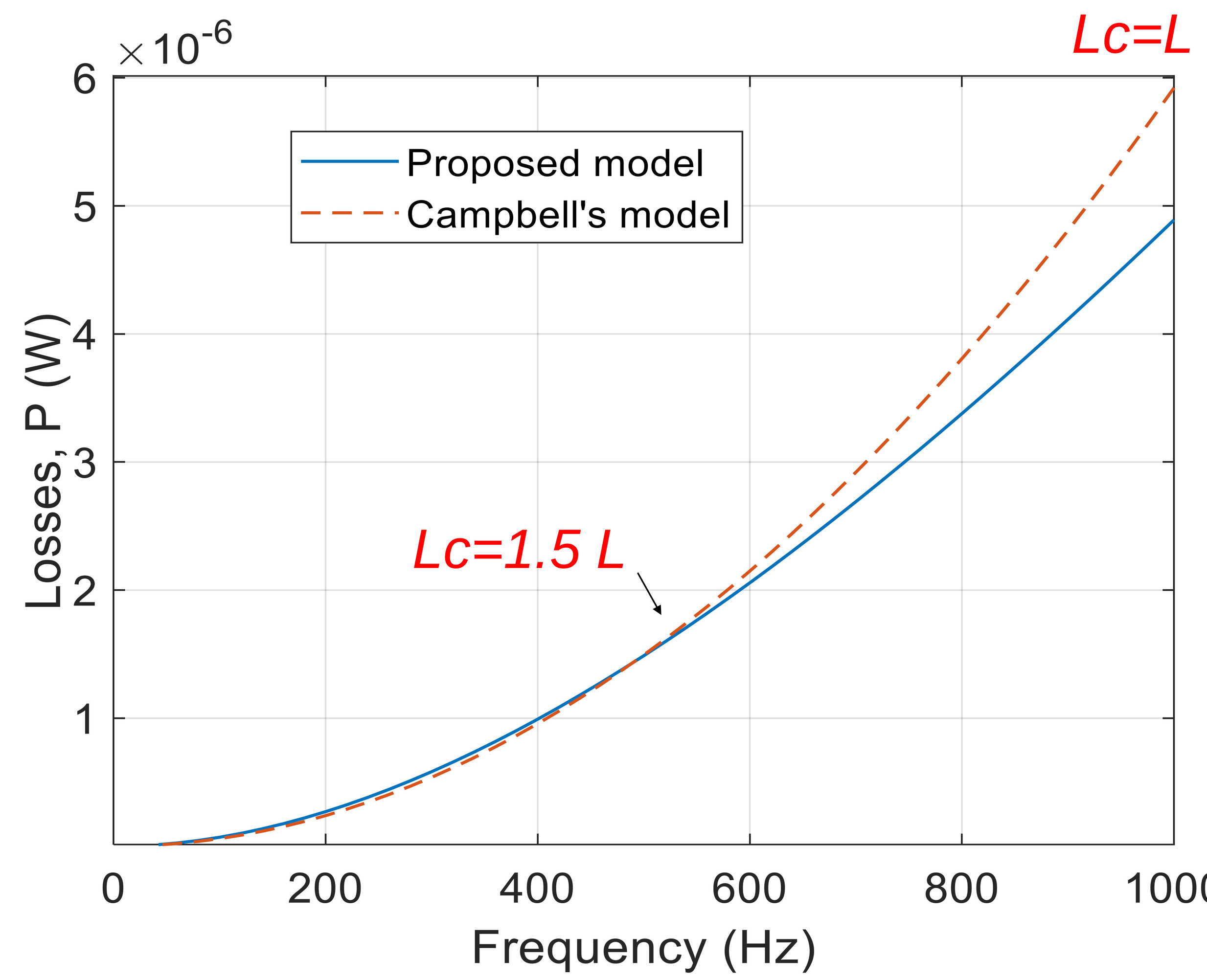
Until convergence (test on the current)

$$P=I(E_{//}L+E_TW)$$

Parameters specification

Parameter	L	W	T	n	η_s	J_{c0}	β	B_0	σ_m
Value	5mm	3,3mm	0,25mm	11	0,5	75 MA/m²	2,28	0,14T	62 MS/m

Results



Eddy current losses evolution with the frequency (Ba=1mT)

Campbell's model

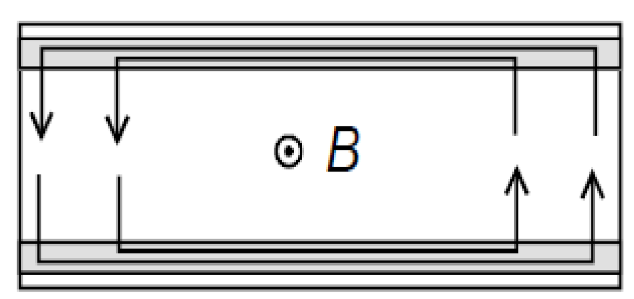
$$Q_c=\frac{B^{a2}}{2\mu_0}\left[2\pi\chi\frac{\omega\tau}{1+\omega^2\tau^2}\right]\ (J/m^3/Cycle)\ (*)$$

$$\chi=\frac{\pi W}{4T}\qquad \tau=\frac{L^2\sigma_m\mu_0}{\pi^2\chi}$$

- Low frequencies
- *Jc(B)* not considered
- *E* perpendicular to the HTS filaments at any point.

Campbell A.M., A general treatment of losses in multifilamentary superconductors, Cryogenics, 22, 3-16, 1982.

Critical length (Lc)



$$Lc=\sqrt{\frac{4\,J_cT_{fil}}{\pi\sigma_m\,f\,B^a}}$$

$$T_{fil}\simeq 20\mu m$$

M. Oomen, "AC loss in superconducting tapes and cables," Ph.D. dissertation, Univ. Twente, Enschede, The Netherlands, 2000.

Low frequencies (J<Jc) → Results similar to that given by (*)

f ↗ → J → Jc ($E_{//}$ not negligible) → (*) is no more valid

Long lengths (subdivision ?)