FRIB Cryogenic Distribution System and Status

This content has been downloaded from IOPscience. Please scroll down to see the full text.
2015 IOP Conf. Ser.: Mater. Sci. Eng. 101 012034
(http://iopscience.iop.org/1757-899X/101/1/012034)

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 129.57.130.18
This content was downloaded on 01/06/2016 at 18:54

Please note that terms and conditions apply.
FRIB Cryogenic Distribution System and Status

V Ganni1, K Dixon1, N Laverdure1, S Yang1, T Nellis2, S Jones2 and F Casagrande2

1Thomas Jefferson National Accelerator Facility, Newport News, VA 23606 USA
2 Facility for Rare Isotope Beams (FRIB), Michigan State University, MI 48824 USA

Email: nal@jlab.org

Abstract. The MSU-FRIB cryogenic distribution system supports the 2 K primary, 4 K primary, and 35 – 55 K shield operation of more than 70 loads in the accelerator and the experimental areas. It is based on JLab and SNS experience with bayonet-type disconnects between the loads and the distribution system for phased commissioning and maintenance. The linac transfer line, which features three separate transfer line segments for additional independence during phased commissioning at 4 K and 2 K, connects the folded arrangement of 49 cryomodules and 4 superconducting dipole magnets and a fourth transfer line supports the separator area cryo loads. The pressure reliefs for the transfer line process lines, located in the refrigeration room outside the tunnel/accelerator area, are piped to be vented outdoors. The transfer line designs integrate supply and return flow paths into a combined vacuum space. The main linac distribution segments are produced in a small number of standard configurations; a prototype of one such configuration has been fabricated at Jefferson Lab and has been installed at MSU to support testing of a prototype FRIB cryomodule.

1. Introduction

The planning efforts for large accelerator cryogenic refrigeration and distribution systems are a complex combination of science, art, and experience. The large accelerator applications typically involve one-of-a-kind specialized equipment designs which must meet the requirements of various steady-state operating modes at varying capacities. In addition to these basic considerations, the designs must also allow (1) phased commissioning of the subsystems; (2) transient modes of operation such as cool down and recovery from upset conditions; (3) partial system operation during maintenance activities; (4) some error tolerance giving a degree of operational independence from uncertainties in load estimation and variables from the actual manufacturing processes and (5) future upgrade plans. It is prudent to design the system that can operate with the maximum flexibility for all these known requirements to improve the overall availability of the cryogenic system to support the accelerator operations. It is especially important to design for future upgrades during the initial planning stage since the distribution system is so difficult to modify without large negative impacts on availability and cost. The rationale and preliminary plans for the MSU-FRIB accelerator cryogenic distribution system, based on the above factors, were explained previously [1].
2. Design basis
The dynamic and static heat loads handled by the refrigerator and distribution system were presented previously [1]. After the cryo distribution systems designs matured, the heat loads were rechecked and found to be very close the original estimates. The line sizes are selected not only for the present operation but also to support the planned upgrade. An attempt is made to keep the designs as standard as possible to gain the economics of scale in design and production.

2.1. Division of loads
The key considerations for similar cryogenic systems are described previously [2]. To facilitate the requirements outlined above, the MSU-FRIB cryogenic distribution system (figure 1) is divided into four independent process paths, one for each linac segment and one for the separator area. These transfer lines (figure 2) connect the refrigeration system with each segment of the linac.

![Figure 1](image1.png)

**Figure 1.** A simplified flow diagram of the MSU-FRIB cryogenic distribution system.

![Figure 2](image2.png)

**Figure 2.** Linac cryogenic system layout. Three bayonet cans are centrally located in the cold box room, near the top left of the diagram. These are individually connected to the three sections of the linac transfer line, which are arranged parallel to one another in the east-west direction to support the paperclip-shaped accelerator components. The longest section of transfer line, LS2, spans more than 148 m.
Just as the four transfer lines may be individually connected and disconnected from the refrigerator using “u-tubes” between pairs of female bayonets, the many individual cryogenic loads may be individually connected and disconnected from the transfer lines. Although these bayonets between the cryomodule and the distribution system impose a heat load that must be offset by additional refrigeration capacity, this incremental cost to the refrigerator is outweighed by the incremental linac commissioning, improved availability, maintainability, and linac operating capabilities that are provided when cryomodules can be added to, or removed from, the operating distribution system. This design has enjoyed long-term success at JLab, where for 20 years of 2 K operations the linac has been warmed up only twice: once due to an unplanned prolonged power interruption and the other time for the 12 GeV upgrade to modify the cryo distribution in the tunnel for additional cryomodules [3].

2.2. Cold-end heat exchanger
The design of the cryogenic distribution system can also be characterized by the location of the 4 K – 2 K heat exchangers. The ten years of SNS operation with this 4 K – 2 K heat exchanger located in the cryomodule, as compared to JLab’s configuration with the heat exchanger centrally located in the cryo plant, has influenced the placement of the MSU-FRIB heat exchanger within the cryomodule as well. By placing this heat exchanger as close to the major heat load as possible, heat leaks into the return distribution system are absorbed as 4 K loads instead of 2 K loads, leading to improved process efficiency [4]. The 2 K operating philosophy of the cryomodule is based on the JLab and SNS experience; however, a major differentiating feature for the MSU-FRIB cryogenic distribution system relative to the JLab and SNS systems is its additional support for 4 K superconducting magnets in the cryomodule.

