Spectrometer Solenoid Cryogenic Design Enhancements

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T. Niinikoski, S. Virostek and H. Pan

LBNL

Outline

- Design enhancements
- Heat loads on the radiation shield (details)
- Heat loads on the helium vessel at 4.2K (details)

Cryogenic Design Enhancements

Principles and basis

- Heat load reduction is based mainly on Test 2B results and on various analyses; the remaining small excess heat load can be easily explained by any of the items that could not be evaluated
- Two 2-stage cryocoolers are added to increase cooling power to 7.5 W at 4.2 K; this provides over 100% margin for the predicted static load of 3.5 W (the margin is indispensable to cover the dynamic loads)
- As much simplification of the system as possible
- Shield cooling is substantially improved

Main items for heat load reduction to the helium vessel at 4.2 K

- Lower thermal radiation from the shield and from 300 K (better MLI)
- Better heat sinking of the cold-mass support rods
- Improved insulation vacuum and its measurement
- Provisions to measure and damp TAO and 2-phase instabilities (these were not considered in Test 2B or other tests)

Methods of Enhancement

Shield cooling and forces on shield

- Heat transport from thermal shield was improved by
  - ✓ Better flexible Cu bridges to Cu plates linked to cryocoolers
  - ✓ Replacement of Al 6061 by Al 1100 (but bore remains Al 6061)
  - ✓ Better designed cuts for eddy current reduction
- ANSYS evaluation shows excellent steady-state thermal performance and acceptable forces during worst-case quench

Improvements of MLI application on shield

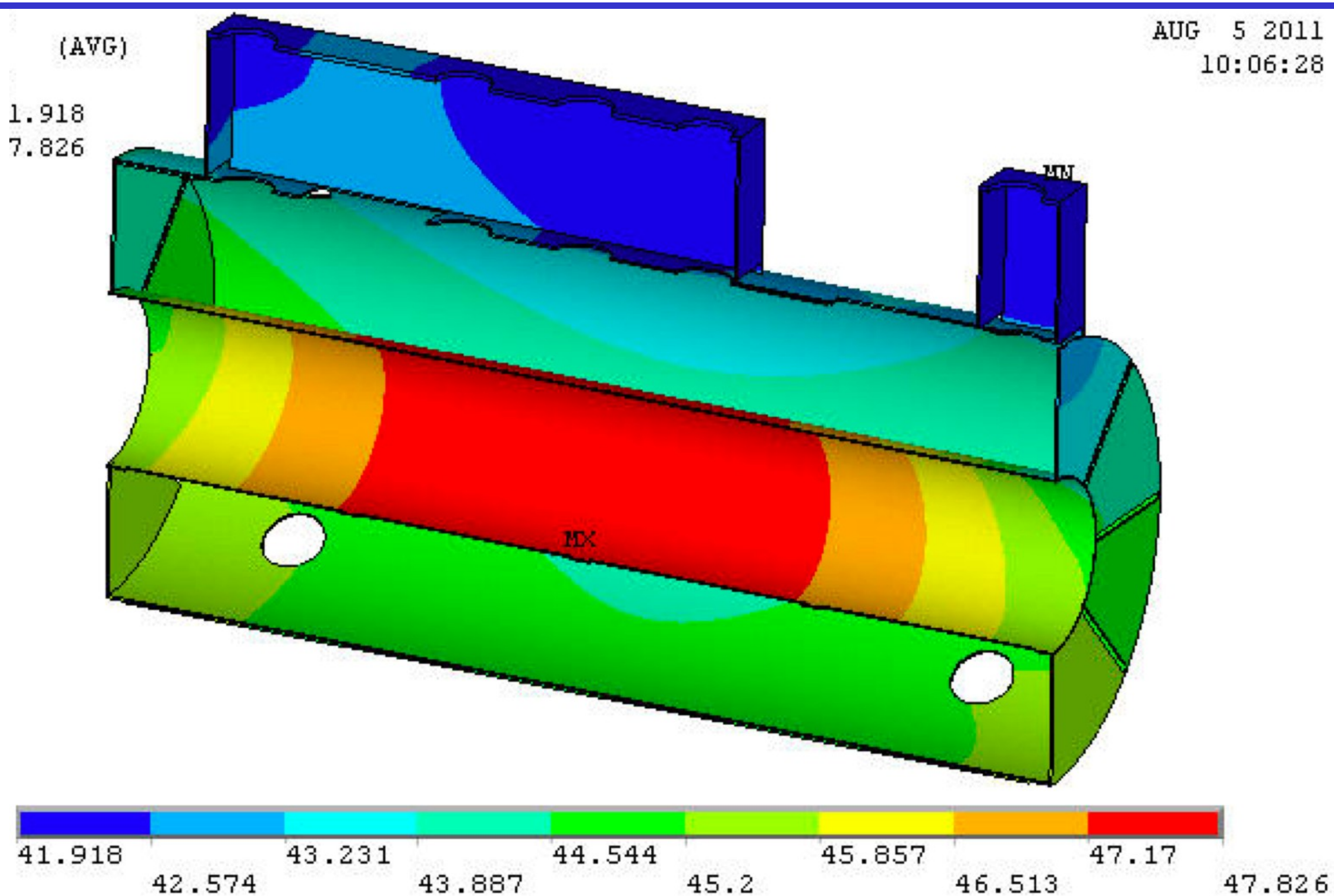
- Careful design of pre-cut 30-layer blankets on shield (but thinner blanket on warm-bore tube)
- 2 blankets with non-overlapping seams
- Avoidance of compressed areas on blankets
- Careful sealing of gaps and cuts by reflective adhesive
- Evaluation gave 147 W total thermal load and its distribution on shield

