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TECHNICAL NOTE

MICE Spectrometer Solenoid:
Summary of Modification Plan

1. Introduction

LBNL has undertaken a process aimed at 1) understanding the current design and performance of the Spectrometer Solenoid magnets and 2) defining a series of system design changes and enhancements that will allow the magnets to be trained to their design current and to operate without helium boil-off. A summary of the work that has been carried out and the resulting list of design changes is presented in the following sections. Details of the related studies and analyses are presented in supporting documents.

2. Preliminary Assessment & Plan

The tasks that have been carried out in the process of completing the plan are as follows:

- All heat loads have been reassessed to ensure that the LHe in the cold mass can be maintained with the final number of cryocoolers.
- The electromagnetic calculations have been redone and cover the cases of both testing and operation.
- A complete set of the latest as-built drawings (including the future changes) has been compiled.
- The instrumentation plan has been modified to ensure that the thermal and EM calculations can be confirmed during testing.
- The mechanical support of the magnet, leads, piping and other internal components have been reassessed for both worst case eddy current loads and shipping acceleration

a. Heat load analysis

In order to better understand the thermal performance of the helium cryostat of the MICE Spectrometer Solenoid, the heat leaks due to the dominant static sources have been re-evaluated. The focus of the calculations was the heat leak into the 4.2K cold mass as these directly relate to the issue of LHe boil-off during operation. The results of this analysis have been compiled in a separate document. Other aspects of magnet thermal performance including heat loads on the shield and vacuum insulation have been considered but are not presented in detail. The dynamic heat loads that occur during cooldown or current ramp-up when the magnet system is not in equilibrium have been ignored in this evaluation. These heat loads are negligible during long-term operation of the magnets.

b. Electromagnetic calculations

The design of the passive magnet protection system has been reviewed and analyzed under the various operational regimes. The results of these analyses have been summarized in a separate document. The areas covered include the calculation of the magnet self and mutual inductance parameters, determination of the coil current decay versus time during a quench, calculation of the hot spot temperature in the magnet for different scenarios (including the worst cases), and analysis of coil voltage versus time during a quench.

c. Fabrication drawings

A collection of more than 200 detail fabrication drawings representing both the latest assembly of the Spectrometer Solenoid (Magnet 2B) as well as the most recent design modifications has been collected from Wang NMR and has been organized in the form of a drawing tree list. The drawings now represent a complete description of the next generation of the as-built magnet. As determined to be appropriate by our analyses, these design changes are included in our part of our current list of magnet modifications. In parallel with the effort to organize the drawings, LBNL has developed a detailed 3D CAD model of the Spectrometer Solenoids. Until now, the only model of the magnets was developed at RAL and was based on an early magnet design. Note that the vendor has not used 3D modeling during the design and fabrication of the magnets.

d. Instrumentation plan

The current configuration of the instrumentation on the spectrometer solenoid magnets has been reviewed, and a series of changes and additions to the system are being implemented. The results of this analysis have been compiled in a separate document. The instrumentation under consideration includes temperature sensors, voltage taps, helium level gages, and pressure gages. The wire type used to connect the instrumentation has also been reviewed. In most cases, the changes to the instrumentation scheme came about due to shortcomings that were identified during the previous rounds of magnet training and testing. Another prime consideration was the ability to record data relevant to the confirmation of our heat load analyses.

e. Mechanical support assessment

During the course of the magnet analyses, the internal mechanical support of the various magnet components has been reviewed. The primary issues in this area are 1) the mechanical stresses imposed on the components and supports caused by thermal contraction during cooldown and by electromagnetic forces during operation (primarily due to eddy currents), and 2) the stresses imparted on the various components caused by accelerations during shipping. The components reviewed are the cold mass supports, the thermal shield and its supports, and the support of the 1st stage copper plate and its relative movement with respect to the cryocoolers and the magnet leads (particularly the HTS leads).

3. Design Modification Strategy

Based on recommendations from the previous review committees, an overall strategy was developed for identifying areas of the magnet design where improvements were necessary. This procedure included the following:

- reduction of heat leaks to the cold mass
- the addition of more cryo-cooling power
- modification of the cold leads near the feedthroughs to prevent burn-out

The details of the plan are described in the sections that follow. Please note that details of the analysis and decision path for many of these proposed modifications are included in supporting documentation.

