Fermilab

Particle Physics Division
Mechanical Department Engineering Note

Number: g-2-doc-1981 Date: October 13, 2014

Project: g-2 superconducting rings

Title: g-2 mandrel LHe piping engineering note

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Reviewer(s): Mark Adamowski

Key Words: Piping note, 31.3, ASME, 5031

Abstract Summary:

This document describes the LHe tubes in the g-2 cryostat rings, which were designed and installed in the g-2 cryostat at Brookhaven National Laboratory in the early 90's. The LHe tubes cool the aluminum superconductor containing mandrel which is Aluminum T6061-T6. The tube itself is Aluminum T6063-T52 and has relief valves set to 100 psi. The design pressure is 291 psid, with the relief valves set lower since a large pressure rise is seen during the relief scenarios analyzed. This piping note analyzes the tubing and shows the system complies with FESHM 5031.1 and ASME 31.3 code for process piping for operational pressure/temperature design, as well as all relief scenarios, which include simultaneous complete loss of vacuum and magnet quench without consideration of the dump resistor.

FESHM 5031.1 PIPING ENGINEERING NOTE FORM

Prepared by: **Erik Voirin** Preparation Date: **10-13-2014**

Piping System Title: **g-2 mandrel LHe Tubing**

Lab Location: **MC1 Building** Location code: **209**

Purpose of system**: Supply Two-phase Helium to cool superconducting coils in mandrel.**

Piping System ID Number: **none assigned**

Appropriate governing piping code: **ASME B31.3**

Fluid Service Category (if B31.3): **Normal Fluid Service**

Fluid Contents: **Two-phase Helium**

Design Pressure: **295 psid @ 4.4K,**

(relief valves set lower (100 psi set point) since pressure rises during a relief scenario)

Piping Materials: **Aluminum 6063-T52**

Drawing Numbers (PID's, weldments, etc.): **g-2 Doc 1830 - Attachment C**

Designer/Manufacturer: **Brookhaven National Laboratory**

Test Pressure: **325 psig** Test Fluid: **Nitrogen** Test Date: **TBD**

Statements of Compliance

Piping system conforms to FESHM 5031.1, installation ***is not*** exceptional: **Yes**

Piping system conforms to FESHM 5031.1, installation ***is*** exceptional and has been designed, fabricated, inspected, and tested using sound engineering principles: **N/A**

Reviewed by: ____ (Print Name)

Signature: ____Date: ______________

D/S Head's Signature: _____________________________________Date: ______________

The following signatures are required for exceptional piping systems:

ES&H Director's Signature: _________________________________Date: ______________

Director's Signature or Designee: ____________________________Date: ______________

Pipe Characteristics

Size**:** **1.5" x 0.75" Rectangular tube; 0.156" wall** Volume: **~ 71 Liters**

0.75" OD x 0.062" wall SS Tubing

Relief Valve Information:

Type: **Spring Loaded** Manufacturer: **2 Circle Seal / 1 Anderson Greenwood**

Set Pressure: not applicable Relief Capacity:

100 psig (lower than 295 psi design pressure due to pressure rise during relief event)

Relief Design Code: **ASME – Non-Code Relief Valves (three PSVs)**

Is the system designed to meet the identified governing code? **Yes**

Fabrication Quality Verification:

Process and Instrumentation diagram appended? **Yes, Attachment C**

Process and Instrumentation component list appended? **Yes, Attachment C**

Is an operating procedure necessary for safe operation? **No**

If 'yes', procedure must be appended.

Exceptional Piping System

Is the piping system or any part of it in the above category? **No**

If "Yes", follow the requirements for an extended engineering note for Exceptional Piping Systems.

Quality Assurance

List vendor(s) for assemblies welded/brazed off site: **Brookhaven Nat'l Lab**

List welder(s) for assemblies welded/brazed in-house: **Leonard Harbacek**

Append welder qualification Records for in-house welded/brazed assemblies. **Attachment F**

Append all quality verification records required by the identified code (e.g. examiner's certification, inspector's certification, test records, etc.)

