Design details of the Current Lead Test Facility Karlsruhe (CuLTKa)

Richter T., Lietzow R.

Karlsruhe Institute of Technology

Program/Paper ID #: C2PoF - Test Facilities

Institute for Technical Physics
Hermann-von-Helmholtz Platz 1
76344 Eggenstein-Leopoldshafen
www.itep.kit.edu

Summary

The cryogenic test facility CuLTKa was built up and commissioned. The first CL-tests were conducted succesfully.

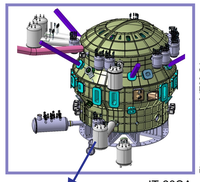
The base of the process design are longtime experiences in designing and operating cryogenic facilities using forced-flow Helium at overcritical pressures. For the detailed design basic design calculations based on common engineering relations were applied.

Comparisons with measured data attest the reliability of these tools. Paired with a flexible process design and reasonable safety margins such a test facility can be realized.

Objectives

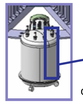
- Sketching the design process of the facility: from demand to facility setup
- Presentation of empirical engineering tools used for the process engineering design and their characterization by comparison with measured data

HTS-current leads for JT-60SA

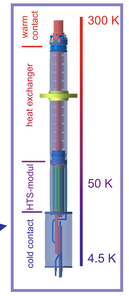


JT-60SA

Figure: courtesy of JT60-SA



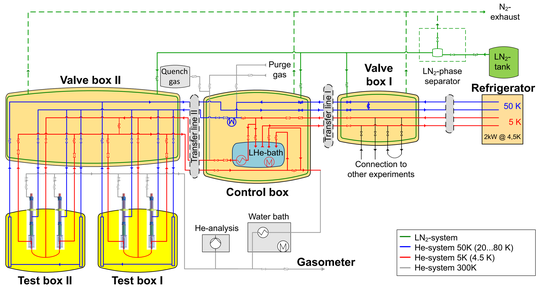
current lead box



Parameter	JT60-SA TF	JT60-SA CS/PF
Nominal current I_{nom}	25.7 kA	20 kA
No. of CL	6	20
Total length of CL	1.7 m	1.7 m
Mass flow @ I_{nom}	1.93 g/s	1.55 g/s
Mass flow @ 0 A	0.6 g/s	0.44 g/s
Heat load @ 4.5 K, 0 A	< 3 W	< 3 W

Facility setup - major properties

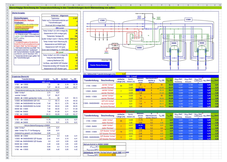
- 2 kW-refrigerator provides 2 He flows at different temperature levels (5 K and 20...70 K) @ overcritical pressures → integration into existing infrastructure of ITEP
- Cryostats installed on a platform → easy installation of test objects; flexible orientation of test boxes; cryostat access by lowering bottom
- LHe-bath (400 l) with cooling heat exchanger (HEX) for temperature adjustment for CL test (pressure vessel)
- 30 kA DC power supply with watercooled flexible copper cables at room temperature
- Separate vacua in test boxes → certainty in leak testing; individual quick pumping
- 2 test boxes to optimize test time and test schedule
- Each test box contains 2 CL with short-circuiting NbTi busbar at 5 K
- No sensitive measurement equipment in test boxes → no electrical interferences; simple, fast, save installation of CL
- He cooling shields in test boxes → controlled cool-down and warm-up



Design aspects - process engineering using empirical calculation methods

Pipe dimensioning and pressure losses

- Realisation of plant model considering pipe diameters, lengths, bends, components (valves, venturis, filters) to determine pressure losses and flow velocities
- Case sensitive pressure loss calculation characterized by Re-number and inner pipe roughness



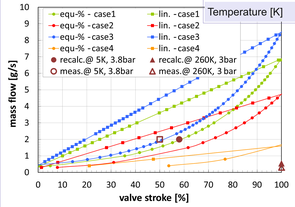
Valve design

- Calculation of valve flow coeff. K_{vs} for compressible and incompressible flow (standard equations without coefficients)
- 4 cases considered:

1) Ideal operation condition
2) Operation cond. at min. pressure, max. mass flow & temp.
3) Operation cond. at max. pressure, min. mass flow & temp.
4) Required mass flow at ambient temp. and max. pressure

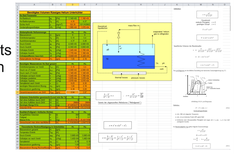
➪ K_{vs} chosen out of the 4 suggested cases
➪ Plot of valve characteristics for compr. & incompressible flow
➪ Opportunity to calculate different pressure losses for chosen K_{vs}

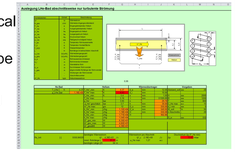
Design case	1	2	3	4
Inlet pressure [bar]	4.0	4.5	3.5	6.0
Pressure loss [bar]	0.2	0.1	0.3	3.1
Mass flow [g/s]	2	3	1	4
Temperature [K]	5	5.5	4.5	300



Design calculations are in good agreement with the measurements. The performance and control behaviour of the facility is very good during cool-down, warm-up as well as during operation.

Stabilization of 4.5 K-level flow by a heat exchanger through a cooling LHe-bath





! **Function:** balancing thermal losses due to long transfer distances from refrigerator (60 m); thermal buffer during faults and control fluctuations of refrigerator, well defined operation temperature of busbar (4.5 K-level of CL)

Process & vessel design: strongly experience based; 2 options for liquefaction (inlet, return flow); heater in LHe-bath

➪ Evaporation due to HEX-cooling vs. liquefaction, determination of max. holding time
➪ Vessel volume ca. **400 l**, max. pressure 10 bar g (overcritical blow-off pressure during fault)

HEX design: calculation in sections; total amount of heat to be extracted divided by no. of sections

- Considered: heat transfer from He-flow to pipe (depending on flow conditions and pressure loss), through pipe and to LHe-bath
- Calculation input: conservative inlet flow conditions (6 K, 4 bar), $\Delta T_{bath\text{-}HEXout}$= 0.2 K

➪ Determined length HEX: **50 m** including 25% safety

Performance of HEX: *good approximation achieved by design calculation!*

Parameter	Unit	Design	Measurement			Recalculation		
Bath pressure	[bar]	1.15	1.16	1.14	1.16	1.16	1.14	1.16
Bath temperature	[K]	4.36	4.37	4.35	4.37	4.37	4.35	4.37
Mass flow HEX	[g/s]	10	8	9	9	8	9	9
Temperature HEX-in	[K]	6	5.4	5.15	5.16	5.4	5.15	5.16
Pressure HEX-in	[bar]	4	4	4.5	3.95	4	4.5	3.95
Temperature HEX-out	[K]	4.57	4.4	4.37	4.38	4.43	4.4	4.43
$\Delta T_{bath\text{-}HEXout}$	[K]	**0.21**	**0.03**	**0.02**	**0.01**	**0.06**	**0.05**	**0.06**
Pressure drop HEX	[mbar]	**46**	**150***	**150***	**170***	**25**	**32**	**32**

* Pressure loss of venturi and shut-off valve included → pressure drop HEX is approached

Performance of whole subcooler: *performs very good!*

- During experiments liquefaction of return flow from the CL

➪ Additional heat input (heater) to reach stable process conditions (e.g. standby overnight)
➪ Theoretical holding time during experiments: 3 to 4 h (HEX heat load corresponds to additional inlet mass flow of 2 to 3 g/s @ ideal liquefaction)

A reliable and flexible system was realized. Experiences in designing and operating cryogenic facilities are the essential base. This shows during process design phase as well as in setting reasonably conservative boundary conditions and safety margins for the design calculations.