HTS 2022 Modelling

UNIVERSITÉ DE LORRAINE

Groupe de Recherche en Energie Electrique de Nancy
Green

Magnetothermal modeling of multilayer HTS tapes for their control at room temperature

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Outlines

- Introduction
- Experimental setup
- Modeling
- Results and validation
- Conclusion

Introduction

Context

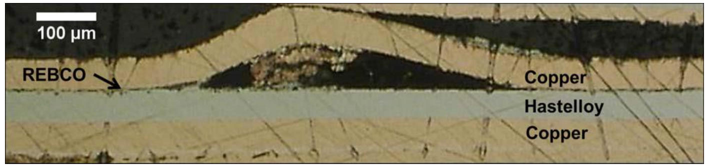
- Structural defects may lead to a substantial degradation of the performances of the HTS tapes.

Objective

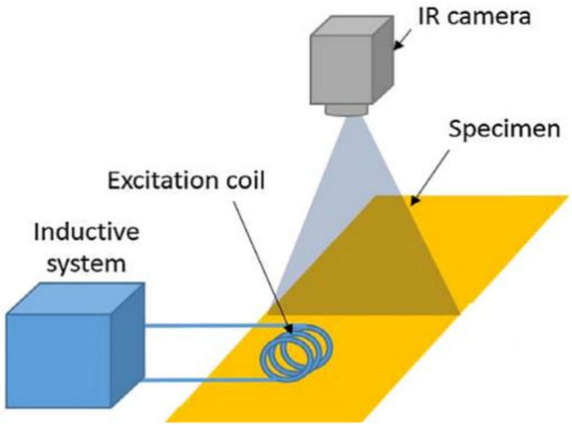
- NDT control of 2G HTS tapes by using eddy current thermography (ECT) at room temperature.

Scientific and technical issues

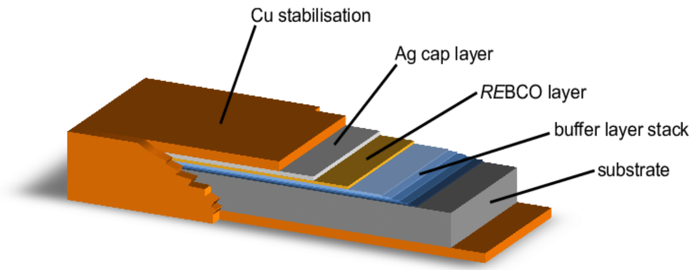
- Thin multilayered structure.
- Multiscale dimensions.
- Materials with different physical properties.



Photograph of a cross-section of a delaminated sample



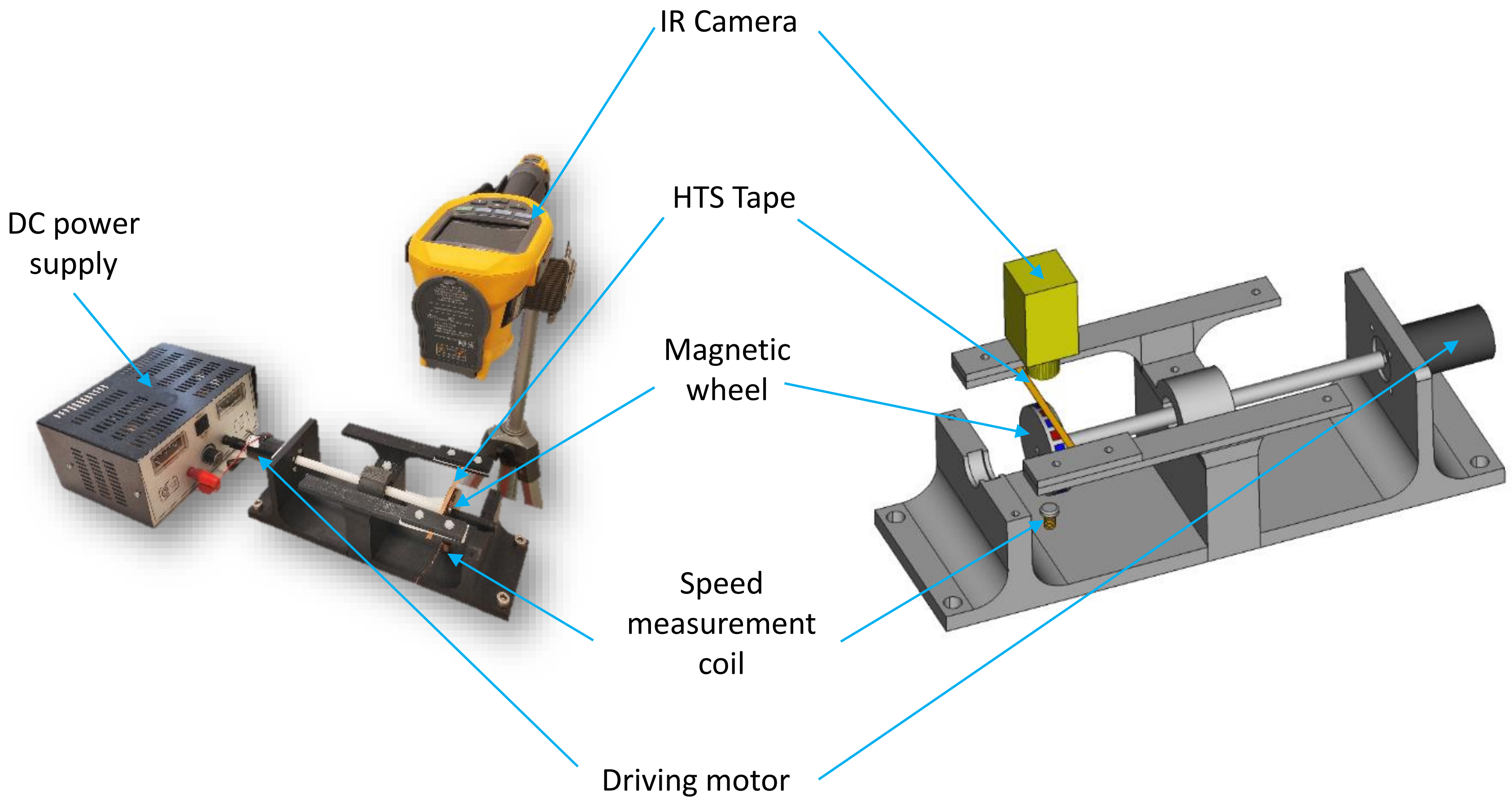
Schematic diagram of an ECT control device



