Design tools and optimization for DC HTS cables for the future railway network in France

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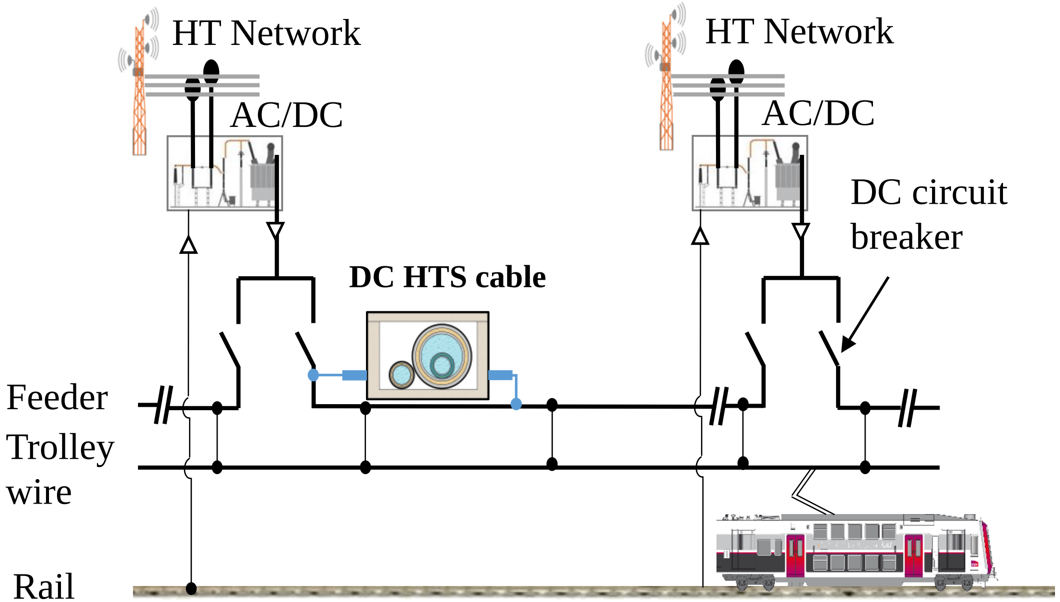
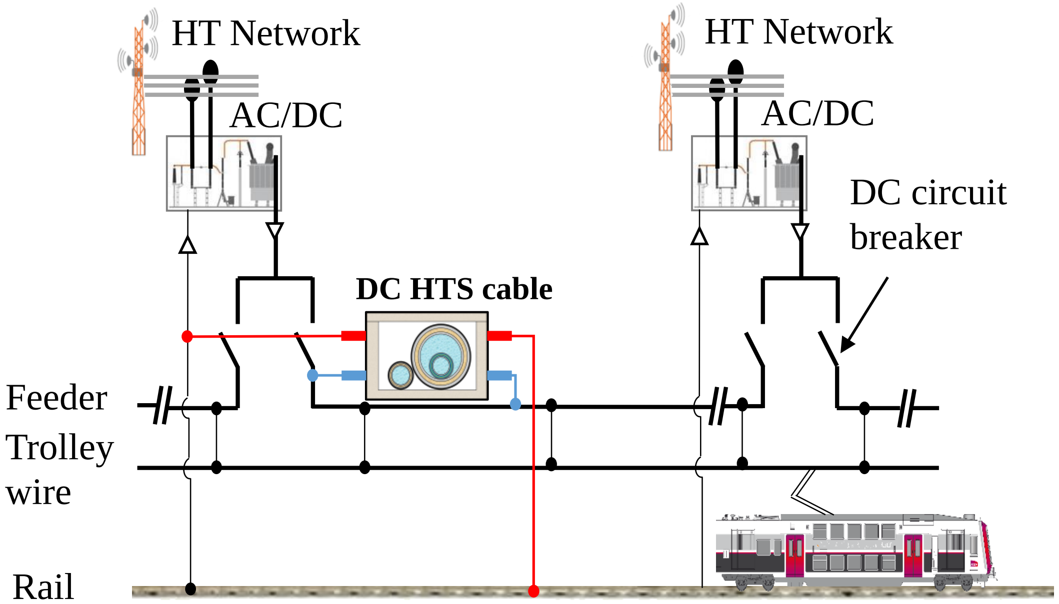
I. Railway context

