Thermalisation of HTS-based current leads using a single-stage GM cryocooler

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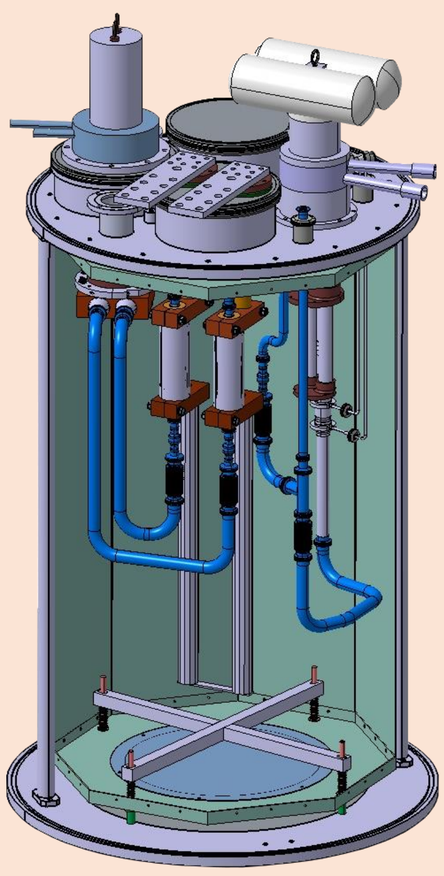
Demonstrator of the HTS current lead cooling



Main components of the loop:

- Single-stage Gifford-McMahon cryocooler AL600
- Double-stage PT420
- Active thermal shields @50K
- Cryocooler-to-helium-gas heat exchanger
- 2 x 3kA current leads with integrated heat exchangers
- Cold circulator
- Measuring apparatus

Characteristics of the cooling circuit	
Working fluid:	helium gas
Operating pressure:	5 bara
Operating temperature	50 K
Cooling capacity @50K	340 W

Motivation

Cryocooler-based cryogenic systems are an attractive alternative for LTS detector magnets. Such a solution requires a design oriented towards a significant reduction of heat input to the cold mass.

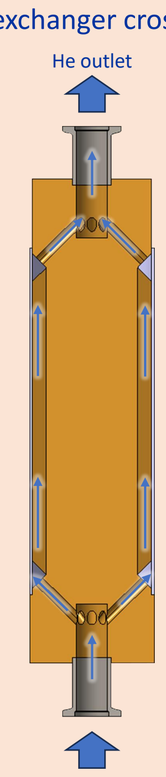
Current leads are one of the main heat sources for the cold mass. Hence, efforts are being made to design conduction-cooled HTS current leads together with an associated cryogenic circuit which intercepts heat at an intermediate temperature of 50K.

Goal

- Design and optimisation of HTS-based current leads featuring an operating current of 3kA
- Design of a remote cooling loop for the CLs operating with helium gas @50K.
- Design the heat exchangers constituting thermal interfaces between helium and the leads
- Intergration, assembly and test of the demonstrator

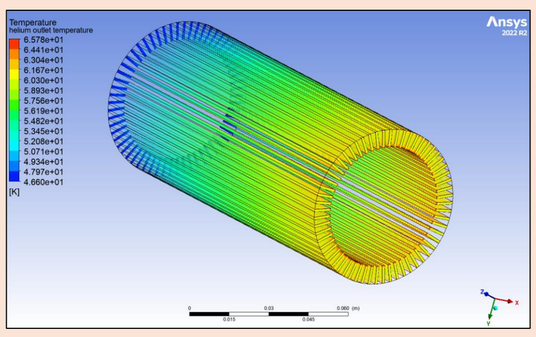
Thermal interface between helium gas and current leads

Heat exchanger cross-section

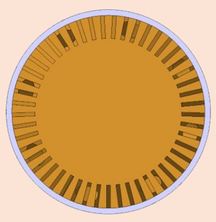


Geometry of the CL heat exchanger	
Overall length of the lead	1.2 m
Length of the cooling channels	147 mm
Manifold inlet diameter	16 mm
Manifold number of holes	9
Manifold single hole diameter	5 mm
Single cut height	8 mm
Cut width	1 mm
Number of cuts	60

Gas temperature distribution [3]



