Test plan for the MICE SS cryostat and magnet

Spectrometer Solenoid Workshop

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Tapio Niinikoski

LBNL

Outline

- Purpose and goals of the Test Plan
- Vacuum and leak testing
- Tests during cooldown
- Measurement of the heat load to the helium vessel and to the shield
- Initial testing of individual coils and of all coils in series
- Training of the coils and testing of quench protection
- Conclusions

Purpose of the test plan

- To foresee all instrumentation needed for the tests
- To evaluate the needs of personnel needed for the tests
- To develop a credible schedule for testing
- To reserve space and other resources needed for the tests

Goals of the Test Plan

Instrumentation: Development, debugging, consolidation

- The test plan helps in establishing the requirements for instrumentation
- Time should be allocated to the debugging of the instrumentation

Validation of magnet and cryostat design:

- Characterization of steady state and transient behavior of the cryogenic system
- Training of the coils and mapping of the field

Controls:

- Minimal automation is required in the testing
- Time should be allocated to tests aiming at the development of controls and interlocks

Vacuum and leak testing

Instruments required:

- Pirani and ion vacuum gauges
- Helium mass spectrometer leak detector
- Residual gas analyzer (RGA), if available
- All level gauges must be turned “off” (risk of burning the sensor wire)

The pressure/vacuum should be monitored and recorded:

- During all purge and evacuation operations (evacuation time constant gets shorter when water desorbs from the MLI)
- During the two phases of the cooldown

Leak testing:

- Immediately after purging and final evacuation, leak check vacuum chamber and helium circuit against ambient; then leak check between helium circuit and the vacuum chamber.

Foreseeable duration: 2 shifts (16 h)

Tests during cooldown

First phase, using LN2 (about 8 hours; all cryocoolers are “off”)

- Record vacuum during whole cooldown
- Record all temperatures during the whole cooldown (coils, helium vessel, shield)
- Keep maximum $\Delta T \leq 40$ K by controlling the inlet temperature and flow rate of nitrogen; record the evolution of the good flow rate for future cooldowns
- Watch for any cold spots on the external envelope of the vacuum chamber (however, cold touches on VC are unlikely because the shield is not cooled in this phase); watch for cooling of the shield to detect cold touches with the helium vessel
- Stop before the coldest point of the solenoid reaches 78 K, trying to avoid accumulation of LN2 in the helium vessel
- Test presence of LN2 by evacuating the helium circuit while monitoring all temperatures; substantial cooling upon evacuation suggests the presence of liquid. If this happens, stop evacuation, turn on the heater on the bottom of the vessel, and monitor the pressure and temperatures.
- When there is no liquid in the vessel, evacuate N2 gas and purge with helium gas; check leak detector while purging with He gas.

Tests during cooldown (cont.)

Second phase, using LHe (2 h to 3 h for coils, ≈ 24 h for shield)

- Start cryocoolers when helium circuit is filled with clean helium
- Record all the time all temperatures, vacuum and helium leak rate
- Keep maximum $\Delta T \leq 40$ K by controlling the flow rate of helium (this is done best by controlling the flow rate of He gas out of the magnet); an automatic flow controller might be handy
- Start recording the lowest level gauge when the lowest point in the coil reaches 30 K temperature; cooling becomes fast soon after this
- Monitor cold spots on the vacuum chamber and warm areas of the shield (to identify possible touches between the shield and the VC)
- After initial filling of the helium vessel, stop helium transfer and monitor boiloff rate, the transient behavior of which may correlate strongly with the transient of the shield temperatures
- When the outlet flow stops and the pressure of the helium bath drops below that of the helium outlet line (equipped with a check valve), the helium bath can be topped up using the LHe refill line

Measurement of the heat loads

Static heat load measurement (24 to 48 h)

