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Report on WP/Task 8.6:

HTS ReBCO Cable

T. Winkler, GSI on behalf of WP 8.6

I.FAST 2nd annual meeting, 19.04.2023

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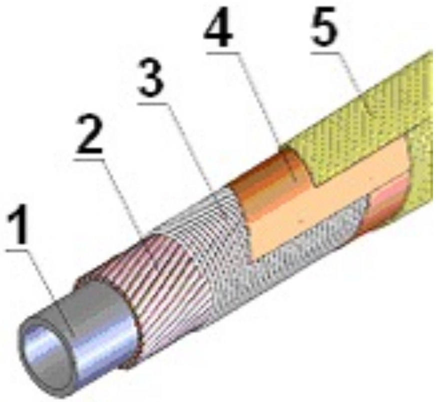
WP/Task structure and objectives

- Design Parameters for a round, high current, low AC loss HTS ReBCO cable
- Application: fast ramped, high field accelerator magnets
- Milestone: M24 (submitted for review)
- Deliverable: M32 Report on cable parameters
- Members:
  - Institute of Electrical Engineering (IEE), Slovak Academy of Sciences, Slovakia
  - ILK Dresden, Germany
  - GSI, Germany
  - EMS Chair, University of Twente (UT), Netherlands

Cable layout

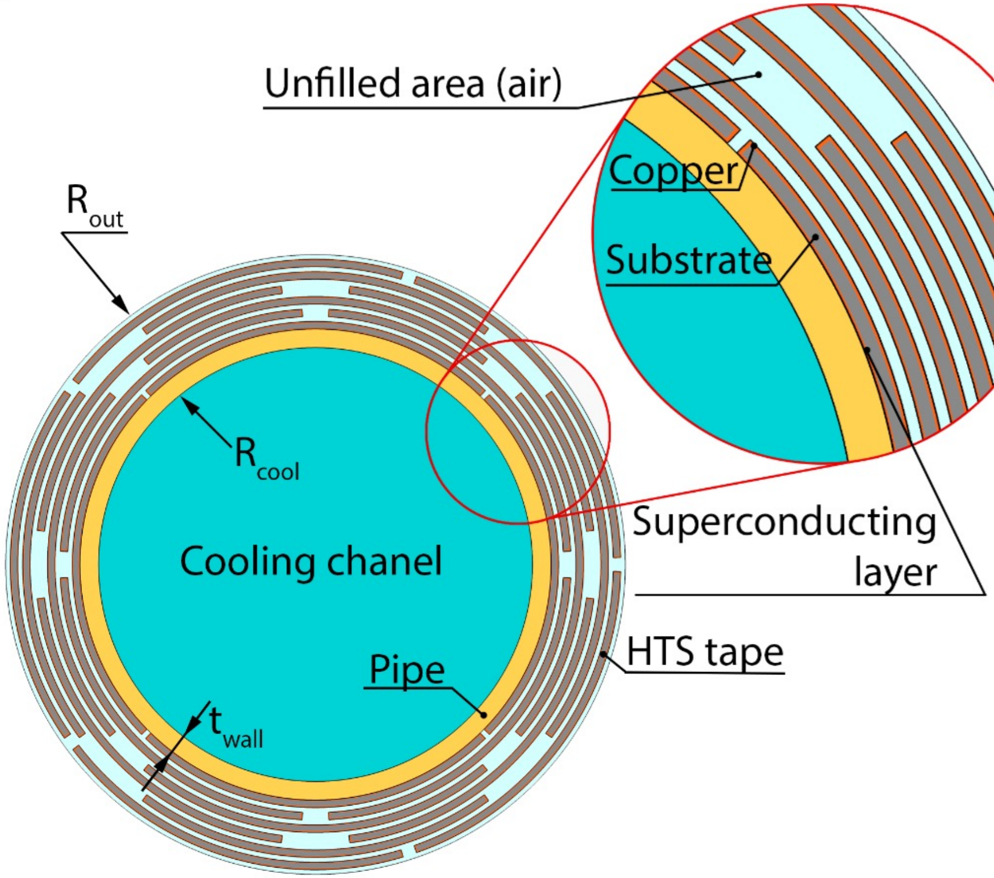


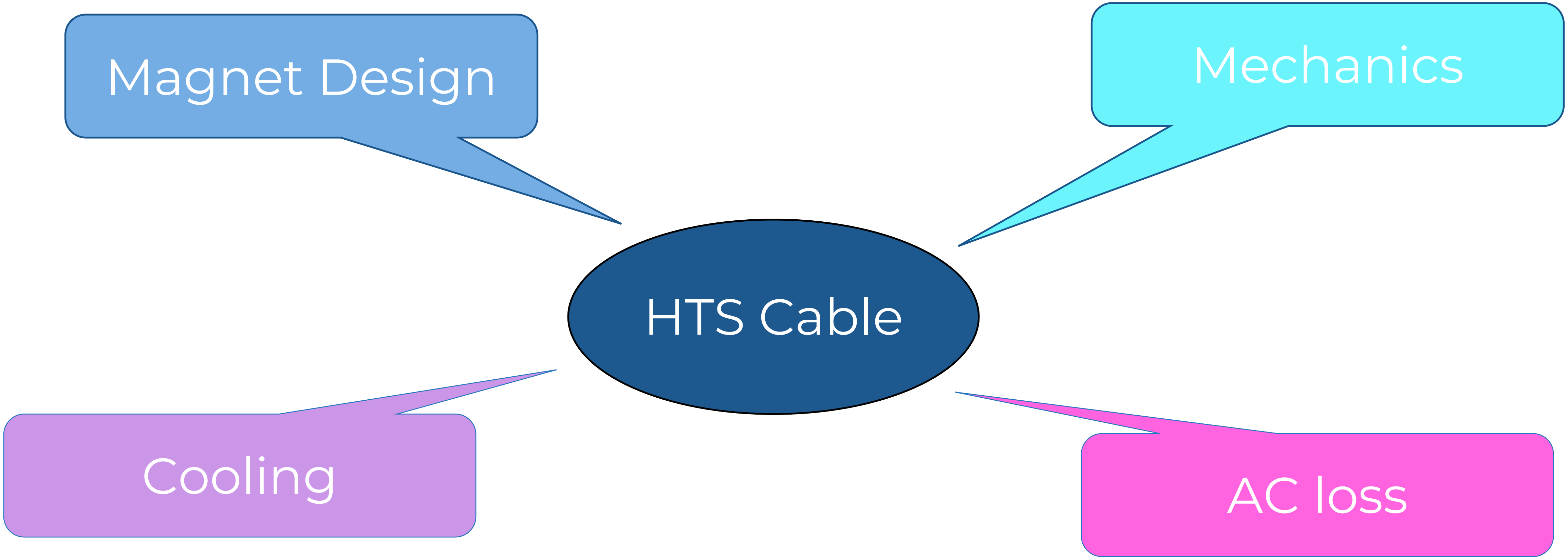

CORC by ACT, advancedconductor.com

Starting point:

- SIS100 cable (GSI/JINR) (LTS)
- CORC/CORT type cable (ACT/IEE) (HTS)

Idea: use good direct cooling properties, and windability of SIS100 cable and apply it to HTS





AC loss and the cooling capacity are the main focus of year 2

AC loss estimate for CORT cable

assumptions: tapes are in magnetic field higher than the penetration field, e.g. saturation of screening currents

$$Q_{h,CORT} = B_{max} N I_c \frac{1}{\pi cos\alpha} w$$

In an alternative from LTS strands, with diameter d_f:

$$Q_{h,LTS} = B_{max} N I_c \frac{8}{3\pi} d_f$$

Assuming $w = 3$mm and d_f = 3 μm:

$$\frac{Q_{h,CORT}}{Q_{h,LTS}} = \frac{3}{8cos\alpha} \frac{w}{d_f} \approx \frac{w}{2d_f} = 500$$

=> Increasing the operating temperature alone won't solve this problem!

AC loss estimate for CORT cable: experimental verification

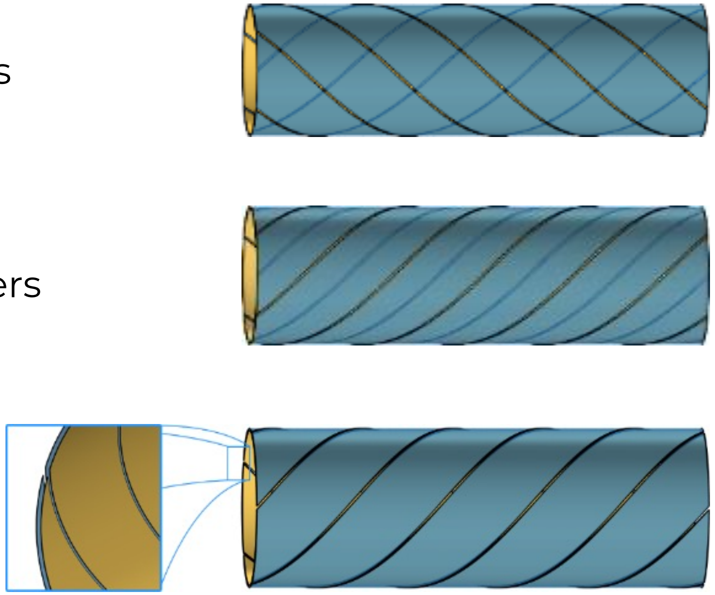
$$\Gamma = \frac{Q_{cable}}{L_{cable} S_{cable}} \frac{2\mu_0}{B_{max}^2}$$