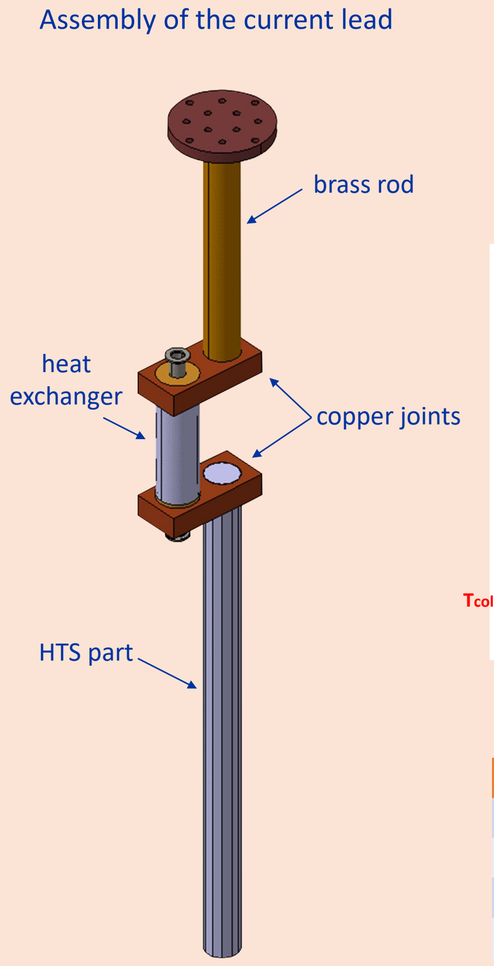
Cooling channels



Brass heat sink

Design and optimisation of the current leads

Assembly of the current lead

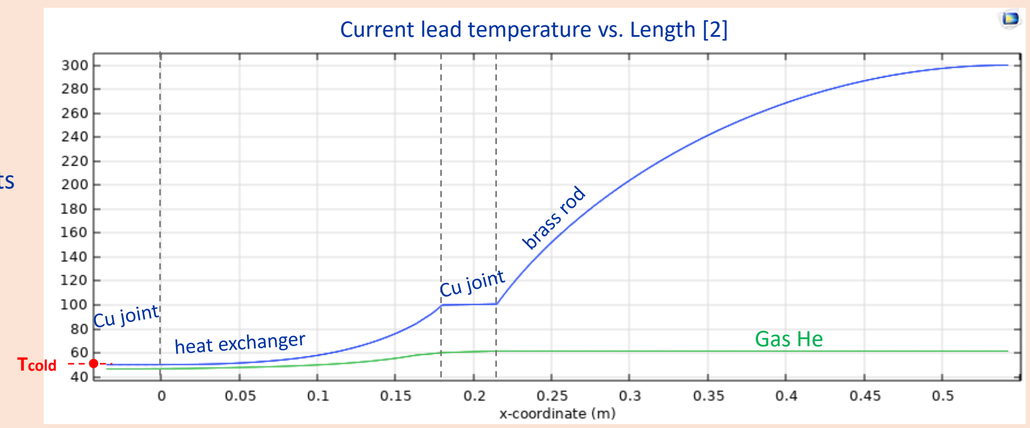


Heat balance of the current lead [1]

$$\frac{d}{dx}\left(k(T)A\frac{dT}{dx}\right) + \rho(T)\frac{I^2}{A} = \dot{m}_f C_p(T_f)\frac{dT_f}{dx}$$

conduction — Joule heating — gas enthalpy

Current lead temperature vs. Length [2]



The geometry of the current lead was optimised towards the lowest temperature of the copper joint connected to the HTS part, which is indicated as **Tcold** in the plot.

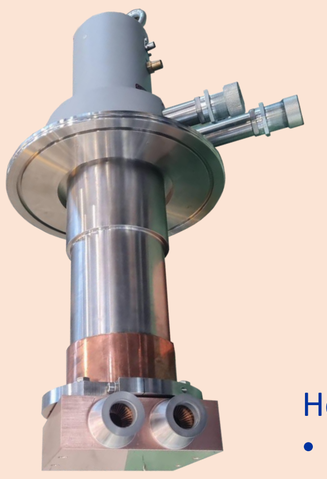
Characteristics of the current leads	
Material:	Brass
Current:	3 kA
Dissipation:	151 W
Outer diameter:	51/65

Heat Exchanger HEX102	
Operating temperatures (GHe)	46.6 → 61.6 K
Tcold	50 K
Operating Pressure	5 bara
Mass flow	2 g/s

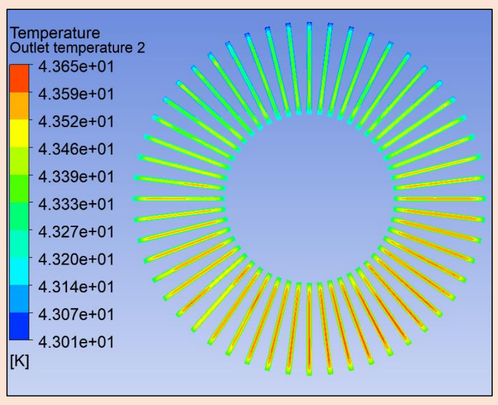
Thermal interface between cryocooler and helium gas

Geometry of the HEX101	
Manufacturing technology:	EDM
Number of cooling channels:	2 x 52
Width of the cooling channel:	0.6 mm
Length of the cooling channel:	11 mm

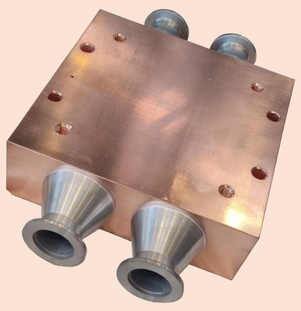
Assembly of the heat exchanger with the AL600



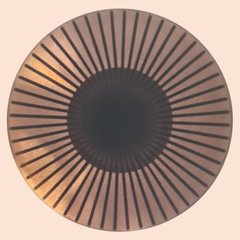
Outlet He temperature [3]



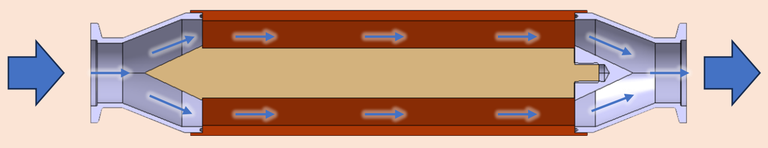
Heat exchanger HEX101



Cooling channels



Section view of the HEX101



Heat transfer characteristics:

- Steady state is considered
- Mass flow of 2 g/s
- Operating static pressure of 5 bara
- Flow velocity of 1.22 m/s
- Laminar flow, Re= 1030
- Linear pressure drop of 4.7 mbar
- Inlet temperature of 60 K
- Outlet temperature of 43 K

Conclusion & Acknowledgement

- Design of the HTS current lead cooling system was done
- Thermal interface between cryocooler and helium gas was designed and manufactured, to be tested soon
- Optimized design of the 2 x 3 kA HTS current lead prepared
- Preparations for the test campaign are underway

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References

[1] Martin N. Wilson, *Superconducting Magnets*, Clarendon Press, 1987
[2] COMSOL Multiphysics®
[3] Ansys® Fluent, Release R2, 2022