Unipolar DC HTS cable

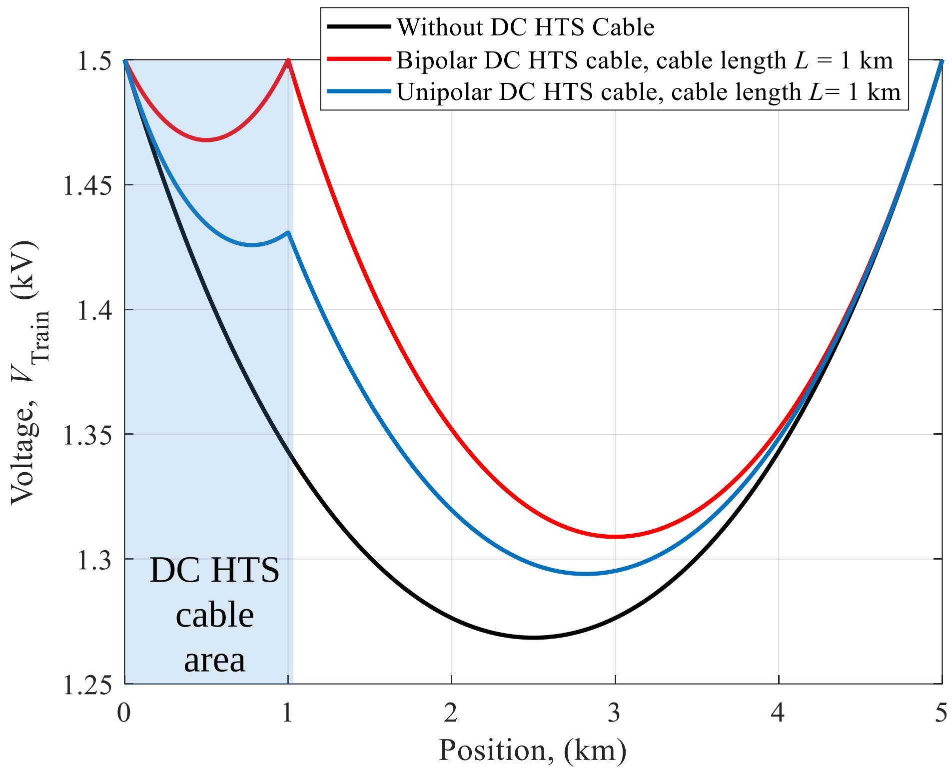


Bipolar DC HTS cable



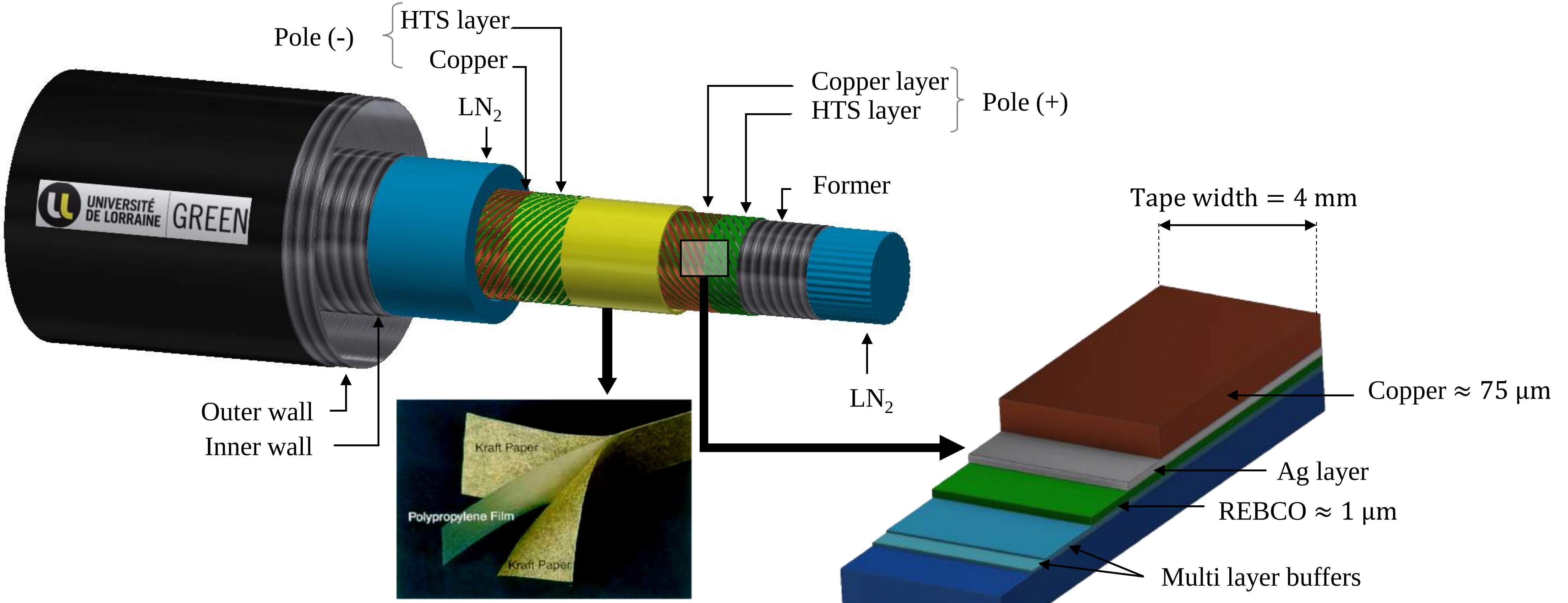
I. Railway context

Parameter	Value
DC HTS Cable Length	1 km
Distance between substation	5 km
Output voltage of the substation	1,5 kV
Substation resistance	0,03
Rail resistance	0,0158
Line resistance	0,028
DC superconducting cable resistance	≈ 0
Train power	7 MW



- Estimation of the length and topology of the superconducting cable to meet the specifications of the railway load.

II. Design of DC HTS cable

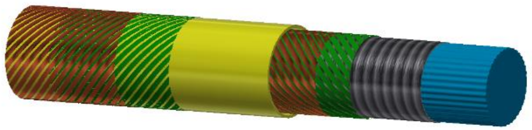


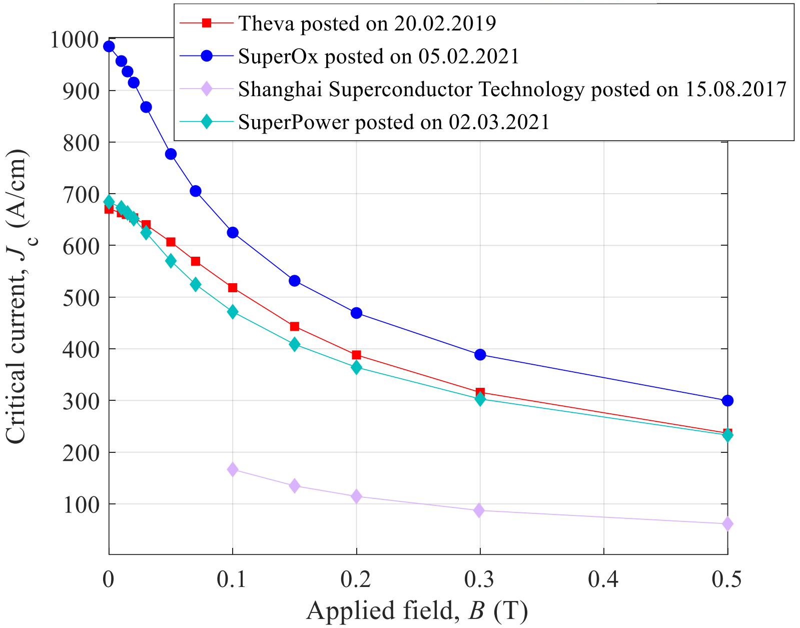
Electrical insulation
Dielectric rigidity (50 kV/mm).

III. Sizing process

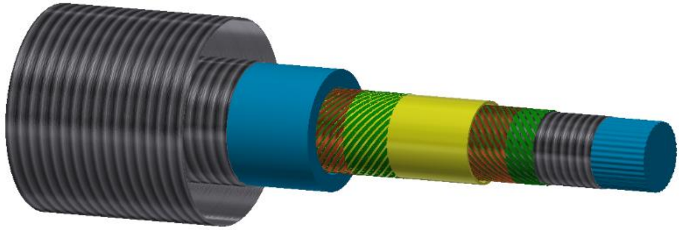
Parameter
Railway Network
Operating voltage 1,5 kV Operating current 10 kA
Standard data DIN 10380
Standard data for cryogenic tanks
Data $J_c(B,\theta,T)$
Cable length and topology

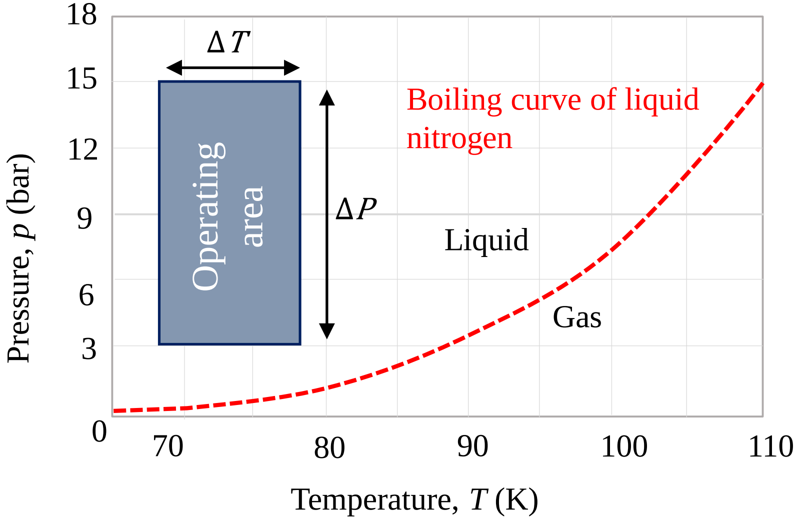
Electromagnetic sizing





Hydraulic and thermal sizing





The critical current must be higher than the transport current (with a margin of 20%)

https://figshare.com/collections/A_high_temperature_superconducting_HTS_wire_critical_current_database/2861821