4. Heat load reduction to 4.2K

One of the primary requirements of the Spectrometer Solenoid magnets is the ability to run in steady state at full operating current while maintaining the LHe in the cold mass with recondensation provided only by the cryocoolers (no boil-off). The following design improvements are being implemented to directly reduce the heat load on the Spectrometer Solenoid cold mass:

- Improved vacuum pumping and instrumentation will be implemented to ensure adequate cold mass insulation. The pump port size is being enlarged from the current 25 mm to a DIN 100 flange with a gate valve. A 300 L/s turbopump will be used as the primary pumping system with a dry scroll pump for obtaining rough vacuum. Instrumentation will include thermocouple, piranni and ionization gauges as well as an RGA.
- All 4K areas will be covered with actively cooled shield where possible, including around the cold mass supports where they penetrate the thermal shield – partially covered areas are being further analyzed.
- Baffles or jogs are being added to the cold mass vent lines to prevent direct radiation shine to 4.2K.
- Possible thermo-acoustic oscillations in vent lines will be addressed by monitoring with fast pressure gauges read on an oscilloscope. Any significant observed oscillations will be addressed through a design change or by adding an appropriate damping material to the line.
- The cryocooler recondenser pipe connections to the cold mass will be direct and will not include any type of intermediate manifold (as in Magnets 2A and 2B). While the effect of the manifold on the efficiency of the cooling circuit is not known, all of the offline cryocooler and lead tests performed at Wang NMR used the direct connection approach.
- Application of the MLI on cold mass bore is being improved by procuring precision cut blanket assemblies and by reducing the compression of the MLI layers.
- Sensor wires will be optimized by ensuring that they are all phosphor bronze and with proper heat sinking. Quad flat 4-wire cable (phosphor bronze) made by LakeShore will be used where possible due to its superior electrical and thermal properties and the fact that it can be readily fixed to a first stage heat sinking surface.

5. Radiation shield heat load reduction:

Although the temperature of the radiation shield has less direct effect on the heat leak to the cold mass, several deficiencies in the design of the shield system were previously identified. Correction of these issues during reassembly of the magnet is expected to result in reduced shield operating temperatures. These improvements to the shield will indirectly reduce the heat leak to 4.2K due to conduction in the cold mass supports and by radiation. The following design improvements are intended to directly reduce the heat load on the shield and to improve its thermal conductivity:

- The thermal connection between the cooler first stage and the radiation shield will be improved by replacing the previous aluminum banding with flexible copper sheets.
- The majority of the shield is being remade using series 1100 aluminum which has at least five times higher thermal conductivity as compared to the existing series 6061 aluminum shield material.
- Application of MLI on shield bore tube will be improved by reducing the compression of the MLI layers and by applying it in a way that allows it to contact the colder surface.
- The LN reservoir that was attached directly to the thermal shield in Magnets 2A and 2B will no longer be included in the assembly. In practice, the reservoir was primarily useful during the initial cooldown of the shield and was generally not used after that point in the training process. It appears that the reservoir became a net heat load on the shield and was responsible for at least some of the observed extra heat load on the shield as compared to the tests on Magnet 1 (with no reservoir). Concerns about protection of the HTS leads in the event of a power failure are being addressed through the addition of an external dump circuit.
- The heat loads from the following will be decreased as possible: shield pass through holes for the cold mass supports, intermediate cold mass support heat intercepts, and shielding of the warm end of the supports.

6. Other key improvements:

As mentioned previously in this document, two critical areas of the magnet design requiring improvement are 1) the chosen amount of cryocooling power available for recondensation of the liquid helium in the cold mass, and 2) the stabilization of the cold leads on both sides of the feedthrough to the cold mass. The design modifications being implemented are summarized below.

- The total cooling power is being increased by using five 2-stage pulsed tube coolers and one single-stage cooler. A layout of the modified design showing the positions of the six cryocoolers is shown in Figure 1. This drawing represents the magnet layout produced by Wang NMR. The detail drawings required for carrying out this approach have already been generated by the vendor through a PO change order.
- The thermal/mechanical stabilities of the cold leads will be improved by adding extra copper/superconductor near the cold mass feedthroughs. The added copper lead material will significantly stiffen the leads to prevent movement caused by electromagnetic forces and will provide a more effective means of cooling through conduction.

7. Improvements to magnet QC/QA

In order to provide increased oversight of the magnet assembly process, to better document the details of the assembly of the magnets, and to assist the vendor with QC/QA, the MICE Project will maintain a regular presence at the assembly plant during completion of the magnets. Rutherford Appleton Laboratory (RAL) has provided a full-time mechanical engineer for a period of one year to assist in this task. LBNL will also provide technical and engineering support for this effort. It should also be noted that Wang NMR is agreeable to this arrangement.