Heat Load on Shield

The first stages of the cryocoolers can absorb 147 W just above 40 K temperature

Source of heat load onto the shield	Heat load with new MLI design	Notes
	(W)	
Radiation to outer cylinder (perfect MLI)	4.0	Distribute uniformly on the relevant area
Radiation to end plates (perfect MLI)	1.9	Distribute uniformly on the relevant area
Radiation to bore tube (15 layers perfect MLI)	3.0	Distribute uniformly on the relevant area
Radiation through imperfections of MLI	12.5	Distributed close to MLI penetrations of tubes and supports
Radiation to the ends of the bore tube through MLI gap	3.8	Distributed to the two ends of the bore tube
Conduction along shield supports	0.6	8 "G10" supports each with 4 rods 4cm x 2.5 cm, length 10 cm
Heat sinks of cold mass supports	6.4	8 "G10" supports each with 4 rods 4cm x 5 cm, length 10 cm
Heat sinks of pipework	2.0	Applied on heat sink posts
Heat sinks of wires	0.2	Applied on heat sink posts
Heat sinks of magnet leads (I = 300 A), from Wang	91.4	8 Cu leads of 5 mm diam, 300 mm length; applied on Cu plate heat sink
Cryocooler sleeve tubes	21.2	5 2-stage and 1 single stage cryocoolers; applied on Cu plate heat sinks
Total	**147.0**	

Shield Temperature Distribution



Details of Helium Vessel Improvements

MLI and reflective coating

- Although MLI helps little against thermal radiation from 60 K, the blankets were improved
- Reflective adhesive coating will be applied on the cold bore of the helium vessel, because MLI must be wrapped on the shield bore tube.
- The MLI performance parameters were taken from LHC studies
- The packing density was taken as 20 layers/cm for all blankets; compressed areas will be eliminated by supports that enable the tailoring of well-fitting blankets

Conduction and the heat sinks of magnet leads, tubes and wires

- All heat sinks are improved
- Guided thermal radiation along tubes is reduced
- The LHe fill line is heat sinked to 4.2 K on the level of helium bath surface (this should reduce 2-phase instabilities); the original fill line does not create a compressed bump under the new MLI design
- A helium fill line for the topping-up of the bath is added into one of the gas outlet tubes

Helium Vessel Improvements (cont.)

Cryogenic vacuum

- The vacuum will be pumped by a high-speed turbomolecular pump with high compression ratio for helium; an ion gauge will enable the measurement of pressure down to 10^{-7} mbar
- A helium leak detector and an RGA will complete the vacuum instrumentation during the tests
- MLI on helium vessel will reduce conduction through residual gases

Thermo-acoustic oscillations (TAO)

- A fast pressure gauge will detect any TAO and 2-phase instability
- If any of these will persist during steady state operation, mitigating measures will be adapted to the particular line(s)

Support rods of the helium vessel

- Thermal radiation leakage along supports reduced by sealing structures
- Heat sinking to be improved with larger straps and lower shield temperatures

Summary of 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	Nov 2010: Shield 60 K, no res. Gas, low rad trgh pipes, 5% duty cycl probes	May 2011: As Nov. 2010, but neck tubes revised, 5 sleeves	Item Nb, see Notes
	(W)	(W)	(W)	(W)	(W)	
Radiation from shield	0.050	0.252	1.002	0.175	0.175	1
Radiation from 300 K	0.000	1.000	1.000	0.500	0.500	2
Support rods	0.310	1.100	1.100	0.188	0.188	3
Neck tubes	0.060	0.060	0.060	0.060	0.201	4
Cooler sleeves	0.750	0.750	0.750	0.750	1.250	5
Instrument wires	0.050	0.310	0.050	0.050	0.050	6
Magnet leads	0.870	0.870	0.870	0.870	0.870	7
SC wire joints	0.400	0.400	0.400	0.100	0.100	8
Residual gases	0.000	0.000	0.110	0.000	0.000	9
Radiation through pipes	0.000	0.250	0.500	0.200	0.100	10
LHe level probes	0.000	0.000	0.261	0.065	0.065	11
Cold shorts	0.000	0.000	0.000	0.000	0.000	12
Cryocooler underperformance	0.000	0.000	0.000	0.000	0.000	13
TAO + LHe fill line instability	0.000	0.000	0.000	0.000	0.000	14
Sum	**2.490**	**4.992**	**6.103**	**2.959**	**3.500**	

Conclusions

Predicted performance

- The static and dynamic heat loads at 4.2 K can now be absorbed in steady and transient states without losses of liquid helium
- Instrumentation and controls are being implemented to validate the new design enhancements

Test plan

- The cryogenic performance will be evaluated to a greater detail during the forthcoming tests, in view of enabling the design of optimal control system for routine operation during MICE experiments.