Typical structure of REBCO HTS tape

Experimental setup

- Avoid the thermal disturbances of current supplied inductors.
- Rotating magnetic wheel.



Photograph and schematic draw of the experimental setup

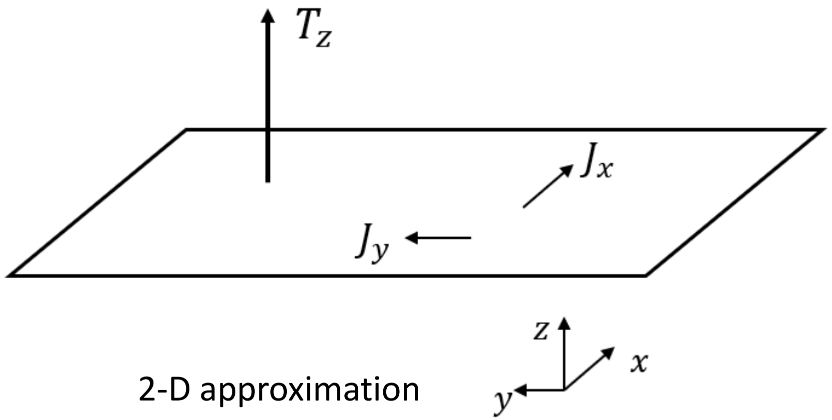
Modeling

Electromagnetic model

- Eddy currents:

$$\vec{\nabla} \times \bar{\bar{\sigma}}^{-1} \vec{\nabla} \times \vec{T}_z = -\partial_t \left(\vec{B}_z^s + \frac{\mu_0}{4\pi} \int_v \frac{\vec{\nabla} \times \vec{T}_z \times \vec{r}}{r^3} dv \right)$$

$$\begin{cases} J_x = \dfrac{\partial T_z}{\partial y} \\ J_y = -\dfrac{\partial T_z}{\partial x} \end{cases}$$



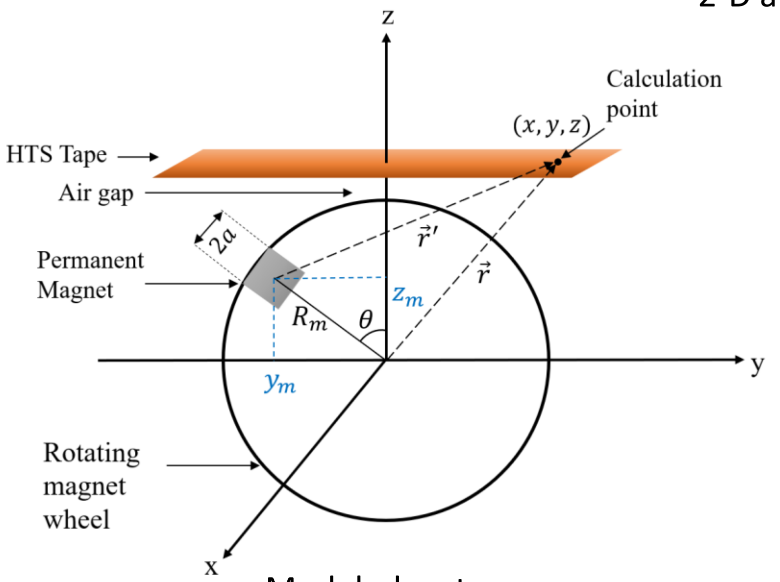
2-D approximation

- Source magnetic-flux density:

$$\vec{B}_z^s = \frac{B^r}{4\pi} \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{k=0}^{1} (-1)^{i+j+k} atan2(ST, RU) \vec{e}_z$$

$$\begin{cases} S = x - (-1)^i a \\ T = (y + R_m sin\theta) - (-1)^j a \\ U = (z - R_m cos\theta) - (-1)^k a \\ R = \sqrt{S^2 + T^2 + U^2} \end{cases}$$

$$\theta = \Omega t$$



Modeled system

System specifications

Parameter	Value	Description
$L \mid W \mid T$	50 | 4 | 0.1 mm	Tape dimensions
$a \mid R_m$	2.5 | 22.5 mm	Geometry of the magnetic wheel
B^r	1.4 T	Remanent magnetization of magnets
Ω	826.73 rad/s	Angular speed of the magnet wheel

