Heat loads to Spectrometer Solenoid helium vessel

Spectrometer Solenoid Review

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Outline

○ Basis of heat load evaluation

○ Summary of heat loads to the helium vessel at 4.2 K

○ Principles of the evaluation of heat loads to the helium vessel

○ Heat load to the shield

○ References

Basis of evaluation

Static heat loads only are considered

- The magnets and cryostat are assumed to be in steady state

Dynamic heat loads are not included here; there is notably

- Relaxation of non-equilibrium heat
- Relaxation of the thermal distribution of the shield etc.
- Transient behaviour of the vacuum
- Magnetic field redistribution (flux jumps)
- Eddy current heating during and after current ramp up or down

Without ohmic heating of the wire joints, our evaluation falls short by 0.9 W from the experimental result of Test 2B

The excess may be due to any one of the unevaluated sources

Heat loads to 4.2 K

Source of heat	MICE Note 236, Ref. [1]	Test 2B conditions with shield at 98 K (Sanders, Ref. [2])	Update of September 2010	Item Nb, see Notes
	(W)	(W)	(W)	
Radiation from 80 K	0.050	0.252	1.002	1
Radiation from 300 K	0.000	1.000	1.000	2
Support rods	0.310	1.100	1.100	3
Neck tubes	0.060	0.060	0.060	4
Cooler sleeves	0.750	0.750	0.750	5
Instrument wires	0.050	0.310	0.050	6
Magnet leads	0.870	0.870	0.870	7
SC wire joints	0.400	0.400	0.400	8
Residual gases	0.000	0.000	0.110	9
Radiation through pipes	0.000	0.250	0.500	10
LHe level probes	0.000	0.000	0.261	11
Cold shorts	0.000	0.000	0.000	12
Cryocooler underperformance	0.000	0.000	0.000	13
TAO + LHe fill line instability	0.000	0.000	0.000	14
Sum	**2.490**	**4.992**	**6.103**	

Principles of evaluation

Radiation from the thermal shield ≈$(T_{\mathrm{hot}}^4 - T_{\mathrm{cold}}^4)$

- Test 2B measurements indicate 98 K shield temperature close to the cryocoolers
- The outer shell of the shield was assumed to be 98 K
- The end plates were assumed at 100 K
- 110 K on the bore tube
- The MLI performance was taken from Ref. [4] (LHC studies)
- The packing density was estimated as 20 layers/cm for blankets on outer shell and on end plates
- The packing was evaluated to be about 50 layers/cm on the shield bore tube
- The degradation of the MLI performance with the packing density was taken from Ref. [5] (LHC studies)

Principles of evaluation (cont.)

Radiation from the thermal shield (cont.)

- The heat load on the 4.2 K vessel through the MLI then consists of
  - 367 mW on the outer shell
  - 79 mW on the end plates
  - 416 mW on the inner bore tube
- The imperfections of the MLI were evaluated to yield
  - 93 mW through cuts and joints
  - 48 mW from the shield end plate through the gap between the shield and the helium vessel
  - Principle: two cavities connected by orifice => black body radiation formula ≈ correct

Principles of evaluation (cont.)

Radiation from OVC at 300 K to helium vessel at 4.2 K

- Principle: two cavities connected by orifice => black body radiation formula ≈ correct
- It was estimated that 20 cm^2 total area of orifices connect the two cavities
    - The main orifices are the gaps at the holes for the 8 large supports of the 4.2 K mass
    - Thermal radiation also penetrates along the glass-epoxy composite of the support material

Support rods of the helium vessel

- Requirements: large forces, very small movement upon cooling!
- We assume the value evaluated in Ref. [2]. Takes into account shield temperature ≈ 100 K and ≈ weak thermal links to the anchor points

Principles of evaluation (cont.)

Neck tubes and cooler sleeves

- Original design values were based on valid data and well-reported measurement

Instrument wires and magnet leads

- No heavy Cu instrumentation wires were found => return to the lower value of Ref. [1].
- Electrically insulated low-conductivity wires can be heat sunk by thermal radiation => OK for sensors, but may influence radiation heat load (very) slightly
- Conduction through HTS magnet leads is probably based on the data of the supplier, who recommends much colder top end temperatures around 60 K
  - Can be source of additional heat load
  - HTS lead supplier should deliver information on the domain of intrinsic stability

Principles of evaluation (cont.)