- The topmost level gauge, the bath pressure, and all temperatures will be recorded all the time. The vacuum and helium leak rate will be also recorded.
- The known cooling performance of the cryocoolers can be used as a measure of the heat load to the helium vessel and to the shield; this requires the knowledge of the temperatures of the cold heads
- If the heat load to the helium vessel is smaller than the cooling power at the recondensers, the boiling pressure of the helium bath will go down until the cooling power becomes identical with the heat load to the bath; in the opposite case the boiling pressure will increase and the check valve will let gas come out at a rate that balances the lack of cooling power.
- If the heat load is very much smaller than the cooling available at the recondensers, one or two of the cryocoolers can be turned off. After reaching a new equilibrium, it may be possible to measure the heat load more accurately
- It is important to monitor the temperature distribution of the shield over a long period of time, in view of getting an idea of the speed at which the MLI will settle in thermal equilibrium

Measurement of the heat loads

Dynamic heat load measurement (16 h, partly during next item)

- The topmost level gauge, the bath pressure, and all temperatures will be recorded during all dynamics of the transients. The vacuum and helium leak rate will be also recorded.
- The known cooling performance of the cryocoolers can be used as a measure of the heat load to the helium vessel and to the shield; this requires the knowledge of the temperatures of the cold heads, but also the bath temperature and pressure will be used for obtaining the dynamic heat loads with precision.
- Ramping of the current in one or more of the coils will generate a heat load that can be determined from the recorded data. The eddy current heating of the shield will be monitored by the thermometers attached to it.
- Instabilities and TAO in the helium columns of the inlet and outlet lines will be monitored by the fast pressure gauges in them

Initial testing of coils

During cooldown and after thermal stabilization (8 h)

- The evolution of the coil resistance is a good and direct measure of the speed at which its average temperature is dropping. Any irregular behavior of the resistance may suggest problems with a joint. The resistance is best measured with DC and with both polarities.
- The coil isolation with respect to the cryostat should be checked during the cooldown; this is particularly important during the first cooldown
- When the coils are at 4.2 K, it may be possible to use the voltage taps to detect bad joints, by inserting 5% to 20% of the maximum current to the coils. This is easiest to do with a bipolar supply that has a very low noise. An nV DVM is very useful here.
- After connecting the current supplies, the joint resistances and load due to the current leads can be determined calorimetrically with ≈ 20% of the maximum current, by determining accurately the increase in the heat load to the helium vessel.
- The dependence of the heat load on the current ramp speed can also be determined calorimetrically

Training of the coils and testing of quench protection

Testing of the quench protection

- After the safe current ramp speed has been determined, and before training starts, it is important to first check that all quench protection devices are operational and activated; these are usually designed so that a complete check-up is easy to do
- The quench trigger is fired at low current, and the operation of all protection devices is monitored. The decay of the current of the coils is recorded as well as the pressure of the helium bath. All temperatures are recorded, even if the readout is not immediately operational during the transient. This may not be applicable to the spectrometer solenoids, unless some kind of quench heaters will be retrofitted in the system.

Training of the coils and testing of quench protection

Training and quench recovery

- The safe current ramp speed is applied up to about 80% of the maximum design current
- For the last 20% and 10% of the maximum current, the ramp speed may have to be reduced, depending on the designed operational margins of the conductor in the highest field zones of the coils, and on the available margin of the cryocooler power
- The cooldown of the magnet after quench is done with the line entering to the bottom, and for the final filling the refill line is used
- It is important to record also the evolution of the shield temperature during and after the quench, in order to make sure that the proper steady state conditions are established before starting the cycle for the next training quench
- The integrity of the current leads should be checked before the next training cycle

Conclusions

Cryogenic performance

- The knowledge of the cryogenic performance is required for the good design of the control system, and for establishing safe practices for the operation of the magnets
- The heat load measurements can be compared with the predictions, which are still awaiting some input from the final mechanical design
- The work presented here is in progress. Further iterations and input from all are most welcome.

Magnet performance

- Training results can be compared with the simulations, if the recorded data has the required time and temperature resolution
- Quench transients are predicted by the simulations presented by Soren Prestemon in this Workshop
- Field mapping can be done at full or partial current