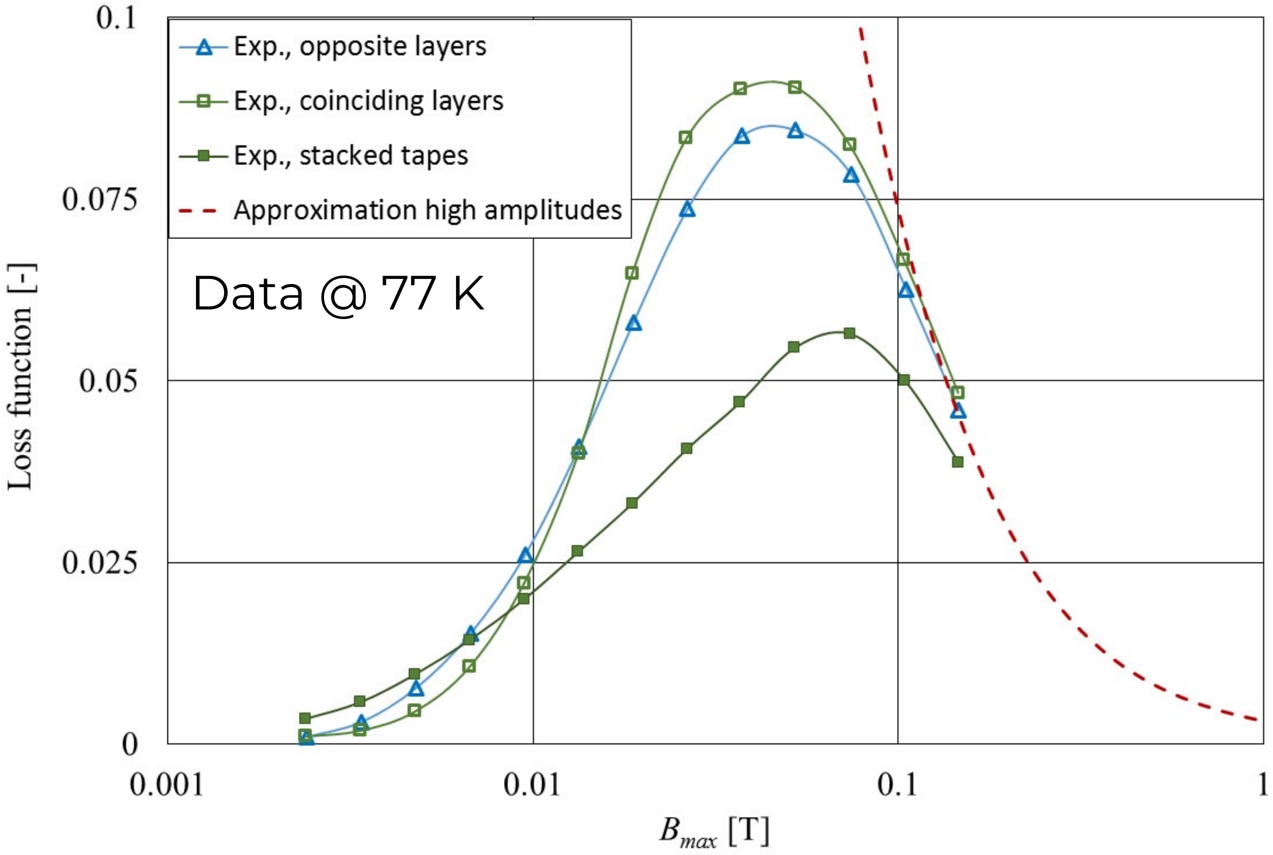
3 samples: 2 x 5 tapes

Opposite layers

Coinciding layers

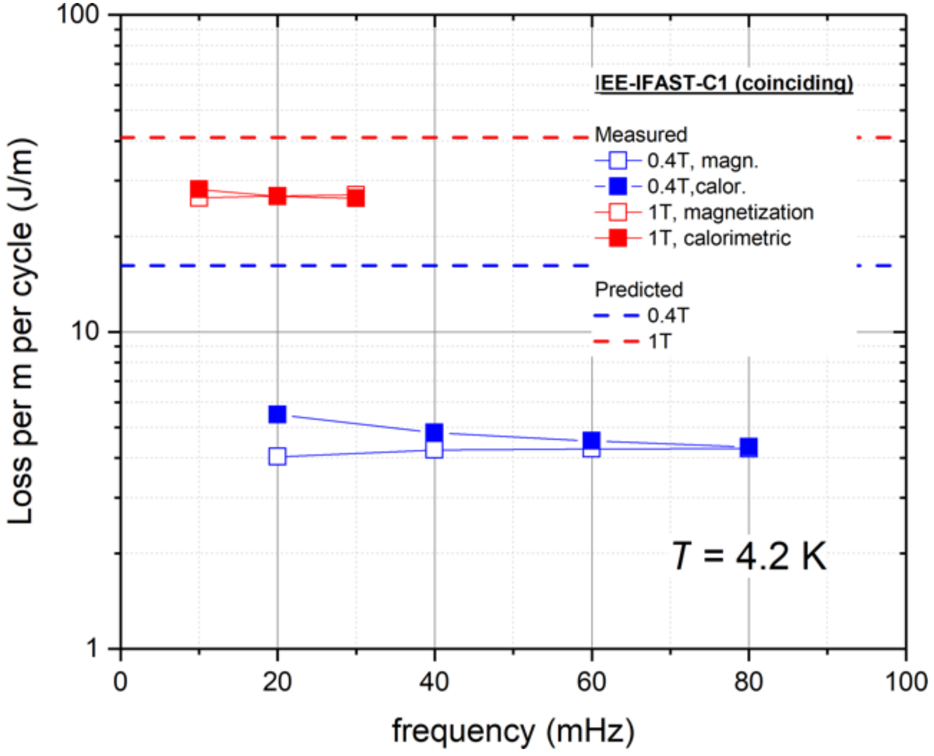
Stacked tapes

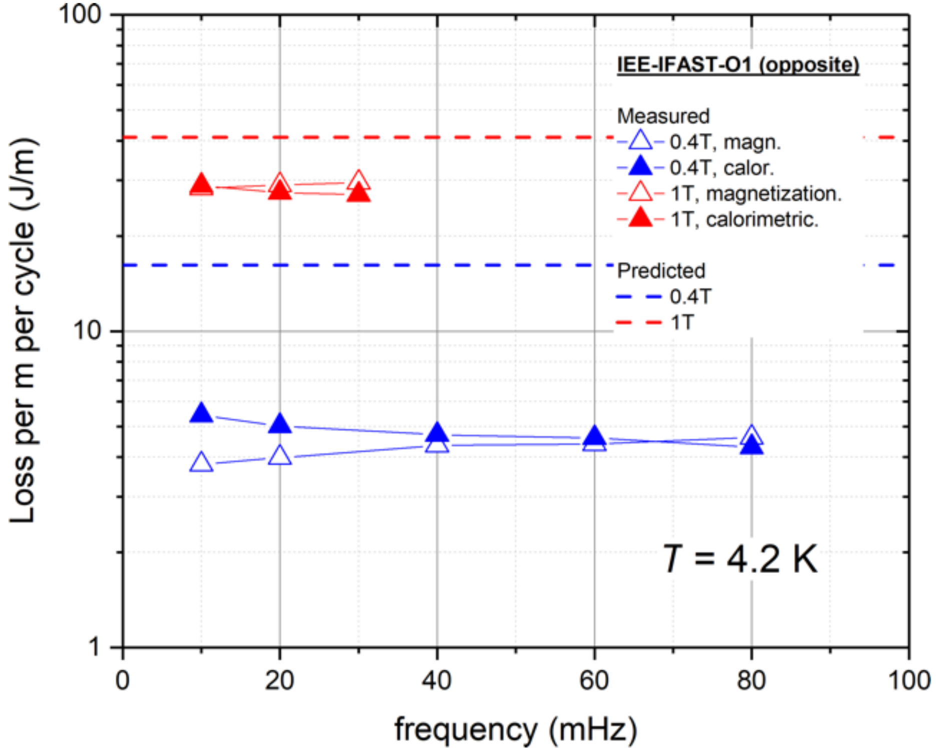




AC loss estimate for CORT cable: experimental verification

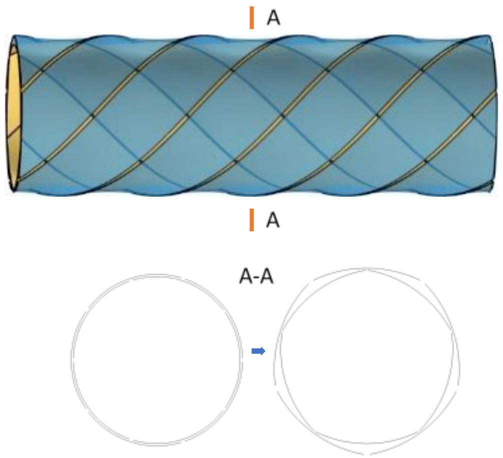
- Measurements at 4 K @ UT