Modeling

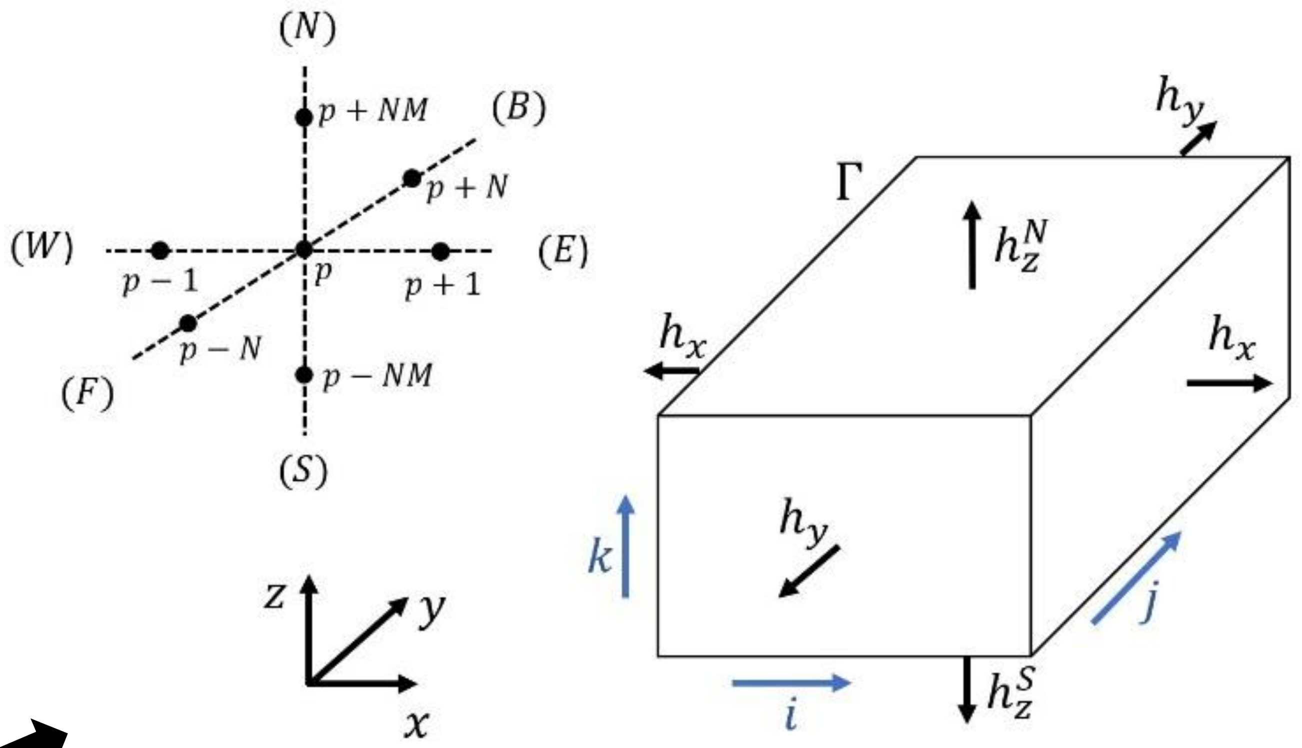
Thermal model

- Diffusion equation:

$$\begin{cases}\gamma C_p \dfrac{\partial T}{\partial t} = \dfrac{\partial}{\partial x}\left(\lambda \dfrac{\partial T}{\partial x}\right) + \dfrac{\partial}{\partial y}\left(\lambda \dfrac{\partial T}{\partial y}\right) + \dfrac{\partial}{\partial z}\left(\lambda \dfrac{\partial T}{\partial z}\right) + \mathcal{P} \\ -\lambda \vec{\nabla} \mathrm{T}.\vec{\mathrm{n}} = h(T - T_e), \qquad on\ \Gamma \end{cases}$$

- Boundary conditions:

$$\begin{cases} \lambda_W \dfrac{\partial T}{\partial x}\Big|_W = h_x(T_p - T_e) \\ -\lambda_E \dfrac{\partial T}{\partial x}\Big|_E = h_x(T_p - T_e) \\ \lambda_F \dfrac{\partial T}{\partial y}\Big|_F = h_y(T_p - T_e) \\ -\lambda_B \dfrac{\partial T}{\partial y}\Big|_B = h_y(T_p - T_e) \\ \lambda_S \dfrac{\partial T}{\partial z}\Big|_S = h_z^S(T_p - T_e) \\ -\lambda_N \dfrac{\partial T}{\partial z}\Big|_N = h_z^N(T_p - T_e) \end{cases}$$



Finite difference discretization strategy

Global index:

$p = i + (j-1)N + (k-1)NM$

$where\ (1 \le i \le N, 1 \le j \le M, 1 \le k \le L)$

Results and validation

Spatial repartition of magnetic flux density Bz in substrate layer

Magnetic flux density profiles along the length of the tape in substrate layer

Spatial repartition of eddy currents

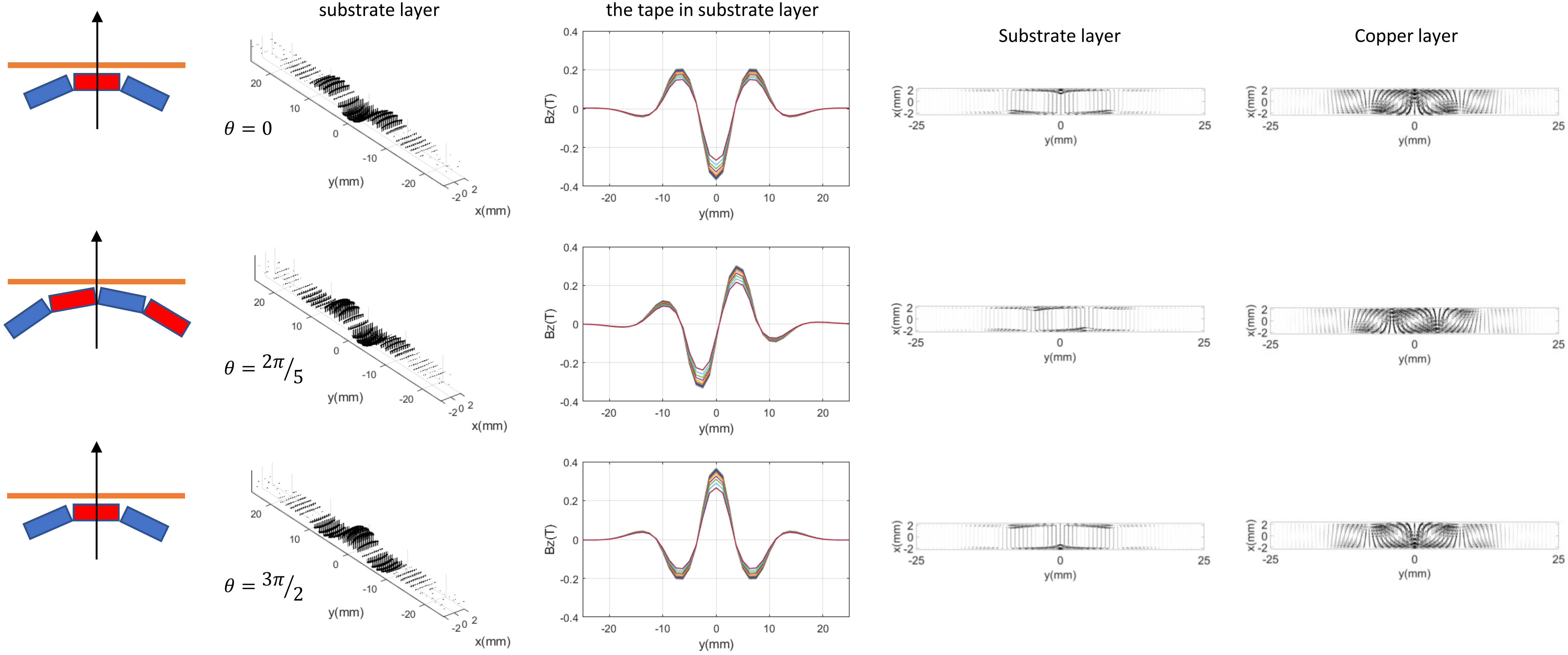
Substrate layer

Copper layer

South magnetic pole facing the HTS tape surface

Interface between magnets facing the HTS tape surface

North magnetic pole facing the HTS tape surface



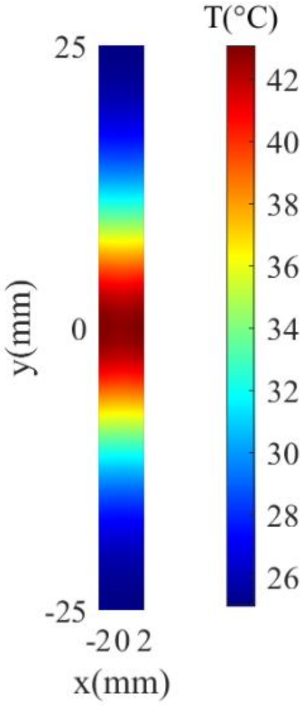
Evolution of the electromagnetic quantities as a function of the wheel position

Results and validation

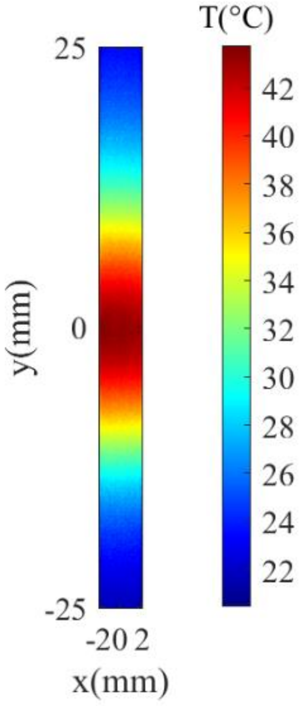
- Unflawed HTS tape:

Photograph of the HTS tape

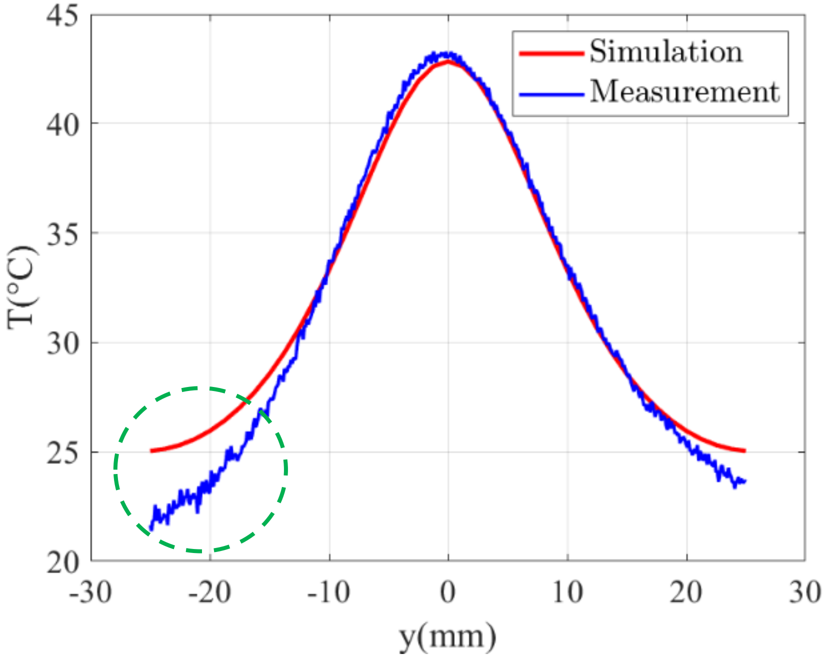
Simulation

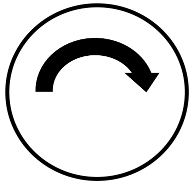


Measurement



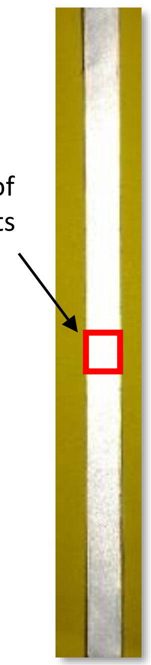
Temperature profiles along the length





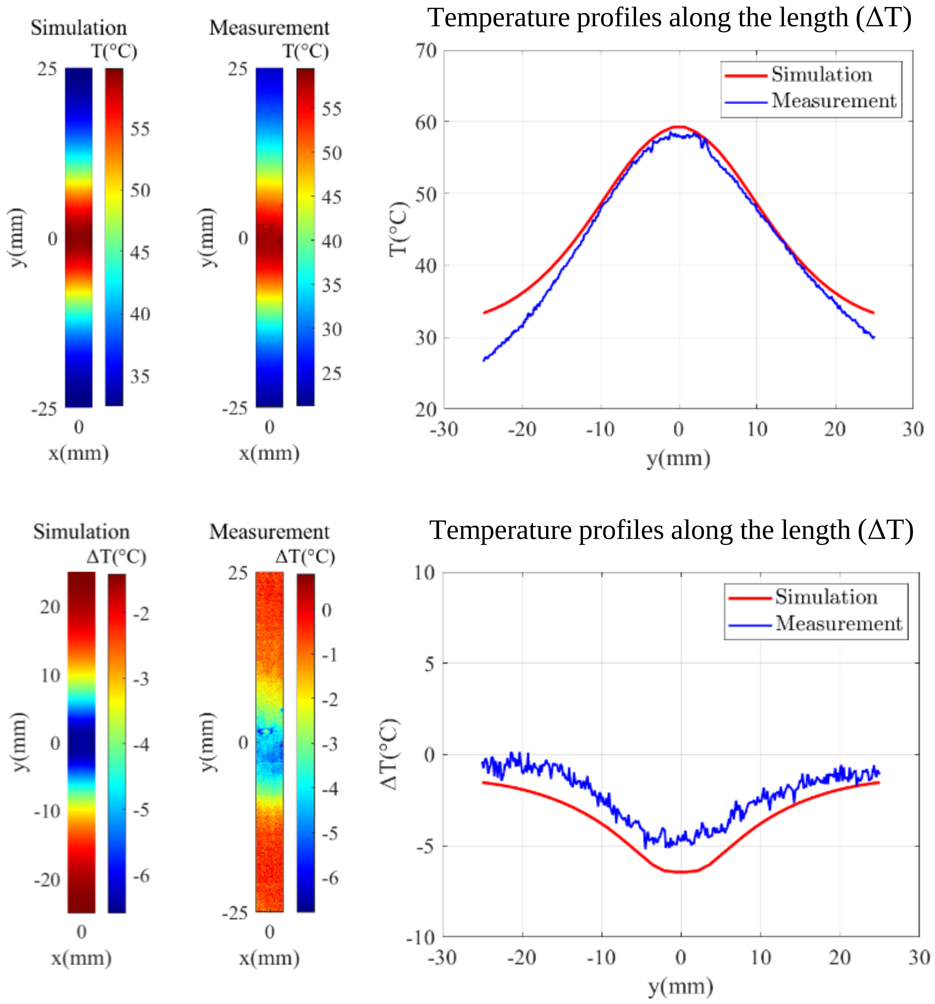
The direction of the rotation
of the magnetic wheel

Results and validation



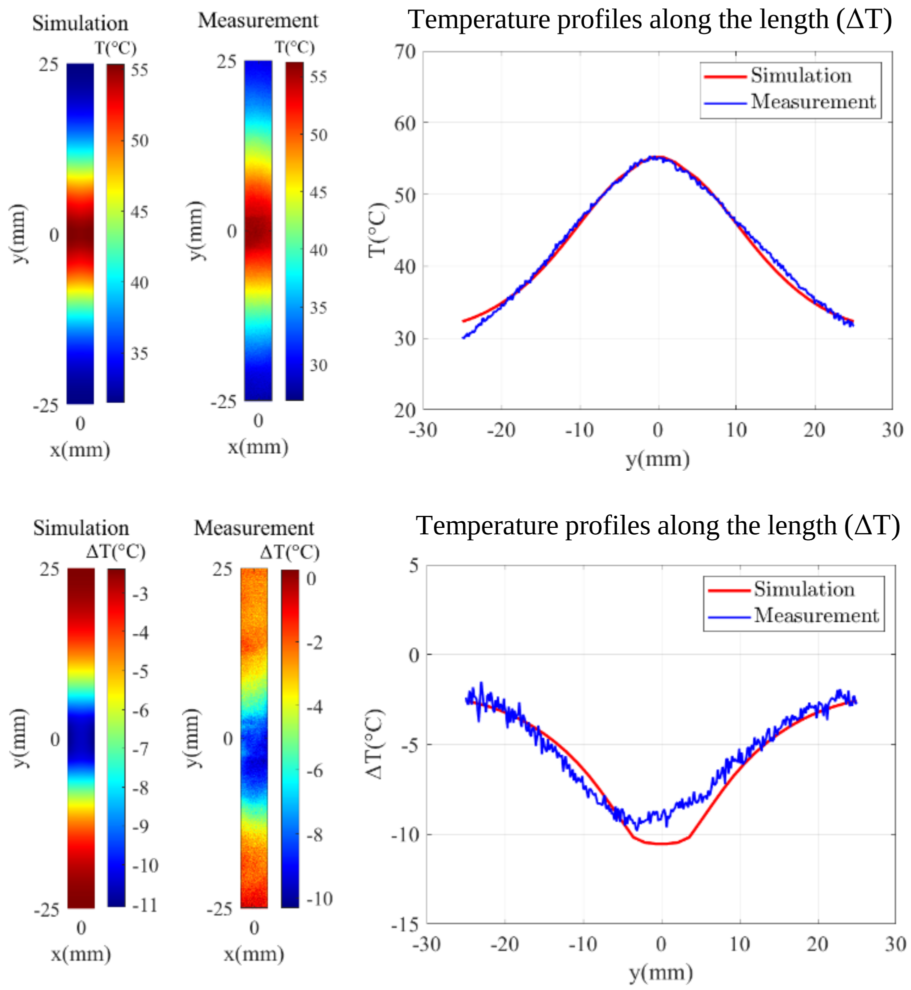
Photograph of the multilayer aluminum tape