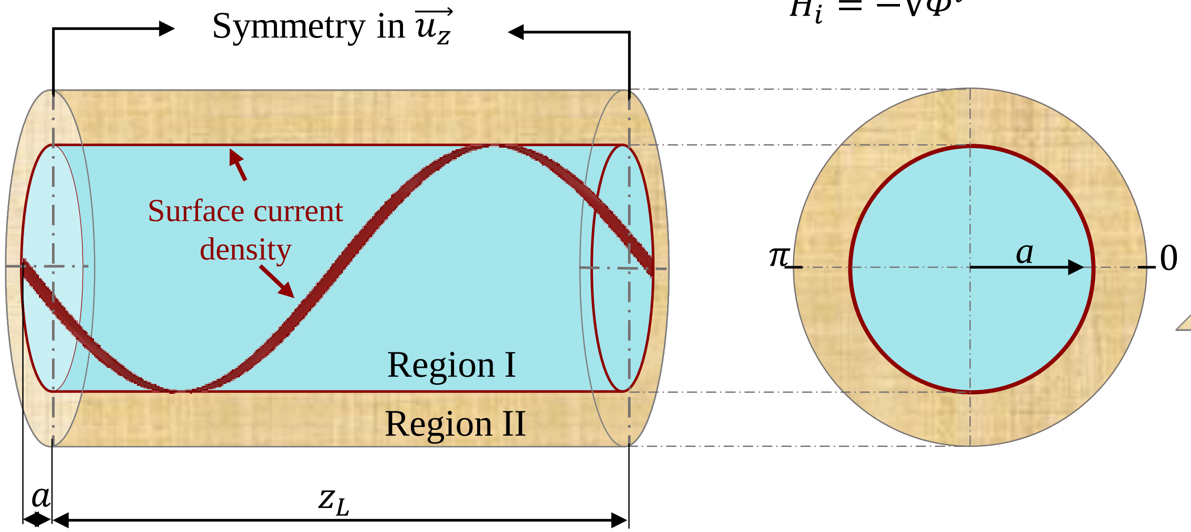
III. Sizing process

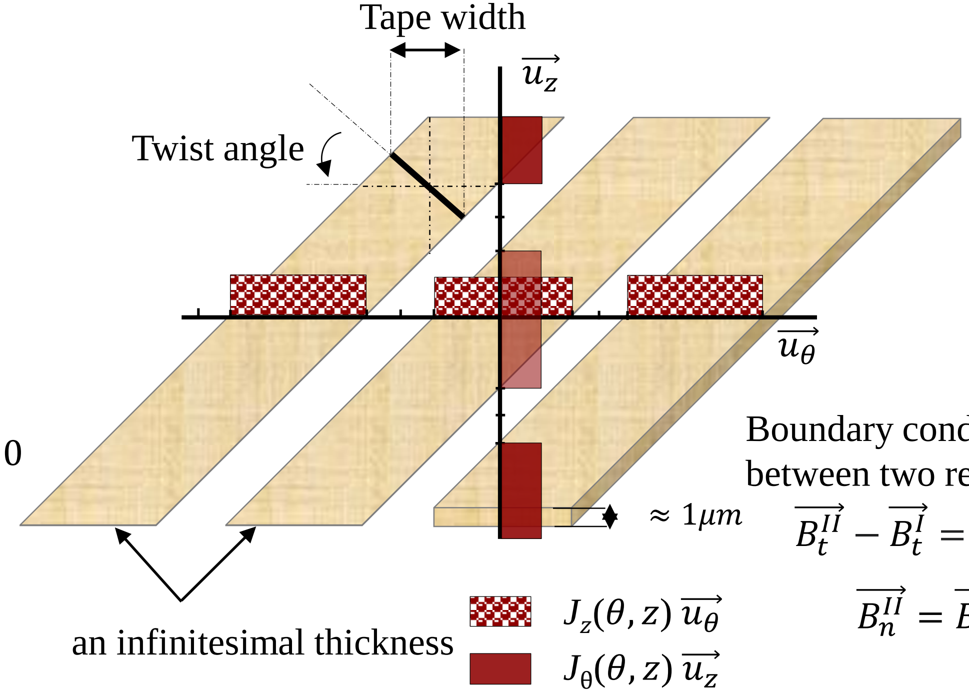
❖ Electromagnetic Study

Equations to solve:

$\Delta\Phi^i = 0, (i = I \text{ or } II)$

$\vec{H_i} = -\vec{\nabla}\Phi^i$





Boundary condition between two regions :

$\vec{B_t^{II}} - \vec{B_t^{I}} = \vec{K_s} \wedge \vec{n}$

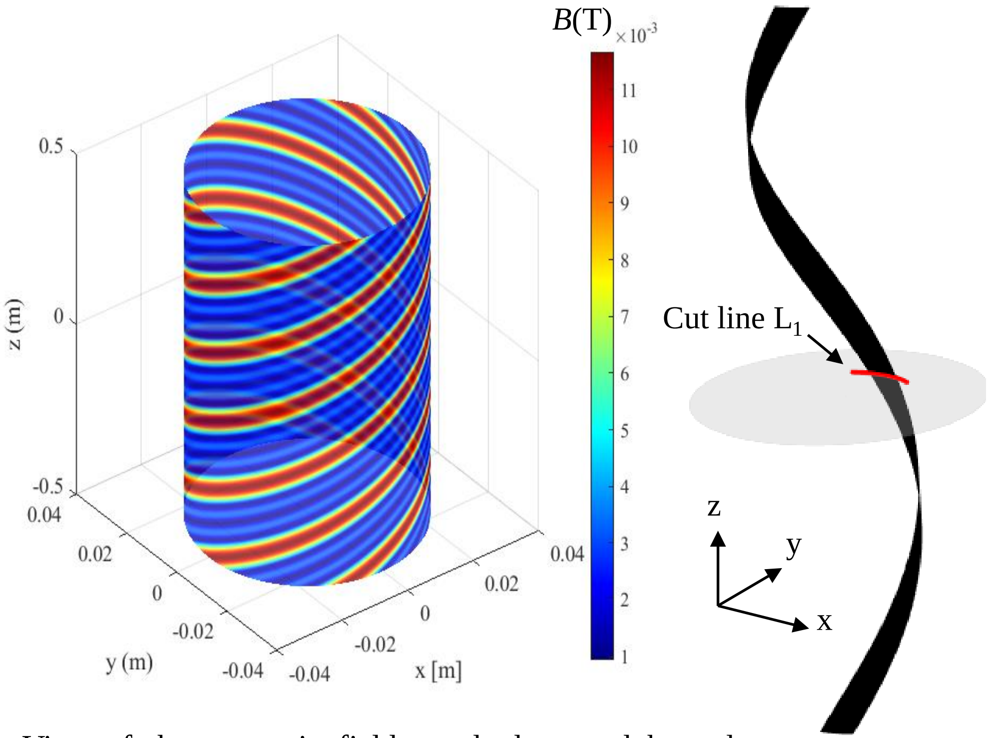
$\vec{B_n^{II}} = \vec{B_n^{I}}$

Expression of the radial magnetic field in the region I :