- Deviation due to higher I_c compared to 77 K

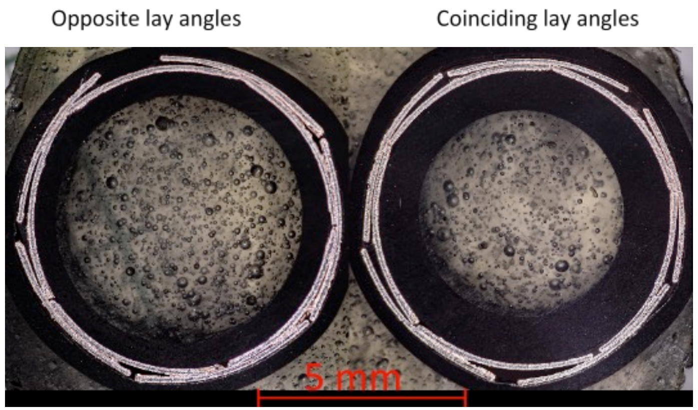




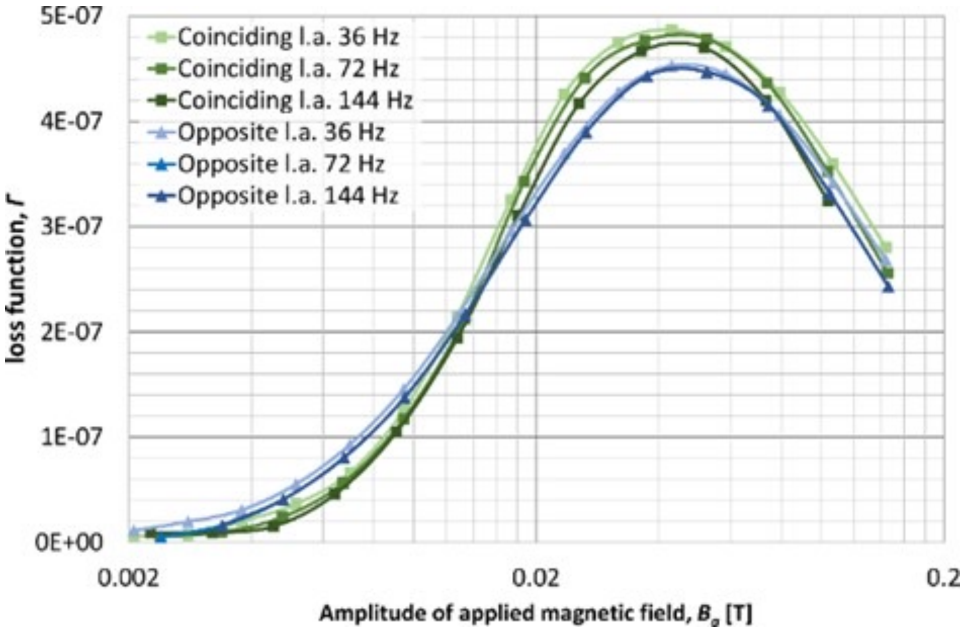
AC loss estimate for CORT cable

Coupling loss depends on
electrical contacts between tapes





AC loss measured at 77.3 K



Modeling and cross sections show that tape contacts are very limited.