- Delamination defect: 5 mm x 5 mm x 20 μm



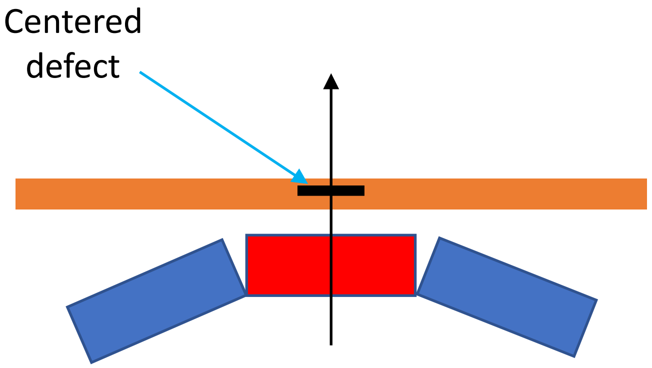
- Pore defect: 5 mm x 5 mm x 30 μm

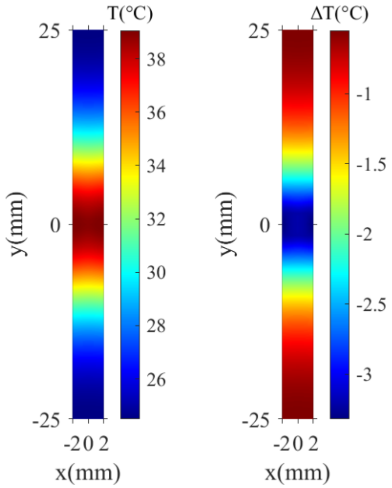
$$\vec{n} \times \vec{T} = \vec{0}\big|_{\Gamma_d}$$

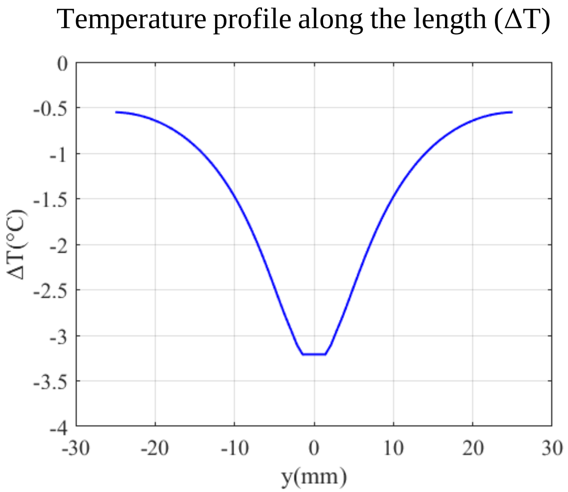


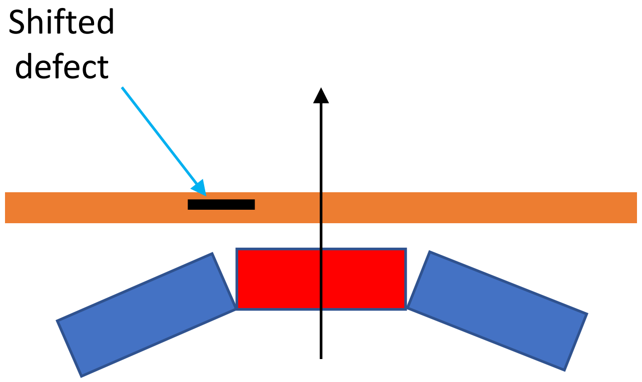
Results and validation

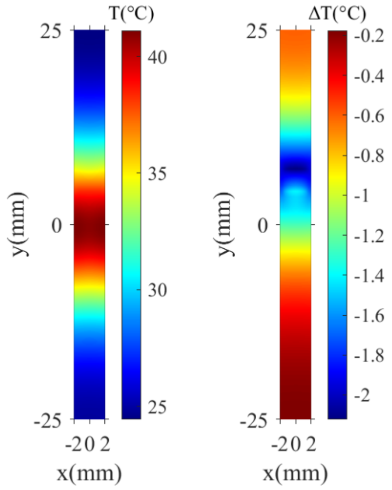
- Simulation of delamination defect in HTS tape: 3.4 mm x 3.6 mm x 30 μm