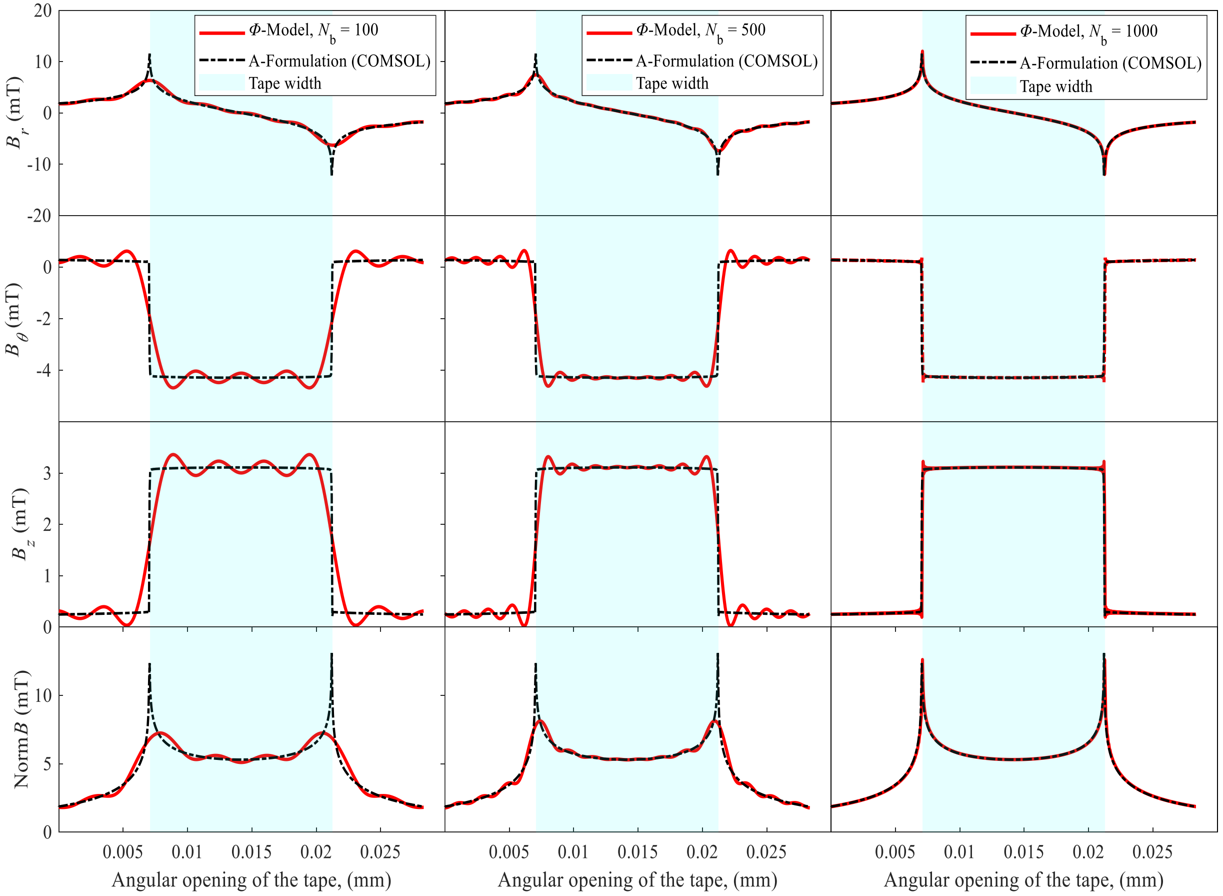
$$\vec{B_r^I}(r,\theta,z) = \frac{2\mu_0 I}{\pi k^2}\frac{a^2}{d} cos(\delta)\, sin\left(\frac{\alpha_z}{\beta_z}\pi k\right) K'_k(k\,m\,a)\, I'_k(k\,m\,r)\; sin\Big(k\big((\theta - \varphi_0) - m\,z\big)\Big)$$

III. Sizing process

❖ Electromagnetic Study



View of the magnetic field standard created by a layer containing 5 tapes. The radius of the cable is 3 cm and the twisting pitch is 10 cm, the current in each tape is 100 A.

