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Best Paths

Transmission for sustainability

COOLING CONSIDERATIONS FOR THE LONG LENGTH HVDC CABLES CRYOSTAT WITHIN BEST PATHS PROJECT

Steffen Klöppel,
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BEST PATHS stands for "BEyond State-of-the-art Technologies for rePowering Ac corridors and multi-Terminal Hvdc Systems". It is co-funded by the European Commission under the Seventh Framework Programme for Research, Technological Development and Demonstration under the grant agreement no. 612748.

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Best Paths project

BEyond State-of-the-art Technologies for Power AC corridors and multi-Terminal HVDC Systems

RD&D project founded by the European commission under FP7

Period: Oct. 2014 - Sept. 2018 (4 years)

Demo	Objective
1	HVDC offshore connection
2	Interoperability of HVDC-VSC multiterminal multivendor solutions
3	Uprating of existing HVDCV multiterminal interconnectors
4	Innovative repowering of existing AC corridors
5	**MgB_2 superconducting links**

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Demo 5 consortium

Nexans

- Optimization of MgB_2 wires and conductors
- Cable system
- Cryogenic machines
- Testing in GHe
- Integration into the Grid

CERN

- Optimization of MgB_2 wires and conductors
- Cable system

Columbus Superconductors

- MgB_2 wire
- Optimization of MgB_2 wires and conductors

TECHNISCHE UNIVERSITÄT DRESDEN

- Cryogenic machines

POLITÉCNICA "Engineering the future"

- Reliability
- Integration into Transmission grid

RTE Réseau de transport d'électricité

- Cable system
- Integration into Transmission grid
- Testing in GHe
- Reliability

IASS POTSDAM

- Scientific coordination
- Dissemination & exploitation

ESPCI ParisTech

- Cable system

KIT Karlsruhe Institute of Technology

- Cable system

RSE Ricerca Sistema Energetico

- Cable system

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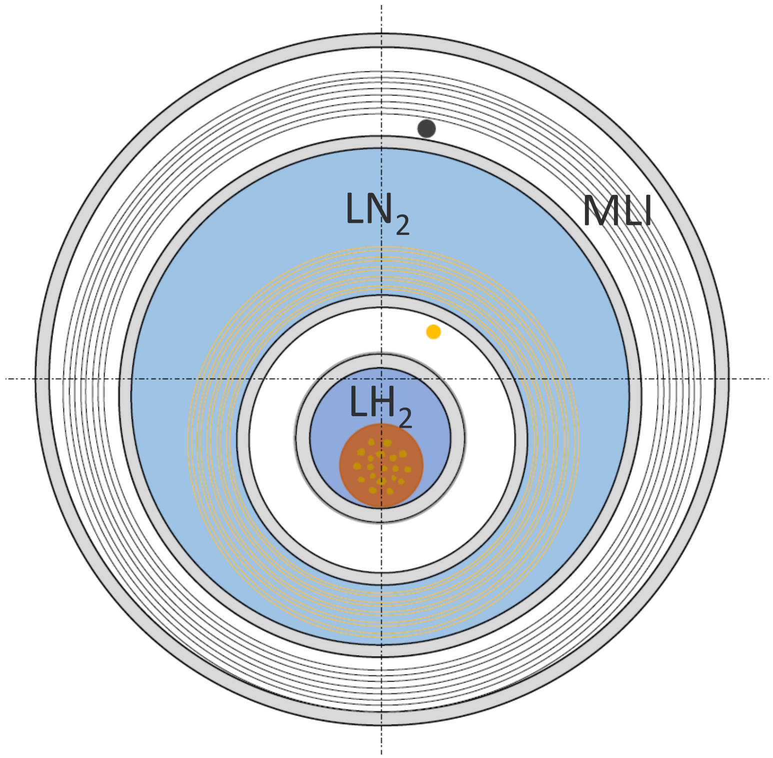
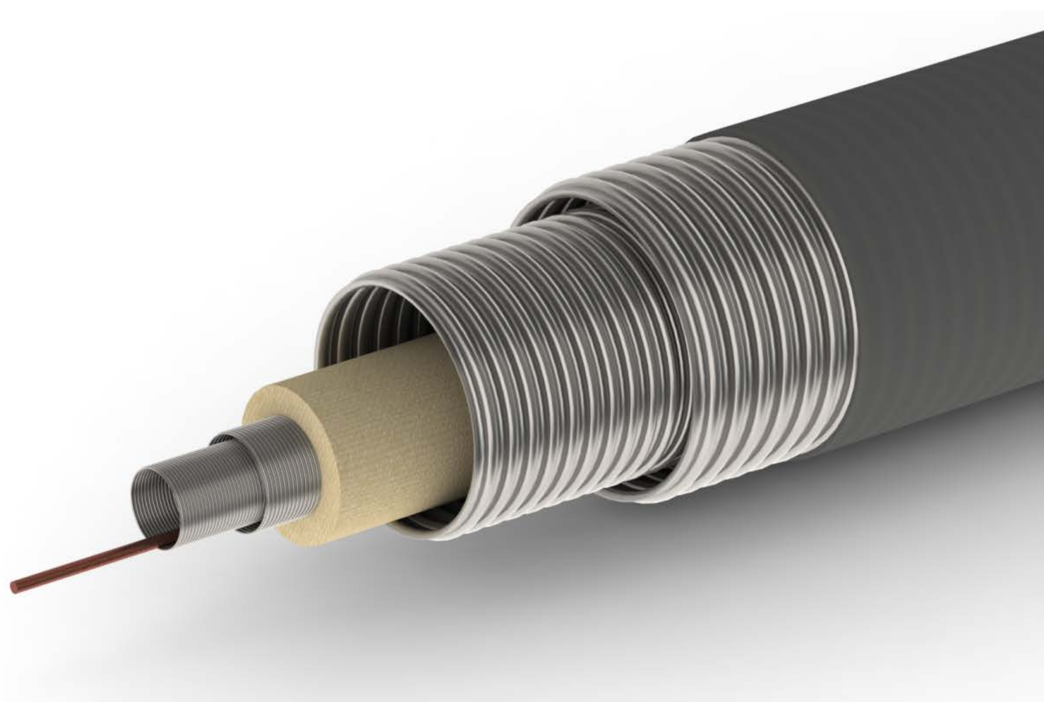
Principle cable cryostat design