Table of Contents

Body:

1. Description and Identification

These three vacuum vessels, also called the cryostats, contain the superconducting coils of the Muon g-2 magnet. Therefore they also contain cooling lines which carry two-phase helium to the superconductor containing mandrels and nitrogen to the heat shields. Figure 1 shows an external view of the 50 ft. diameter vessels and the interconnect region which connects the cryostats together into one common vacuum space. Internal dimensions of these vessels are shown in Table 1. Figure 2 shows the entire magnet cross section, where one can see the position of the three vacuum vessels and their internals. Figure 3 shows a close up view of the three vessels and their internals, where the nitrogen and helium lines are labeled and colored purple and blue respectively.

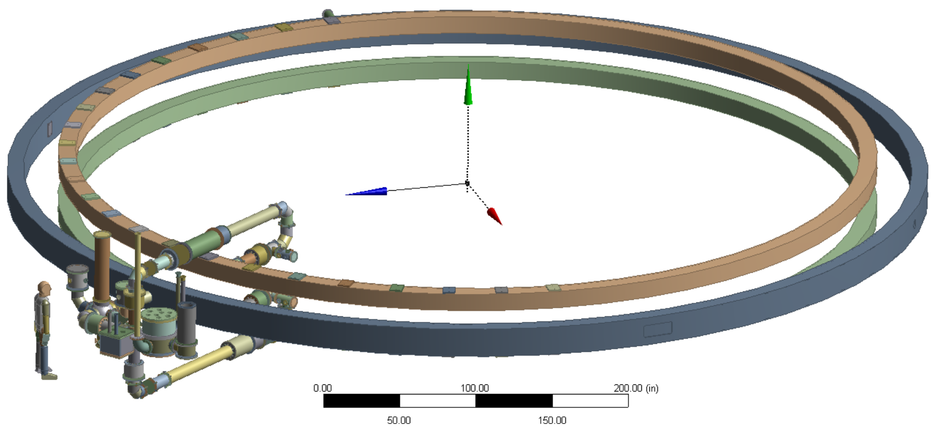

Figure 1: External view of the three cryostats and interconnect region which connects the cryostats together.

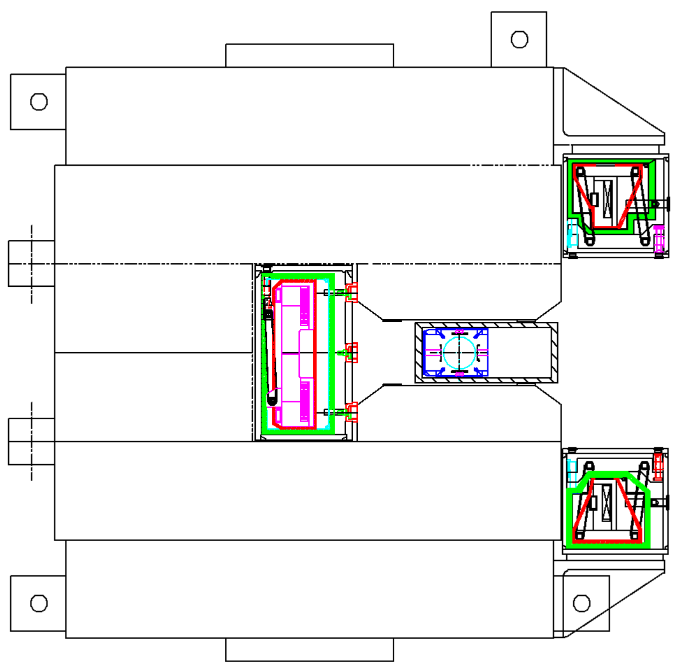

Figure 2: Entire magnet cross section containing the vacuum vessels (cryostats).