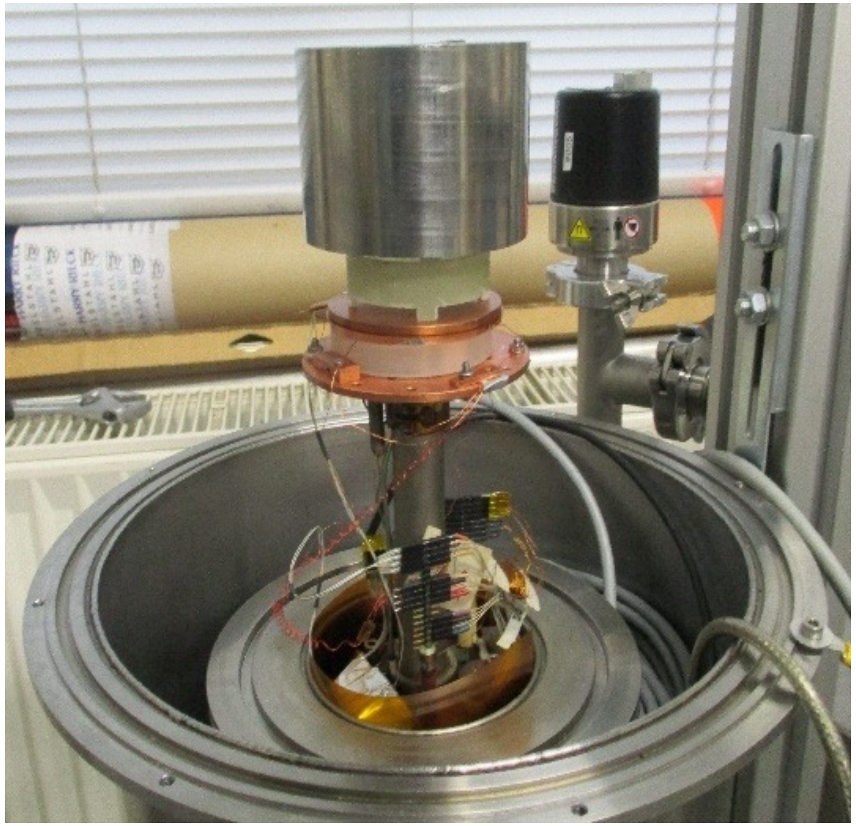
no frequency dependence
=> no coupling currents