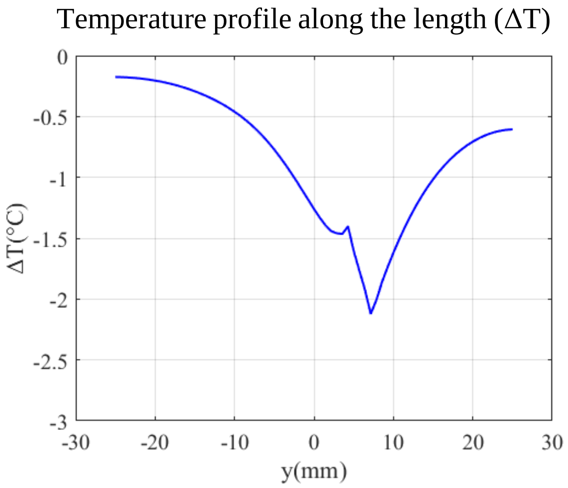








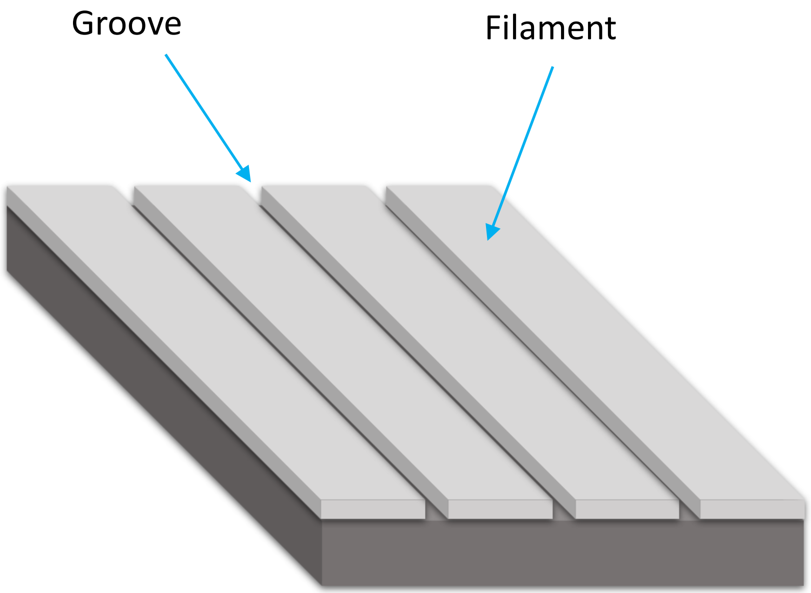




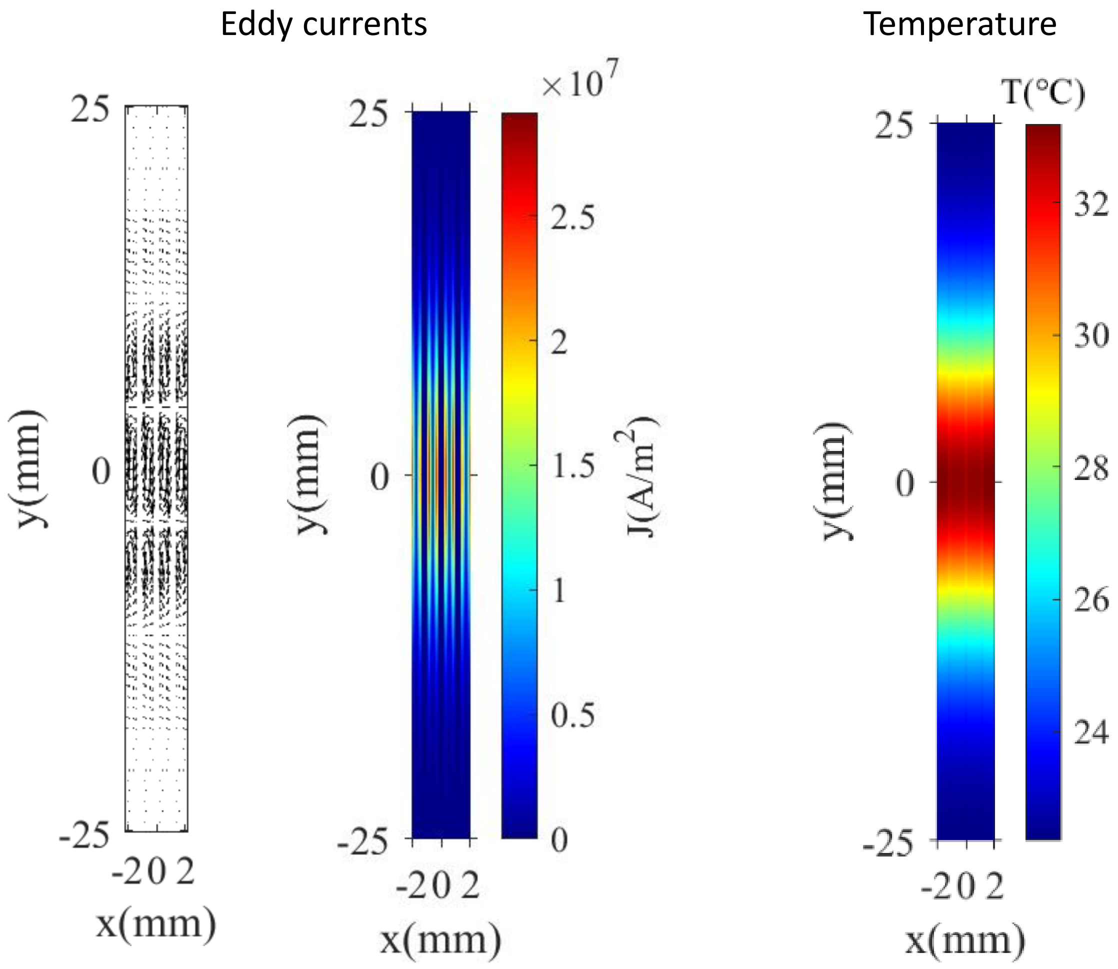
Results and validation

- Control of grooves in striated HTS tape:

Ideal grooves:



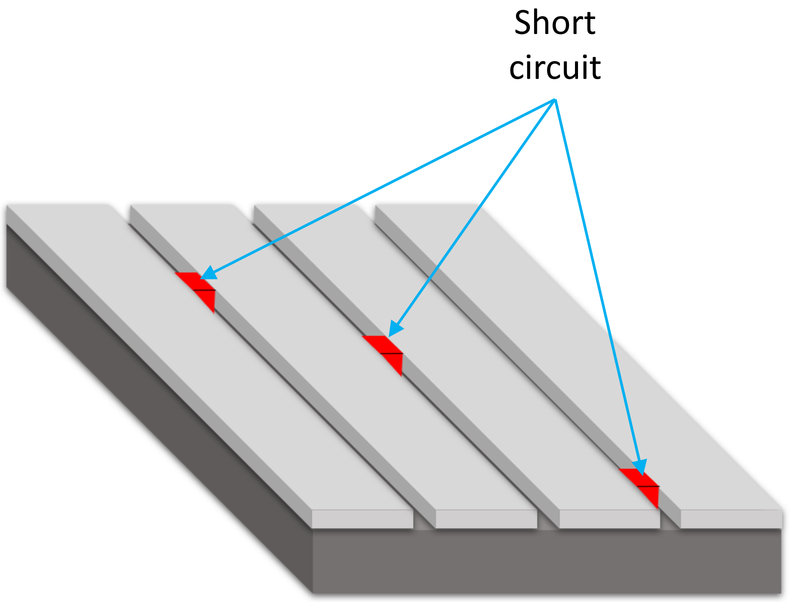
Unflawed striated HTS tape



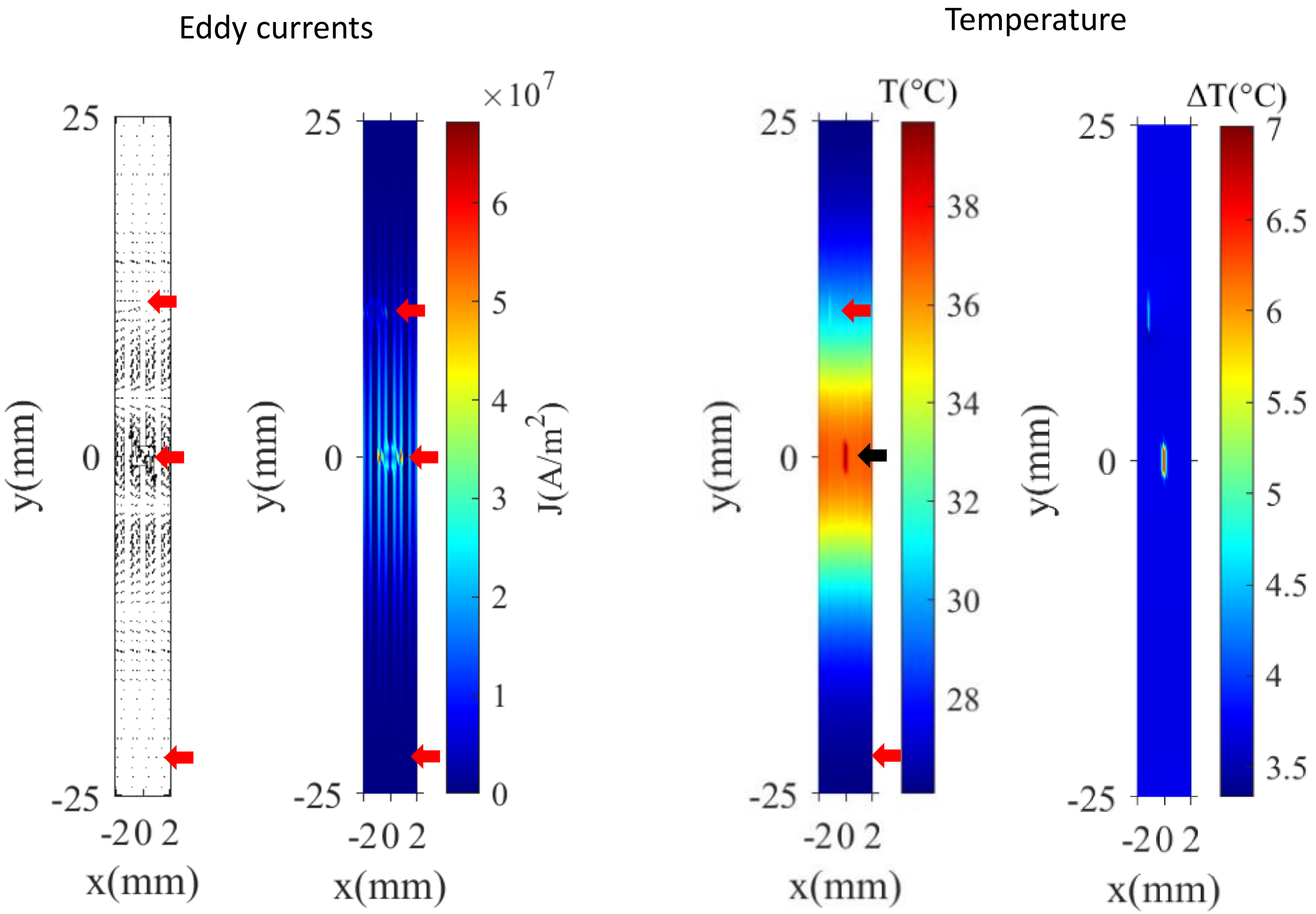
Results and validation

- Control of grooves in striated HTS tape:

  Short circuit between filaments :



Striated HTS tape presenting short circuits between filaments



Conclusion

- Numerical and experimental investigations of structural control in 2G HTS tapes **at room temperature** using eddy current thermography.
- Highlighting the possibility of detection of several types of defects.
- Efficient and rapid numerical modeling.
- Future work: experimental testing of flaws in 2G HTS tapes.

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Thank you for your attention

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