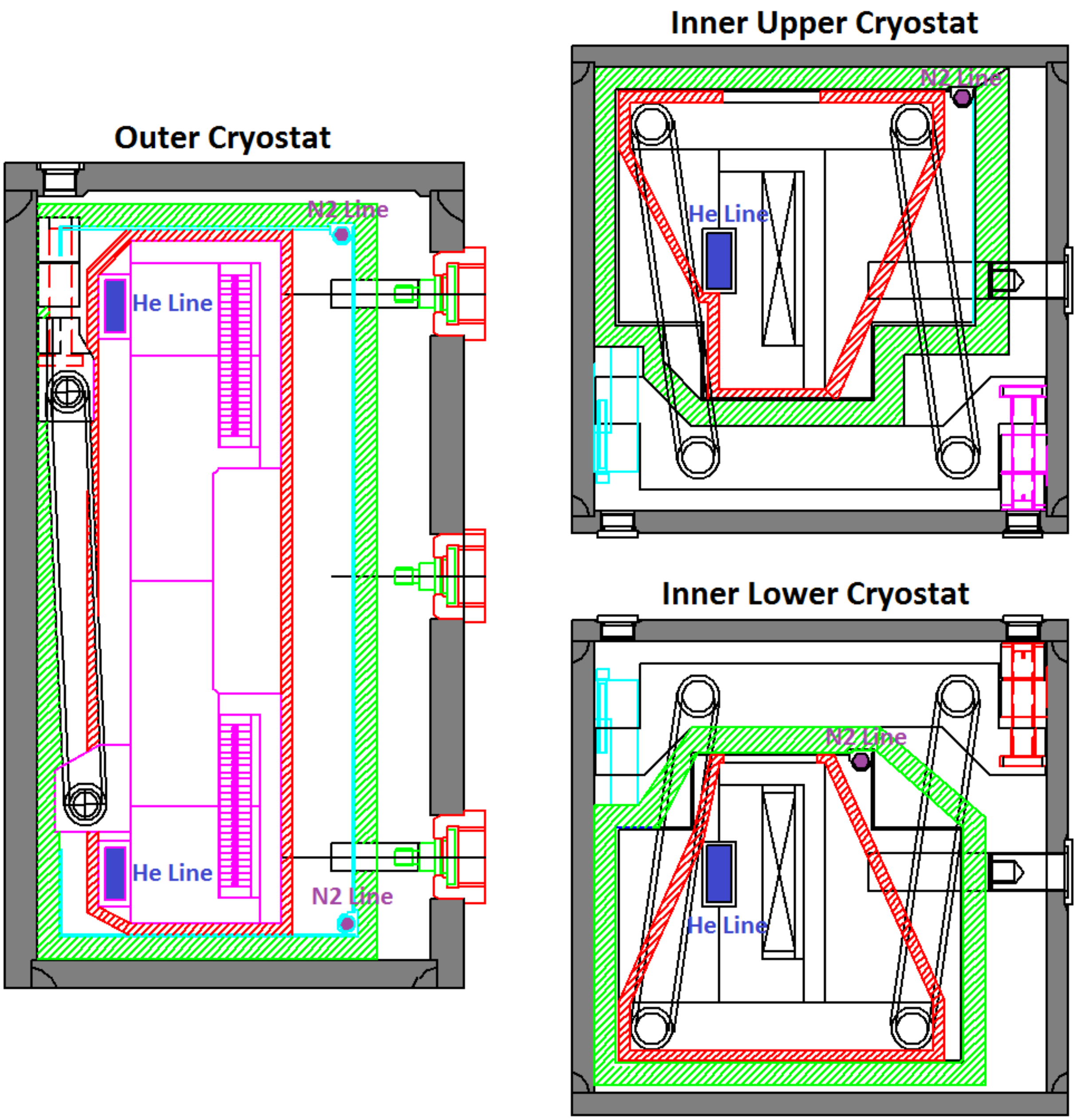

Figure 3: Close up view of the three vessels and their internals, where the nitrogen and helium lines are labeled and colored purple and blue.