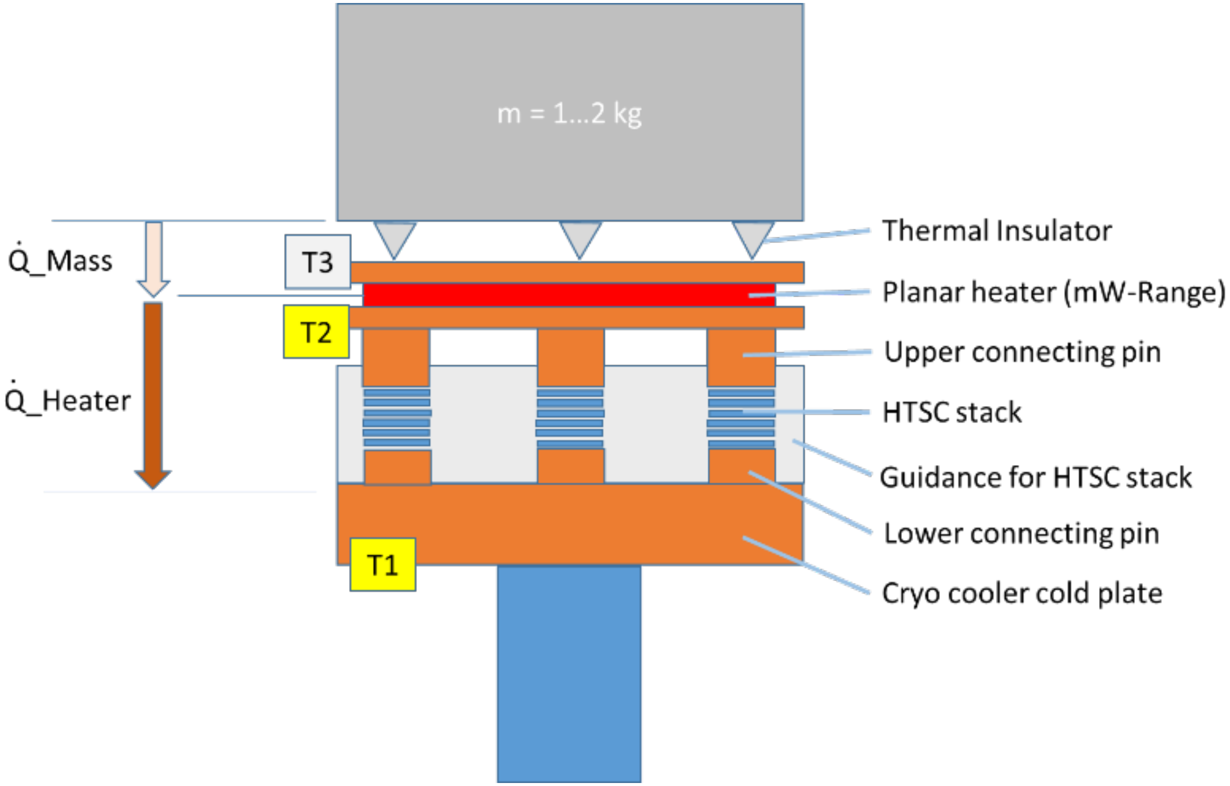
Possible Mitigation Strategies

- Striation of HTS tapes
- Higher operating temperatures

- Cable layout ?
- Magnet design ?