MgB$_2$ cable:

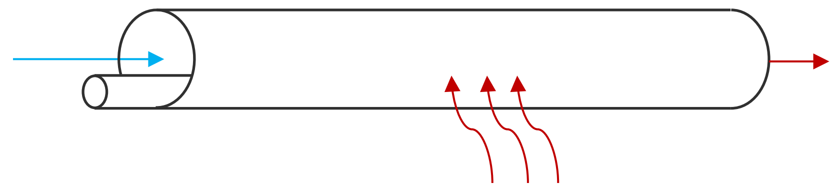
$$d_c = 9\,\mathrm{mm}$$
$$I = 10\,\mathrm{kA}$$
$$U = 320\,\mathrm{kV}$$
$$P_{el} = 3.2\,\mathrm{GW}$$



Simple model

Analytical formulation shows dependencies and possible improvements

→Fast assessment of viable options, influence of parameters on cooled length



$$\Delta p = \frac{\rho}{2} u^2 f \frac{L}{D_i}$$

$$\dot{Q} = \dot{q}\, A_h = \Delta h\, \dot{m}$$

$$L = \frac{D_i}{2} \sqrt[3]{\frac{\Delta p \Delta h^2 \rho}{f \dot{q}^2 \delta^2}} C$$

$$L \propto D_i$$

$$L \propto \Delta h^{2/3}$$

$$L \propto \Delta p^{1/3}$$

$$L \propto \dot{q}^{-2/3}$$

$$L \propto f^{-1/3}$$

$$L \propto C^{1/3}$$

Parameter space?