2) Piping and Instrument diagram

The piping and instrument diagram is in g-2 DocDB: Doc 1830, and also shown in Attachment C. This note only analyzes the internal helium tubing inside the ring cryostats and interconnects, not the entire cryogenic system. The Valve and instrument list for this portion of the tubing is attached as well.

3) Design codes and evaluation criteria

These LHe transfer lines meet the requirements of section 5031.1 of the Fermilab ES&H Manual, which states that this piping system falls under the category of Normal Fluid Service. This means it shall adhere to the requirements of the ASME Process Piping Code B31.3. Section 5032 contains additional requirements for cryogenic system components.

4) Materials

The tubing for the helium and nitrogen lines is fabricated from 6063-T52 Aluminum. The allowable stress for this temper is not listed, though it can be seen by the values in the ASME Table that they use 1/3 the Minimum specified strength, so 1/3 of the 27 ksi listed for this material would be 9 ksi allowed by the code for this material/temper.

The piping will be operated at 4.4K (-451.75 F). This is above the minimum temperature listed for this material (-452K)

5) Pipe Design / Internal pressure design

The helium piping which coils around the mandrels is rectangular tubing which is 1.5" x 0.75" outer dimensions, with a 0.0156" wall, and a 0.1" radius at the corners. Calculations were done for stress due internal pressure, which shows the allowable stress is reached at an internal pressure of 318.02 psid, as seen in Figure #4. This pressure rating value could easily be increased by more rigorous interpretation of Section VIII Division 2, but there is no need to, as this pressure rating satisfies relief scenarios, and matches well enough with the pressure test performed by Brookhaven at 320 psig. Therefore we rate the system to have a design pressure of 291 psi to coincide with this pressure test at 10% overpressure.

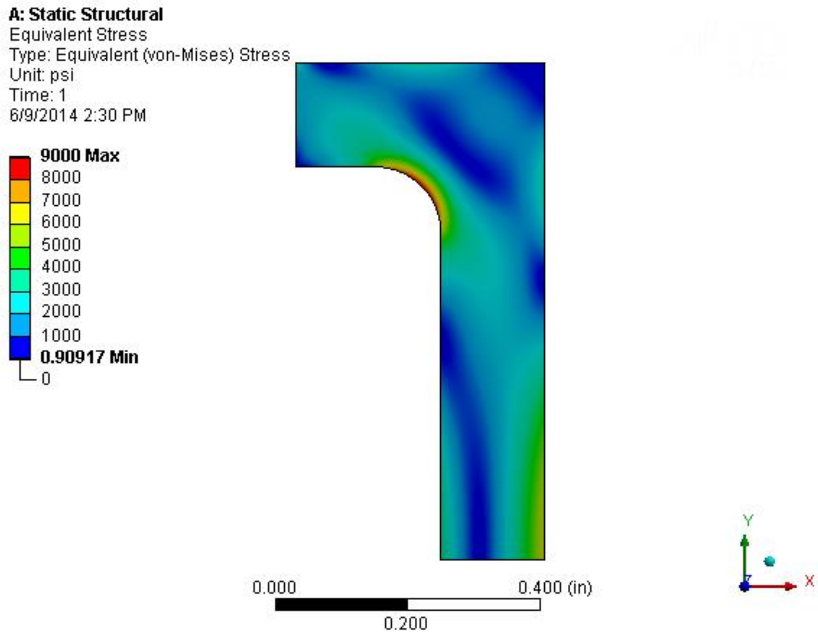

Figure 4: von-Mises stress at 318.02 psid equals ASME allowable at inside radius.