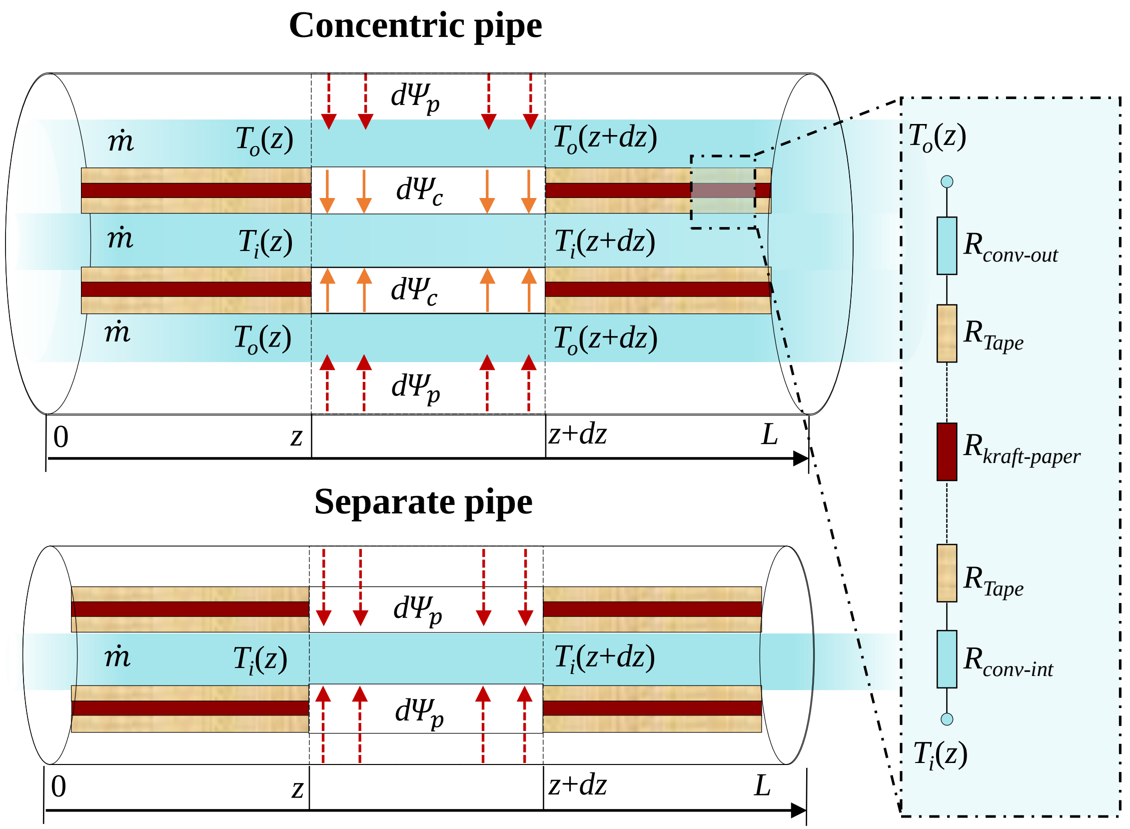


III. Sizing process

❖ Hydraulic and Thermal Design

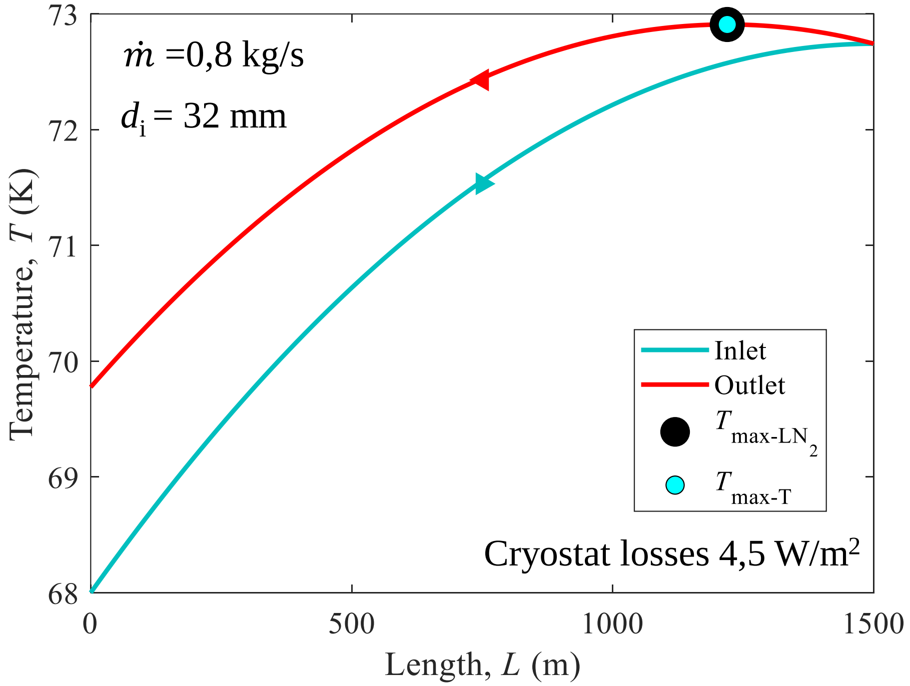
- Model parameters
  - $T_o(z)$ is the temperature in the outer pipe.
  - $T_i(z)$ is the temperature in the inner pipe.
  - Ψ_p is the heat flux from the cryostat.
  - Ψ_c is the heat flux transferred from the outlet pipe to the inlet pipe.
- Calculates the temperature increase of the liquid nitrogen in the cable and the pressure drop.

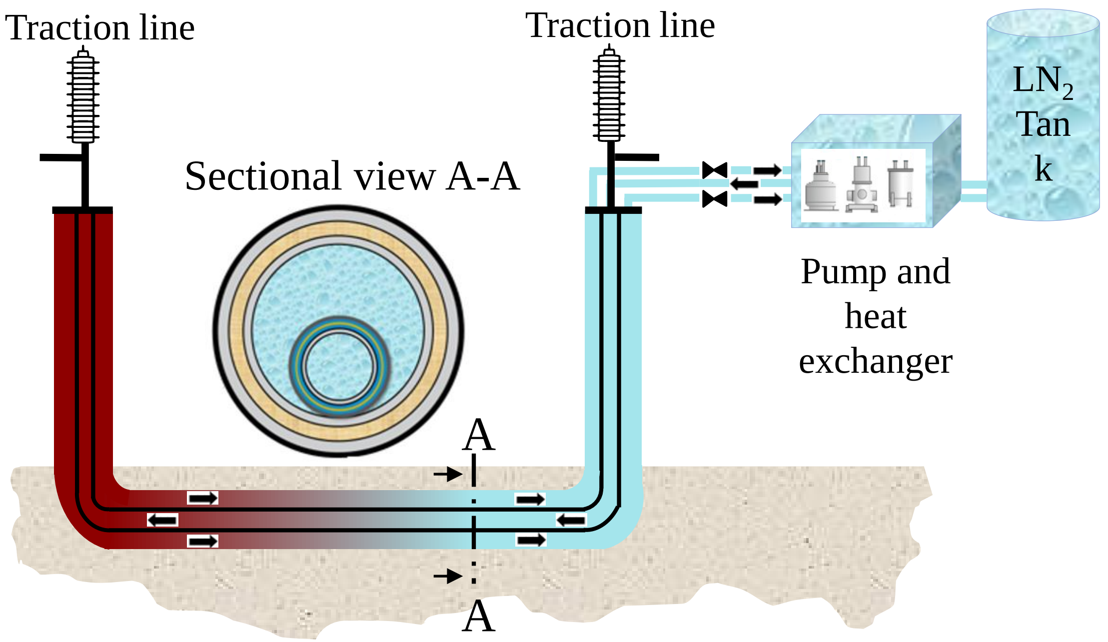
The length of the superconducting cable has an significant impact on the design of the cable and cooling system power.