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Diameter

$$L \propto D_i$$

Limitations outer diameter:

duct size

bending radius } corrugated tubing

cable drum

With straight tubing, any length can be reached

$$\dot{Q} \propto D_i \rightarrow \dot{Q} \propto L$$

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Pressure span

$$L \propto \Delta p^{1/3}$$

Limitations:

Pumping machinery and power

Mechanical integrity cryostat: 20 bar

Single phase fluid only

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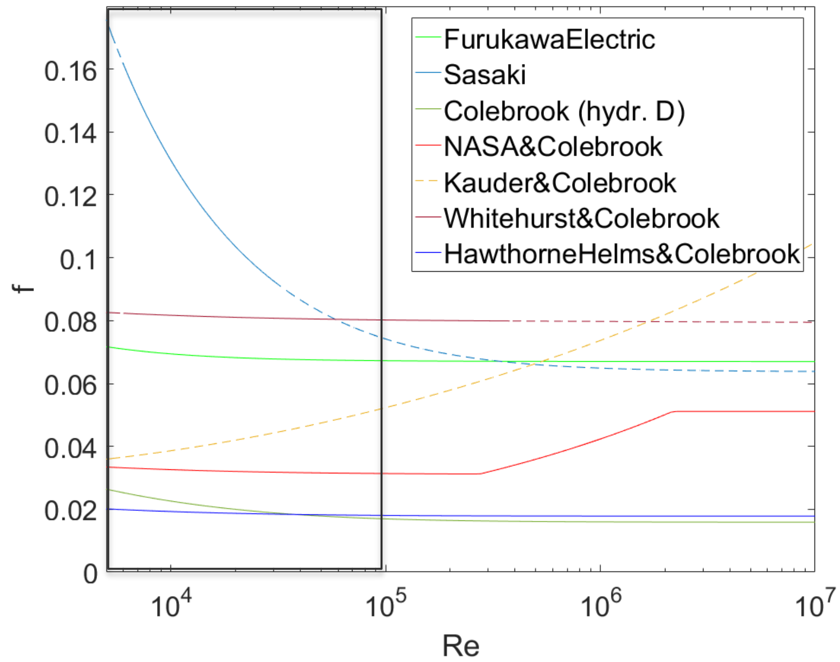
Pressure loss

$L \propto f^{-1/3}$

Literature correlations show large spread (0.02..0.08)

Straight tubes optimal



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Enthalpy span

$$L \propto \Delta h^{2/3}$$

Limitations:

operational range MgB_2

<u>single-</u>phase fluid

lowest starting temperature

$$T_{out} \leq 25\ K$$

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Enthalpy span

$$L \propto \Delta h^{2/3}$$

Alternative coolants:

	LH_2	GHe	LHe→GHe	SH_2+LH_2	SNe+LNe
T_{in}	15 K	15 K	5.00 K	14.4 K	25 K
p_{in}	2 MPa	2 MPa	2 MPa	2 MPa	0,975 MPa
h_{in}	-23.32 kJ/kg	69.10 kJ/kg	11.30 kJ/kg	-	-
T_{out}	25 K	25 K	25 K	25 K	25 K
p_{out}	0.35 MPa	0.5 MPa	0.5 MPa	0.35 MPa	0.1 MPa
h_{out}	55.86 kJ/kg	133.21 kJ/kg	133.21 kJ/kg	55.86 kJ/kg	-
Δh	79.19 kJ/kg	64.11 kJ/kg	121.91 kJ/kg	112.06 kJ/kg	8.3 kJ/kg
L/L_{LH2}	100%	68.8%	106%	125%	36%

Slush hydrogen is the only viable alternative

Continuous, unmanned operation of an auger plant?

Agglomeration of SH_2 in corrugations?