Besides these rectangular sections which wrap around the mandrels, the helium tubing also contains sections of normal circular tubing which connect the mandrel routes together. This is Aluminum as well, ¾" OD tube with a 0.062" wall. The minimum thickness of these tubes is evaluated using the procedures in 304.1.2(a) of ASME B31.3.

The minimum tube thickness for seamless or longitudinally welded piping for t<D/6 is given by the equation shown below. Using this, we show the wall thickness is many times more than adequate, so internal pressure should be of no concern on these tubes:

$$t = \frac{P \cdot D}{2 \cdot (S \cdot E \cdot W + P \cdot Y)}$$

where: t = wall thickness,

P = internal design pressure

D = outside diameter (manufacturers nominal value is used)

S = allowable stress from table A-1

E = quality factor from table A-1B = 1 for seamless, 0.8 for clamshell

W = weld joint strength reduction factor = 1 for seamless tubing, 0.8 for clamshell per 302.3.4.

Y = coefficient from Table 304.1.1 = 0.4

ASME Equation for required wall thickness >> Converted to pressure rating

$$t_m = \frac{P_1 \cdot D_1}{2 \cdot (S_1 \cdot E_1 \cdot W_1 + P_1 \cdot Y_1)} \text{ solve}, P_1 \rightarrow \frac{2 \cdot E_1 \cdot S_1 \cdot W_1 \cdot t_m}{D_1 - 2 \cdot Y_1 \cdot t_m}$$

$D_o := 0.75in$	D = outside diameter of pipe as listed in tables of standards or specifications or as measured
$E_1 := 1$	E = quality factor from Table A-1A or A-1B
$Pressure_{rating}$	P = internal design gage pressure
$S_1 := 9ksi$	S = stress value for material from Table A-1
$t_m := 0.062in$	t_m = minimum required thickness, including mechanical, corrosion, and erosion allowances
$W_1 := 1$	W = weld joint strength reduction factor in accordance with para. 302.3.5(e)
$Y_1 := 0.4$	Y = coefficient from Table 304.1.1, valid for $t < D/6$ and for materials shown. The value of Y may be interpolated for intermediate temperatures. For $t \geq D/6$,

$$P_{ratingASME} := \frac{2 \cdot E_1 \cdot S_1 \cdot W_1 \cdot t_m}{D_o - 2 \cdot Y_1 \cdot t_m} = 1593.375 \cdot psi$$

6) Relief Valves

The piping is protected from overpressure by a Rockwood Swendeman RXSO relief valve: model number 710-N-D-E-H-A-100 set to 100 psi. There are two more circle seal relief valves on the piping, but we ignore these and only analyze the largest relief valve in the relief scenarios due to the complexity of coupling the flow through all three valves located throughout the tubing.

Relief valve calculations for the internal helium tube were performed for several cases, the most severe of which was a total loss of vacuum combined with a magnet quench without the installed quench protection dump resistor. Detailed calculations are shown in Attachment A.

There are no system sources of pressure that can supply Helium at a pressure greater than 300 psi, as upstream relief valves are set at this value maximum, with some being lower. Supply flow from the helium source, MYCOM compressors, is estimated at less than 120 gm/sec, which is far below the relief valve capacity even without the upstream relief valves.

Fire is not considered credible due to the lack of combustible material in the vicinity of the piping, which is encased inside cryostats and surrounded by heat shields and Yoke pieces. Also, the long length of the piping makes it unlikely a significant portion could be involved in a fire. Even if it were included, the heat load would surely be less than the simultaneous loss of vacuum and magnet quench scenario which show hundreds of kilowatts of possible heat input.

7.) Welding Information

Nearly all welding was done during manufacture in the early 90's by BNL. Several helium tubes in the interconnect region had to be cut to prepare for transport. These tubes will be re-welded here at Fermilab by Leonard Harbacek, qualifications attached, but all these welds will be socket type welds, meaning no radiography or in-process weld inspection is required by ASME B31.3.

8) References

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