III. Sizing process

❖ Hydraulic and Thermal Design

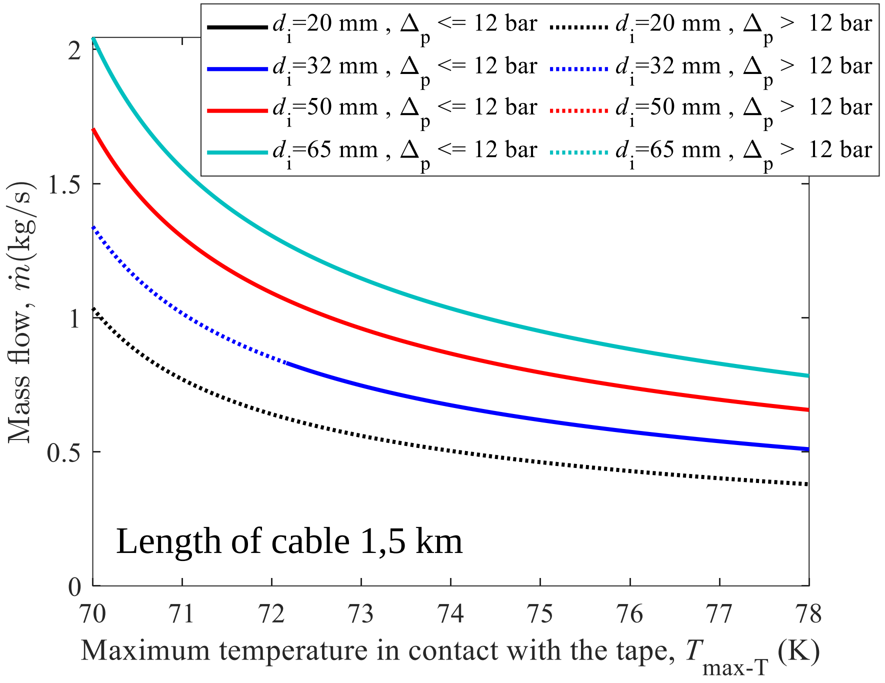


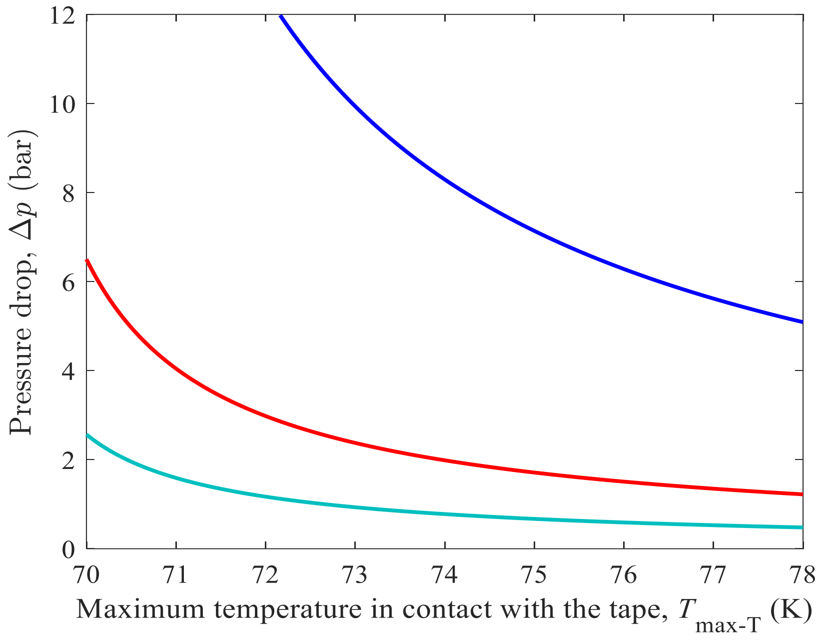


- The calculation of the critical current depends on the maximum temperature in contact with the tape I_c (B,T_{max-T}).

III. Sizing process

❖ Hydraulic and Thermal Design





- Calculation of mass flow and pressure drop for different standard diameters DIN 10380.

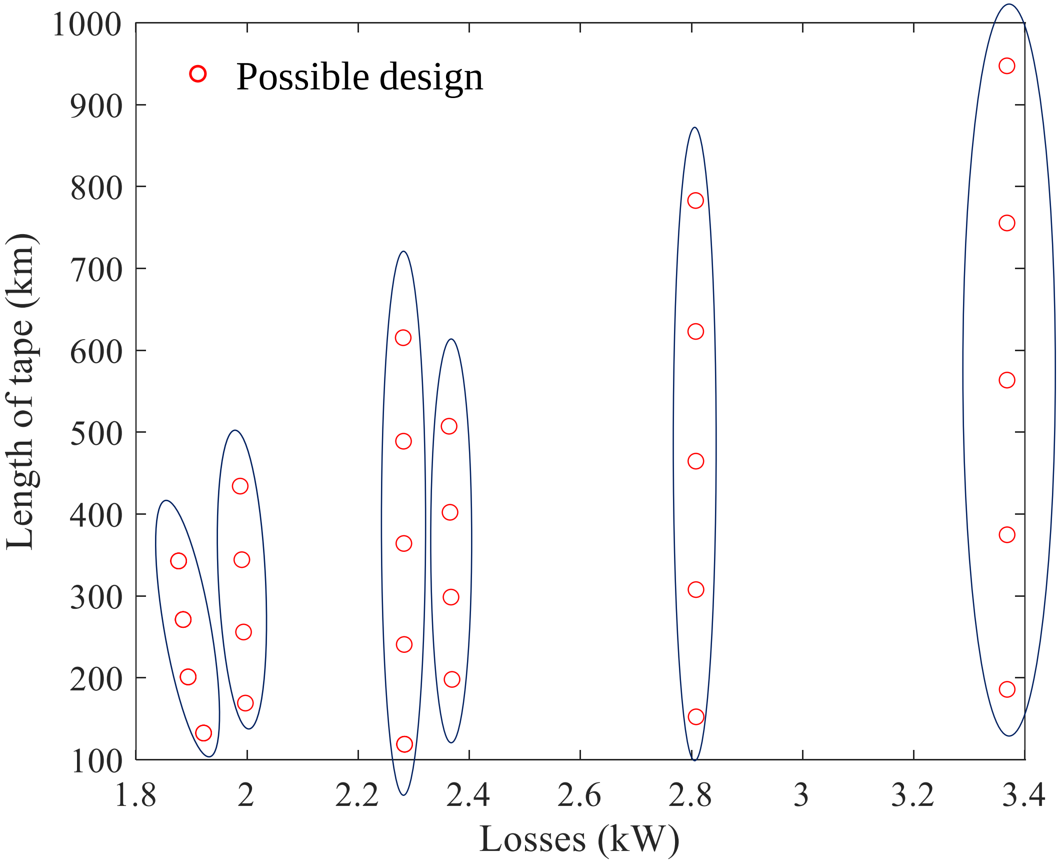
The mass flow rate is limited by the cooling system capacity and the pressure drop.