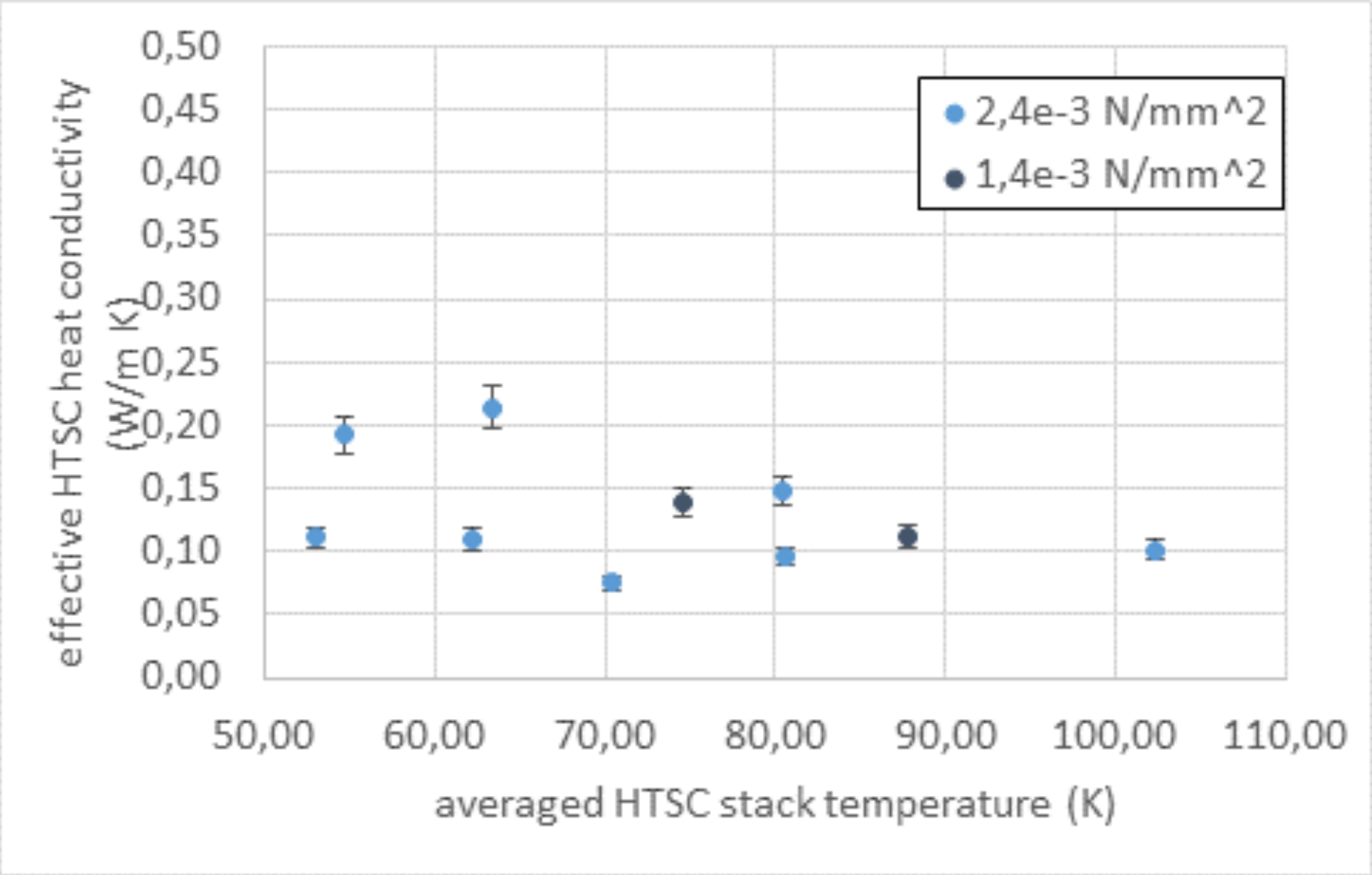
Thermal Conductivity Measurements





Experimental setup for investigation of the heat conduction of HTS materials

Thermal Conductivity Measurements

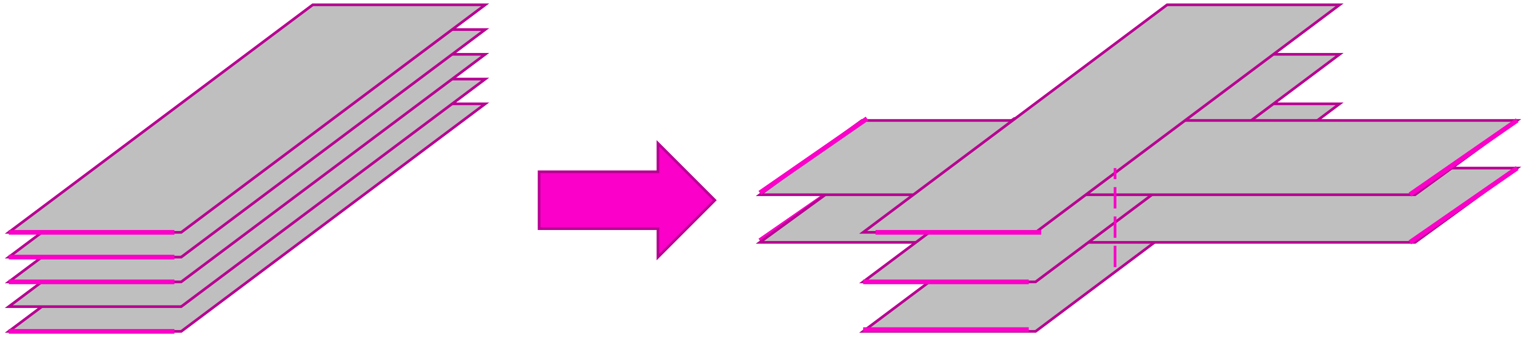


Experimental result:
heat conductivity plotted over the averaged HTSC stack temperature

Effective thermal conductivity for 25 tapes

Thermal Conductivity Measurements

- Multiple steps planned:
  - Comparison measurement using Apiezon N
  - Vary compression force