One area of particular concern is the preparation of the blankets and the application of MLI to the 4.2K and thermal shield surfaces. LBNL has taken full responsibility for this task and has developed a QA plan to ensure that the MLI is adequately prepared, applied and inspected. LBNL and RAL engineers will be responsible for the implementation and ongoing oversight of the QA plan.

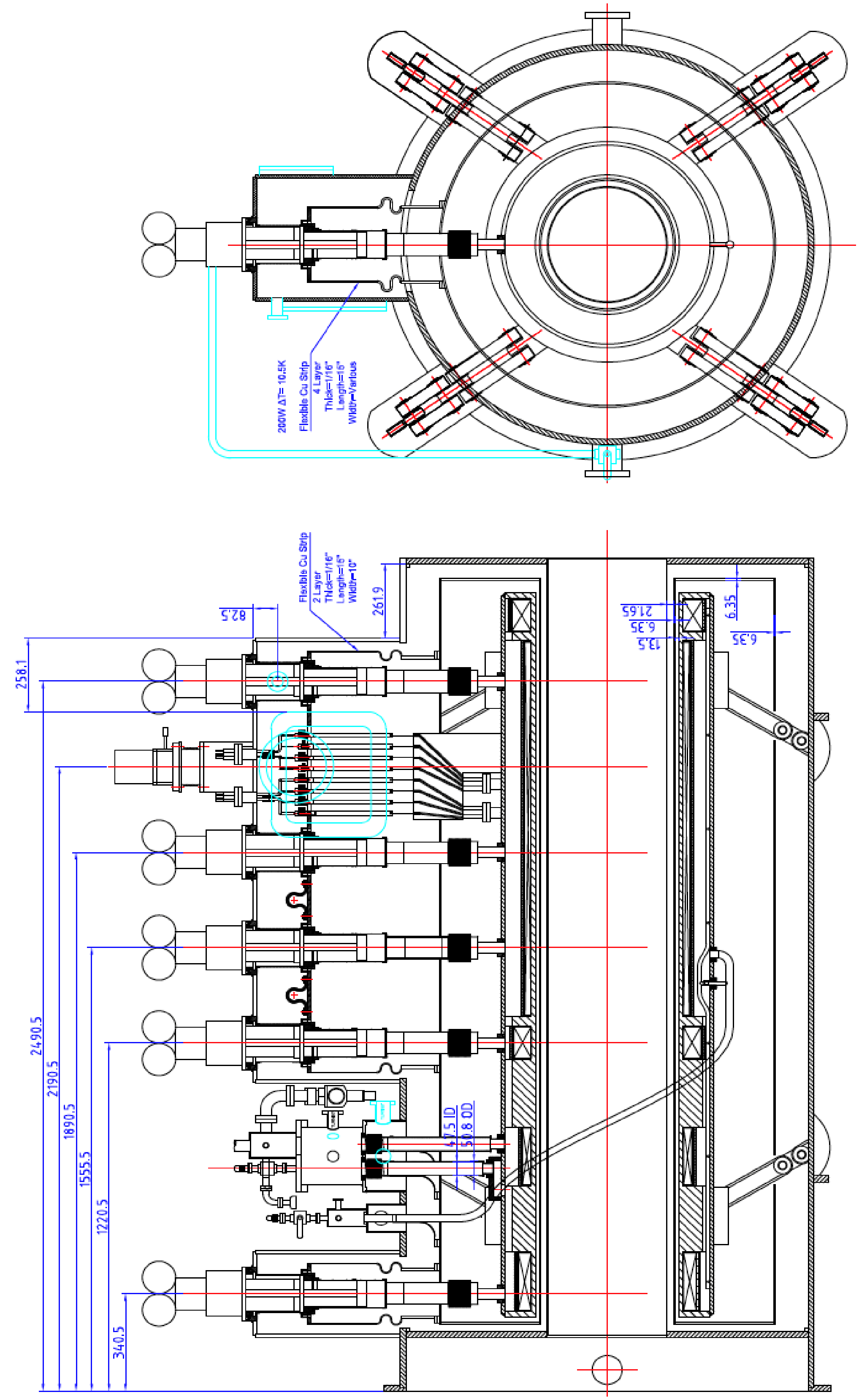

Figure 1: Layout of the modified cooler arrangement (5 ea 2-stage, 1 ea 1-stage)