IV. Results

Standard radius DIN10380

		d_i mm	d_o mm
✖	20	20,2	22,2
✓	25	25,2	27,4
✓	32	33,7	35,9
✓	40	40,0	42,8
✓	50	50,0	52,8
✓	65	65,0	68,4
✓	80	79,8	83,8

Cooling type CP-Transport current more than 10 kA- Cable length 1.5 km



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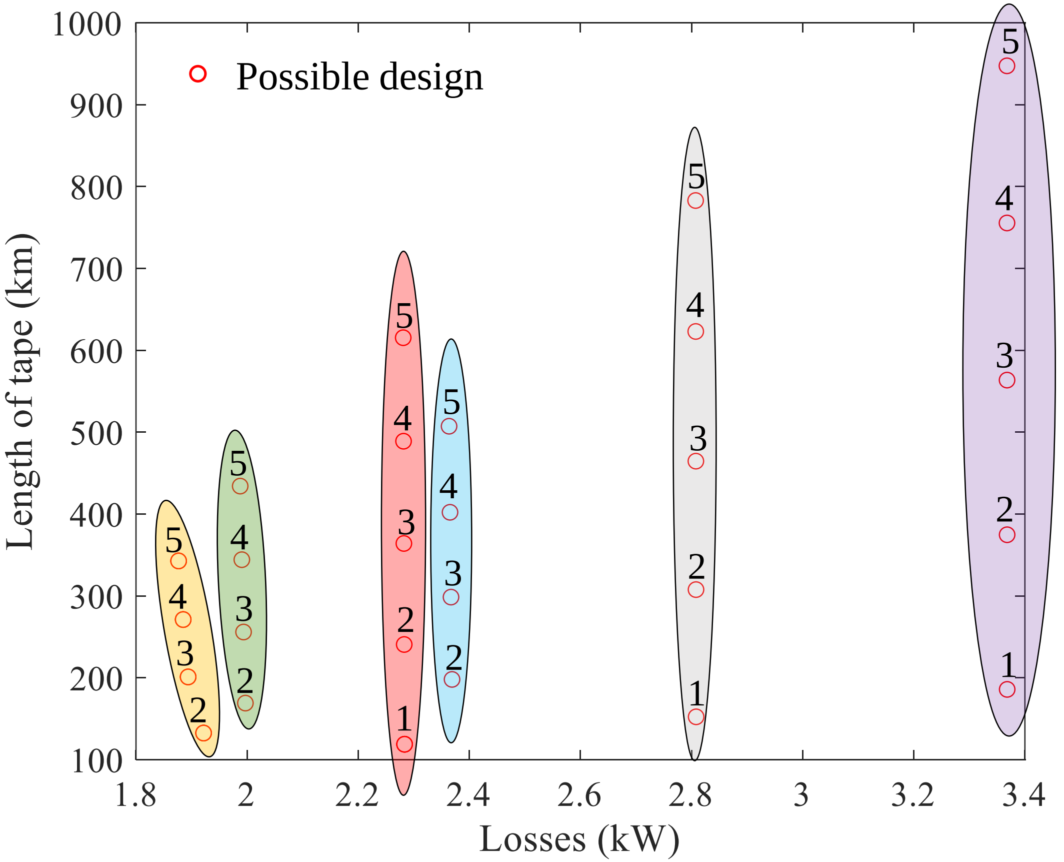

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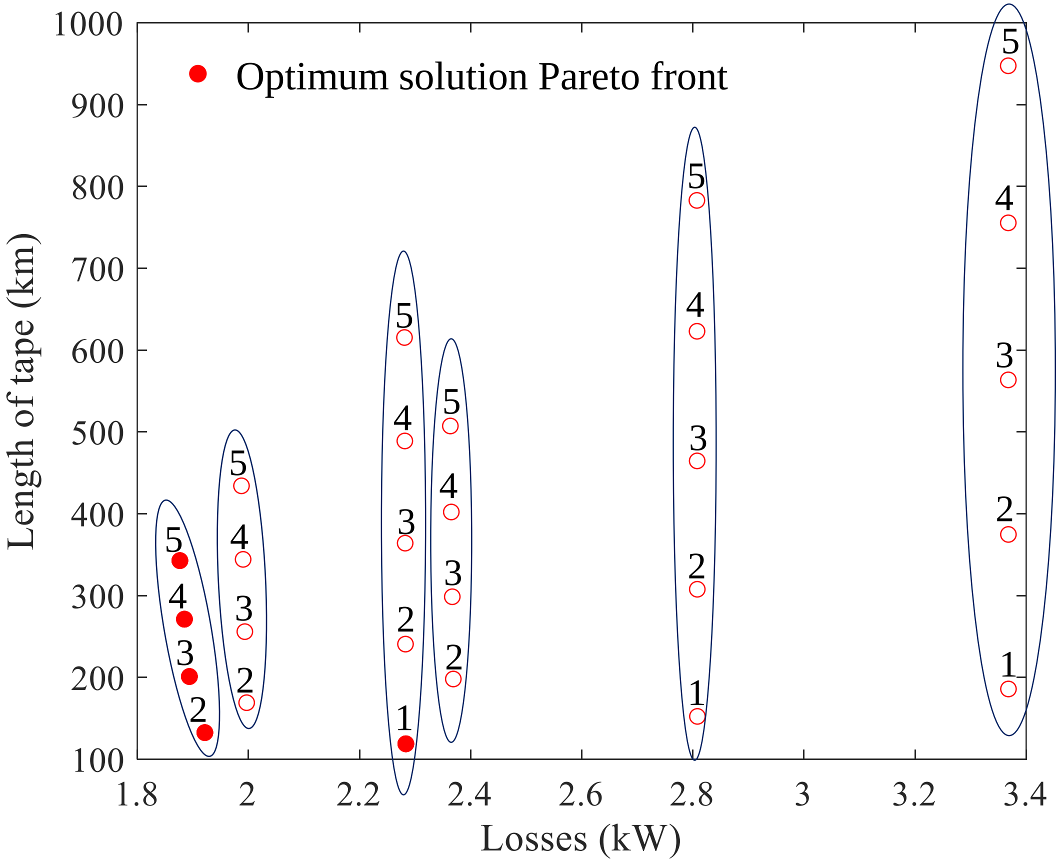