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Heat inleak

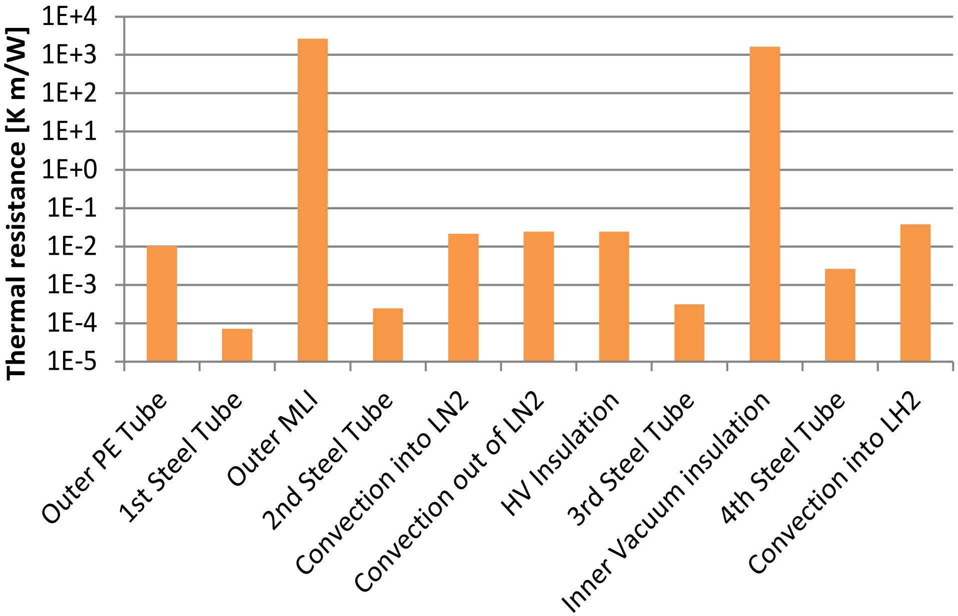
$$L \propto \dot{q}^{-2/3}$$

Load bearing MLI

Margins for:

- Long time vacuum stability
- Bending

Additional AC-losses



Calculation based on literature data

$$\dot{q}_{300\,\mathrm{K}\rightarrow 77\,\mathrm{K}} = 4.3\,\mathrm{W\,m^{-2}}$$

$$\dot{q}_{77\,\mathrm{K}\rightarrow 20\,\mathrm{K}} = 0.9\,\mathrm{W\,m^{-2}}$$

→Neumann: -36% heat inleak

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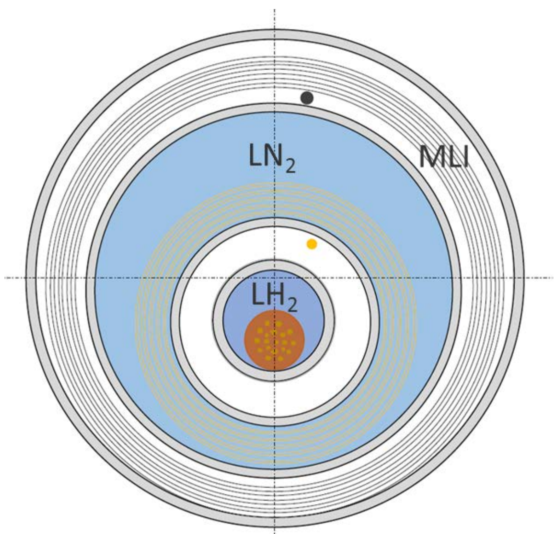
Cable diameter