SC wire joints

- Original design value was very pessimistic, but we adopted it

Residual gases (based on MLI tests for LHC, Ref. (4)

- Assuming a residual gas pressure of 10^{-3} Pa (= 10^{-2} µbar), we get a heat load of roughly 110 mW on the helium vessel and its appendices
    - Elastomer o-rings do permeate He gas of the ambient atmosphere
    - The rotary blade pump used in these tests can backstream helium to yield about 10^{-1} µbar He pressure in the inlet of the pump
- Linear pressure dependence => better pump will help immediately

Principles of evaluation (cont.)

Radiation through pipes

- This was increased to take into account that wall conduction and guided thermal radiation work in parallel

Helium liquid level probes

- Based on 2 AMI level probes with 75 mA current, 11.6 Ω/inch resistance at 20 K, 10 inch length exposed to gas phase, and 20% duty cycle. Should enquire what is the effective duty cycle of the readout instrument used in Tests 2B, and how to reduce duty cycle for normal operation.

Cold shorts

- No evidence exists

Cryocooler underperformance

- No evidence exists

Principles of evaluation (cont.)

Thermo-Acoustic Oscillations and 2-phase instabilities

- No evidence was found for such heat loads => was assumed zero
- TAO or other non-linear transient instabilities could occur notably in the LHe fill line that is fairly long and is filled with 2-phase He during normal operation
  - The heat leak through and into this line, not evaluated yet, should be added as direct load to the 4.2 K vessel
  - One of the improvements suggested for the future tests consists of making a good thermal anchor from the present fill line tube to the main 4.2 K vessel at the level of the top of the vessel.

Heat load to the shield

Experimental results for Solenoid 2, Test 2B (with LN2 vessel)

- From the the cooling power of the first stages of the 3 2-stage cryocoolers and one single-stage cryocooler, we get the experimental load of 277 W with no current in the magnet [3]
- This is in an excess of 100 W to 105 W over the load estimated for the magnet 1 with no LN2 reservoir connected to the shield
  - 100 W corresponds to a thermal radiation heat load to about 1 m^2 oxidized aluminium surface.
- With 250 A current in all coils, the estimated heat load on the shield absorbed by the cryocoolers was 308 W; at full design current of 275 A the load would have been 322 W [3].

Heat load to the shield

Evaluation of the sources of heat load to the shield

- Thermal radiation through MLI blankets = 12 W on the outer shell and end plates of the shield
- About 10 W on the central bore, with a packing density of about 50 layers/cm basing on Ref. [5]
- Direct radiation from the end plates of the vacuum vessel through the gap between the RT bore tube MLI wrap and the inner surface of the shield bore = 4 W, if the gap area is about 150 cm^2
- Radiation leakage through cuts and joints that are poorly covered, corresponding to orifices of about 500 cm2 total area, would contribute about 13 W
- The above loads total 39 W

Heat load to the shield

Evaluation of the sources of heat load to the shield (cont.)

- Basing on photographs taken before Test 2B, there are no bare or poorly covered surfaces that could explain the large heat loss to the shield.
- Additional sources: can these contribute much more than expected?
  - 8 supports of the shield (Prepreg laminates)
  - The heat sinks of the 8 supports of the helium vessel (Prepreg laminates)
- The conduction through pipe connections and wires (small)
- LN2 reservoir on the heat load of the shield of the magnet: Latent heat of freezing the LN2?
- The power of the cryocoolers is clearly sufficient to to absorb 322 W from the shield at 50 K, but Ref. [3] identified a problem of heat transport to the cold heads.

Heat load to the shield

Evaluation of the sources of heat load to the shield (cont.)

- This heat transport problem cannot be solved by additional cryocoolers,
- Requires the improvement in the transfer of the heat from the various sources on one hand, and in the MLI blankets and its joints
- Moreover, the heat sinking of the supports should be improved substantially
- These measures will at the same time reduce the heat load to the 4.2 K system
- They are now underway at Wang NMR.

References

1. MICE Report 236
2. R. Sanders, "Spectrometer Magnet Heat Load", Fermilab June 6, 2010
3. Michael A. Green, "What happened with Spectrometer Magnet 2B", LBNL 7 May 2010.
4. L. Dufay, C. Policella, J.-M. Rieubland and G. Vandoni, "A large test facility for heat load measurement down to 1.9 K", LHC Project Report 510 (paper presented at CEC/ICMC 2001, July 2001, Madison, Wisconsin, USA).
5. L. Mazzone, G. Ratcliffe, J.M. Rieubland and G. Vandoni, "Measurements of Multilayer Insulation at High Boundary Temperature, Using Simple, Non-calorimetric Method", Report CERN LHC /2002-18, presented at ICEC 19, Grenoble, July 2002.