  - Change sample layout to reduce the effect of burr at cutting edge



Summary

AC loss

A simplified AC loss model was developed and experimentally verified.

It shows a big dependency on the sc dimensions.

AC loss of ReBCO cables is mostly hysteresis loss, coupling loss is negligible.

AC loss is a *challenge* for CORT-type cables in fast-ramping applications

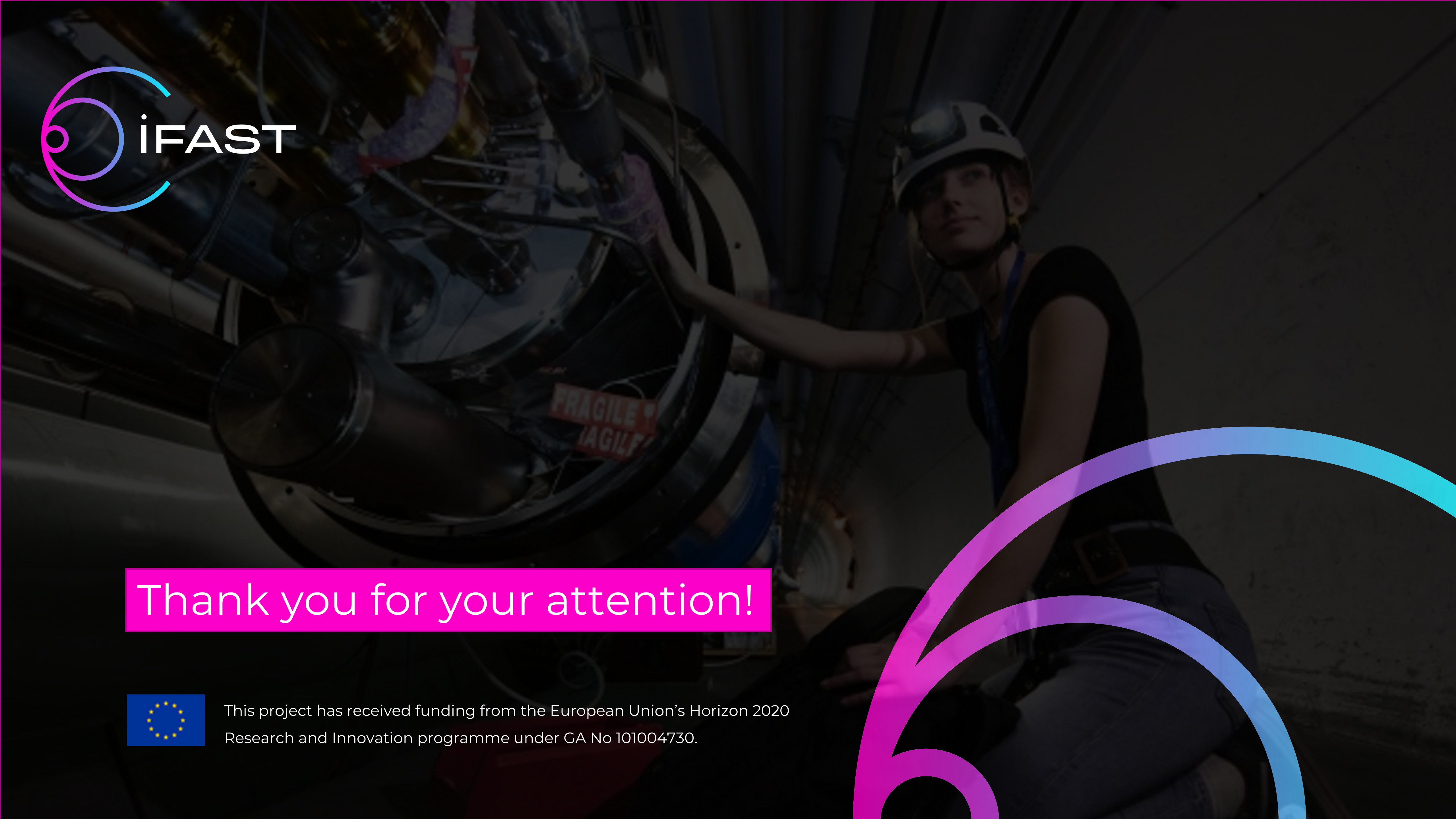
Cooling

A setup for transversal thermal conductivity was built.