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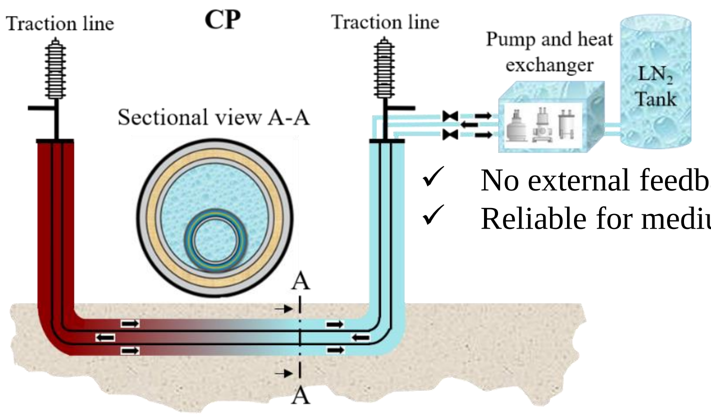
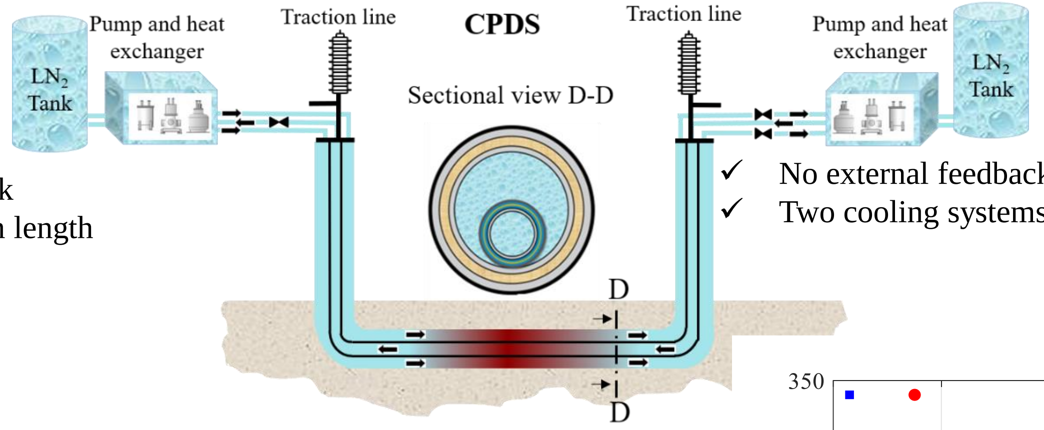
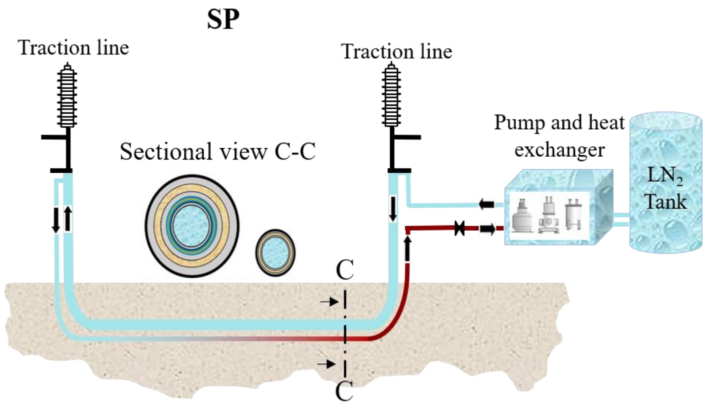


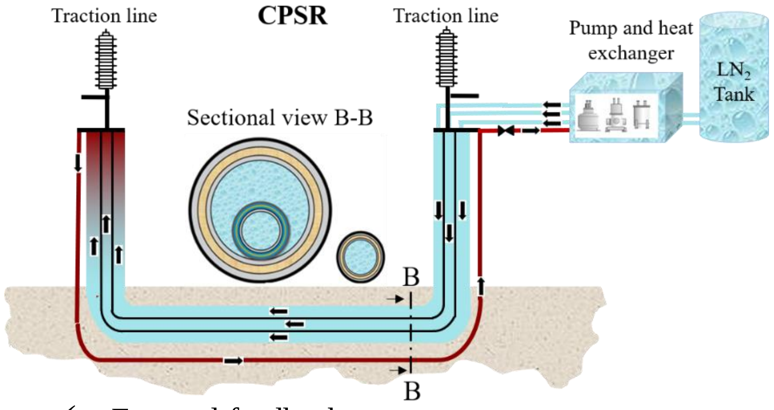
- ✓ No external feedback
- ✓ Reliable for medium length



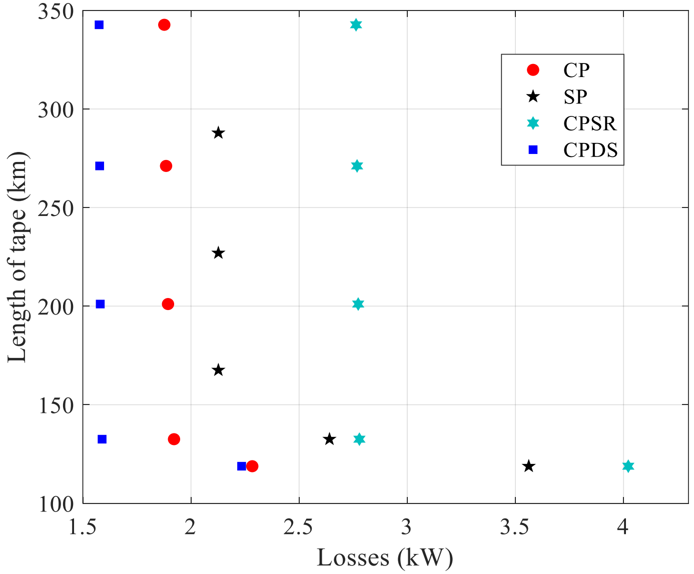
- ✓ No external feedback.
- ✓ Two cooling systems at each end of the cable



- ✓ Small diameter
- ✓ External feedback

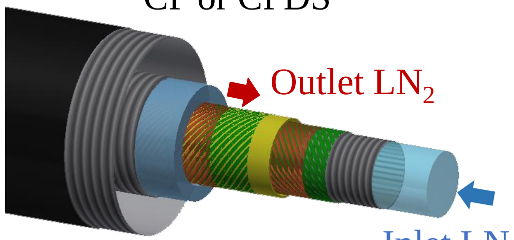


- ✓ External feedback
- ✓ Reliable for long lengths.

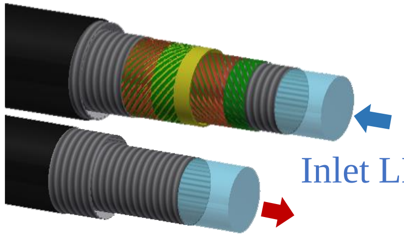


V. Conclusion

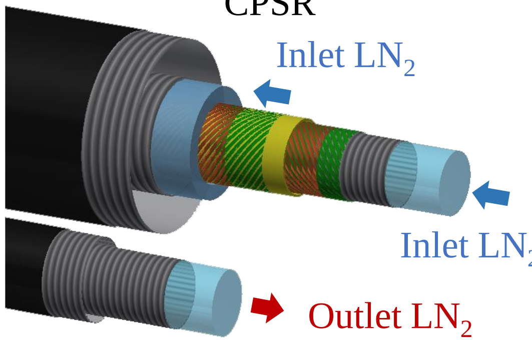
CP or CPDS



SP



CPSR



Cable design

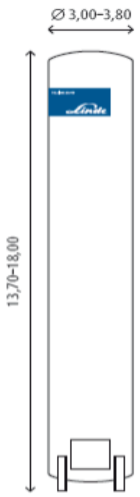
- All cable diameters
- Number of Tape per layer and per pole *N*
- Twisting step and total length of Tape

Thermal and hydraulic properties

- Mass flow rate
- Pressure drop
- Type of cooling

Losses of the installation

- Cable and cooling system losses
- Circulation pump power
- Liquid nitrogen consumption
- Sizing of the nitrogen tank and its autonomy



Thank you for your attention

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