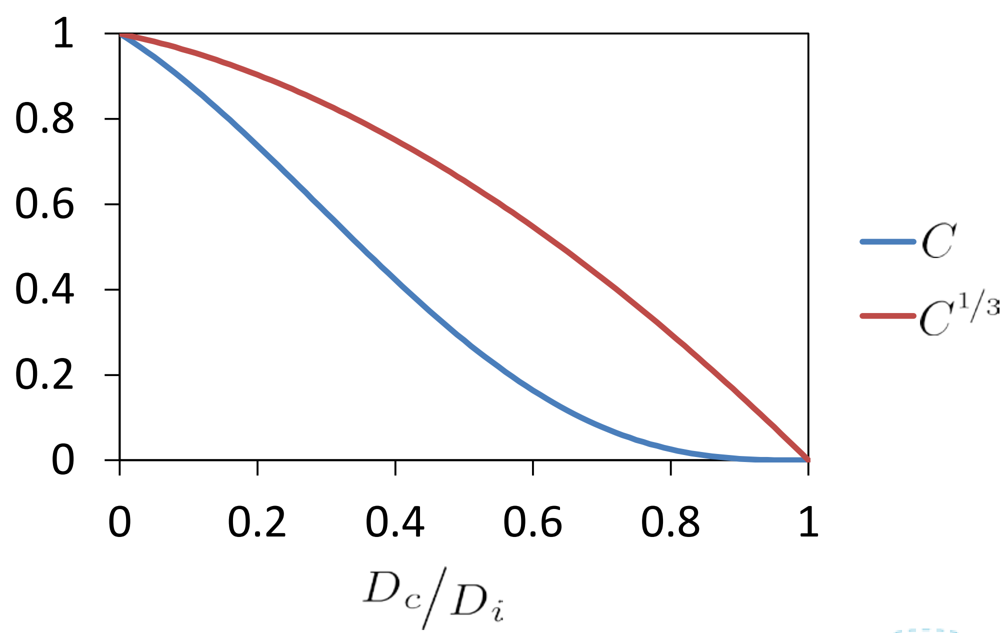
$L \propto C^{1/3}$

$$C = 1 - \left(\frac{D_c}{D_i}\right) - 2\left(\frac{D_c}{D_i}\right)^2 + 2\left(\frac{D_c}{D_i}\right)^3 + \left(\frac{D_c}{D_i}\right)^4 - \left(\frac{D_c}{D_i}\right)^5$$

Small cable → minor influence on length

Larger effect for el. insulation





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Exemplary geometry

Distance between reactive power compensation stations in France: ca. 50 km

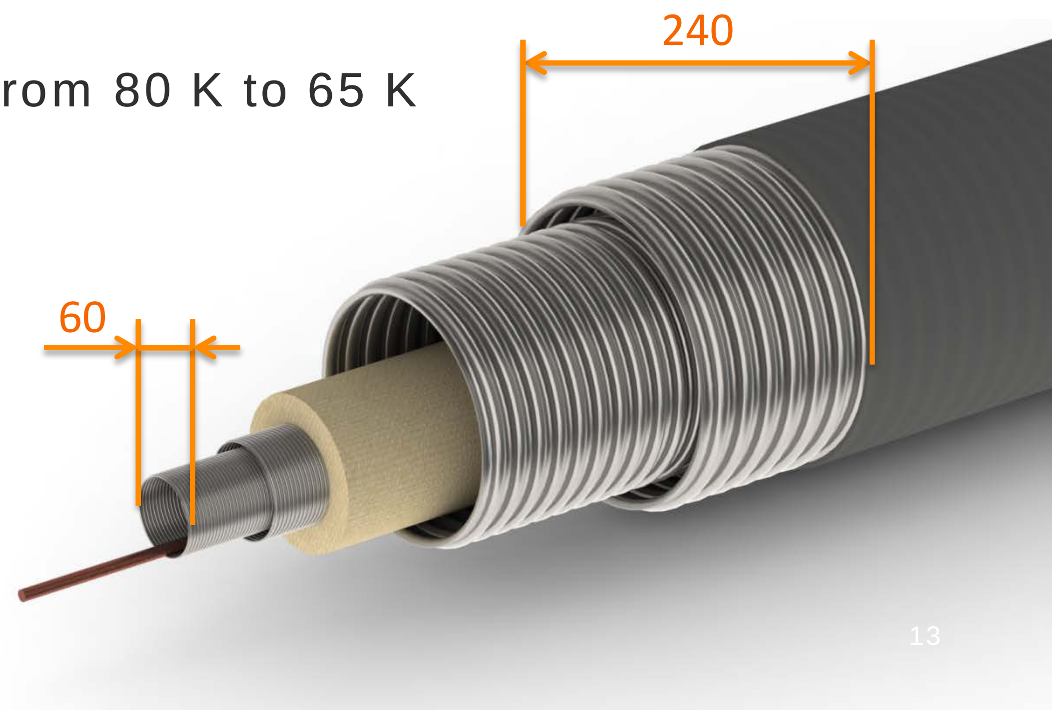
→Cable design for 50 km

Mass flow LH_2: 0.175 kg/s →15 t/d

Mass flow LN_2: 4.4 kg/s →380 t/d=circulation rate

→ 53 t/d for re-cooling of LN2 from 80 K to 65 K

900 m³ storage for two weeks



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Summary

Cooling of kilometric long cables is possible with flexible cryostat

Down scaling of cable cryostat not possible

→Minimal el. power to justify investment (GW range)

integration into grid

redundancy etc.?

Outlook

Replacement of el. insulation with spacer

Design with straight tubing

Design of pump / recooling station

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