First measurements show a thermal conductivity of ~ 0.13 W/m*K.

More measurements ongoing to distinguish between thermal contact resistance and thermal conductivity of a tape.

Increase of parameter space ongoing.



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Thank you for your attention!

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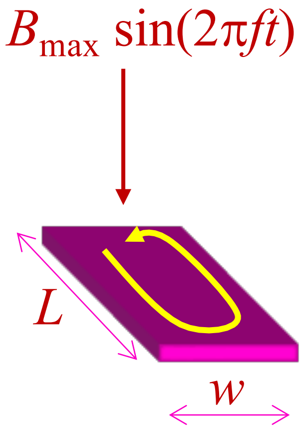
Formula for estimating hysteresis loss in round HTS cable

Assumption: magnetic field variation higher than the penetration field
-> saturation of screening currents

Step 1: single tape (critical current I_c, width w) in perpendicular magnetic field

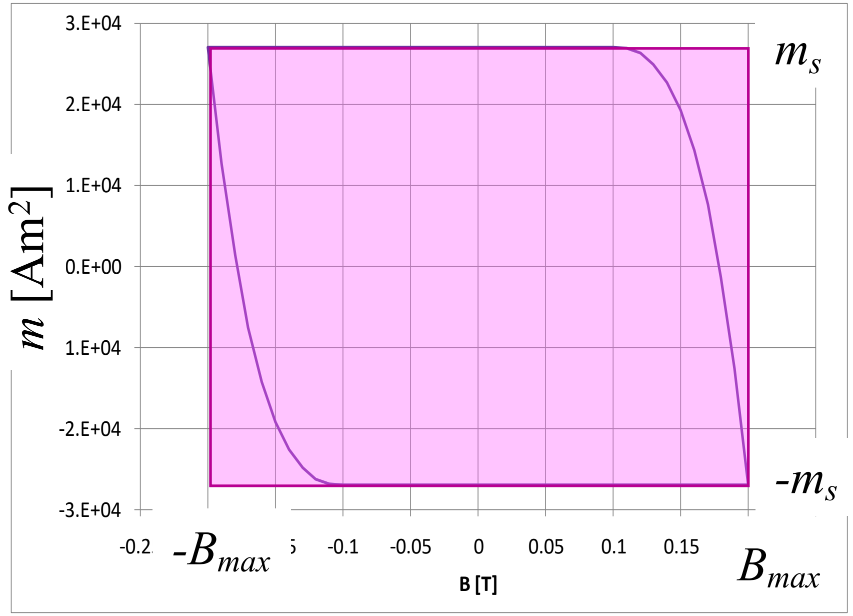


magnetic moment at saturation

$$m_s = \frac{I_c w}{4} L$$

hysteresis loss per cycle and unit length:

$$\frac{Q}{L} \approx 4 B_{max} \frac{m_s}{L} = B_{max} I_c w$$



Formula for estimating hysteresis loss in round HTS cable

Assumption: magnetic field variation higher than the penetration field
-> saturation of screening currents

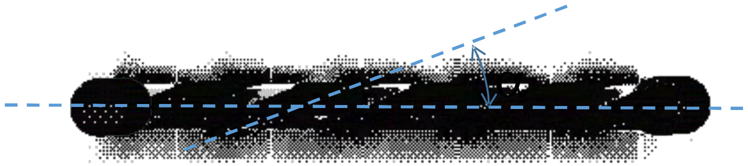
Step 2: tape is wound in helical fashion, orientation of magnetic field changing from 0 to 360 degrees

hysteresis loss per cycle and unit length of the tape:

$$\frac{Q_h}{L} = \frac{2}{\pi} B_{max} I_c w$$

Step 3: tape is wound in helical fashion, at lay angle α

for the cable length L_c is needed the tape length



$$L_T = \frac{L_c}{cos\alpha}$$

hysteresis loss per cycle in one tape in 1 meter of CORT:

$$Q_{hT} = \frac{2}{\pi cos\alpha} B_{max} I_c w$$

Formula for estimating hysteresis loss in round HTS cable

Assumption: magnetic field variation higher than the penetration field
-> saturation of screening currents

Step 4: to reach the necessary critical current,
in CORT there are N tapes

hysteresis loss per cycle in N tapes in 1 meter of CORT:

$$Q_{hCORT} = \frac{2N}{\pi cos\alpha} B_{max} I_c w$$

loss in unipolar cycle is ~½ of the loss in full cycle

$$Q_{hCORT,uni} = \frac{N}{\pi cos\alpha} B_{max} I_c w$$

Notice: the formula(s) are valid for also for other cables from transposed CC tapes