3. System description

3.1. Cryomodule transfer line
The main unit of the MSU-FRIB transfer line, shown in figure 3, is a standardized design that may be reconfigured for a number of different cryomodule lengths. Line sizes within this transfer line are given in table 1. The interface connections to each cryomodule, and to the next transfer line unit(s), are standardized as well.

![Figure 3. Standard transfer line section to interface with the cryomodule, typical of 49 units. These transfer line units vary from 2.8 to 6.7 m in length, in six discrete sizes. Regardless of length, each of these sections includes five female bayonets ranging from 1” to 3-1/8” for u-tube connections, three cryogenic control valves, and several bellows to add flexibility and compensate for thermal contraction of the installed transfer line. The design of these modular units is centered on the thermal performance and minimization of field welds. The build-to-print fabrication drawings and step-by-step assembly and testing procedures used during the production of the transfer line sections are provided in the design package, along with](image-url)
the detailed drawings for the production test fixture. The completeness of this design package, tested using two prototypes, enables any reasonably experienced manufacturer to produce a cost effective product with minimal technical risk.

At one end of each modular section is a can which houses the valves and bayonets; the design of this can minimizes production risk by emphasizing commonality between components, ease of assembly, and integrated testing features for quality verification at several key points of the fabrication process. The planned U-tube connection interface between the transfer line and the cryomodule were given previously [1] and are well documented in a series of Interface Control Documents. To facilitate the installation and disconnection of these U-tubes during system operation in maintenance mode, external tubing at each set of bayonets are planned to provide a helium purge source, a connection to the guard vacuum header, and trapped liquid relief mechanisms where required.

| Table 1. Process line sizes within the main units of the MSU-FRIB transfer line. |
|---|
| **Line** | **Size** |
| Primary supply | 1-1/2 NPS SCH-10 |
| 4 K return | 2 NPS SCH-10 |
| 2 K return | 10 NPS SCH-10 |
| 35 K supply | 2-1/2 NPS SCH-10 |
| 55 K shield supply | 2-1/2 NPS SCH-10 |
| Insulating vacuum jacket | 20 NPS SCH-10 |

3.2. Thermal shield arrangement

A copper shield, cooled by the shield return line, surrounds the internal piping. This shield is constructed of 1/16 inch thick high-purity electrolytic tough-pitch copper sheet which has been rolled and formed. The copper shield is attached to the stainless steel shield return line by mechanical means: the overlapping shield panels are riveted and banded to one another, firmly clamping around the pipe. An interstitial layer of copper foil, just 0.5 mils thick, conforms to the surface roughnesses of the copper and stainless surfaces when compressed by the clamping devices, increasing the effective contact area within the joint. The position of the copper shield is also locked to the pipe in the axial direction by a protrusion which limits the relative motion between these parts caused by differential thermal expansion during cool down.

These mechanical attachment methods have reduced the need for costly brazing operations during fabrication. This construction style is an improvement to those recently used for connection of thermal shielding within the JLab Hall D cryogenic distribution system [5] and is similar to the method of attachment used, for the last 20 years, to connect heater bands onto 80K and 20K beds in large-scale refrigerators including the JLab cold boxes. Limited preliminary testing of the prototype transfer line sections indicates that this method performed well under FRIB operating conditions.

3.3. Shaft transfer lines

The three linac segments of transfer line connect to the cold boxes by way of a vertical chase which contains the three shaft transfer lines shown in figure 4. Like the standard cryomodule transfer line sections, these transfer lines are also designed and assembled in modules: the vertical segments are planned to be installed from the cold box room into a chase which penetrates the ceiling of the linac tunnel, the horizontal and “T” sections are then connected in the accelerator tunnel, and finally the bayonet boxes in the cold box room will be attached. Similar to JLab and SNS, these bayonet boxes provide the primary interface between the linac transfer lines and the refrigeration system.

The cryogenic interfaces at the bayonet boxes are accompanied by an array of uninsulated piping, shown in figure 5; sizes of these lines are given in table 2. This uninsulated piping serves the “warm” utility functions of the cryogenic distribution system: (1) guard vacuum, (2) helium cool down, (3)
magnet lead flow return, (4) warm helium purge supply, and (5) a header to collect the exhausts of the primary reliefs on the 4 K systems of each cryomodule. Each of these warm lines can be individually isolated to provide the required flexibility for independent phased commissioning and partial system operation of each linac during maintenance activities.

![Diagram of cryogenic transfer lines](image)

**Figure 4.** Cryogenic transfer lines pass through a vertical chase to interface with the three linac segments. At the top of each diagram are the bayonet cans within the cold box room; each of these cans includes female bayonets ranging from 2” to 9-1/4.” Branch connections are provided at the top of each vertical section of transfer line for connection to ASME relief valves. Sections of transfer line are fabricated, delivered, and installed independently; tie-in connections between sections are standardized as much as possible to ease the final assembly. The thermal shield and insulating vacuum jacket must be “clamshelled” to cover each of these tie-in connections. The tallest of the vertical sections, for the center LS2 transfer line, is more than 14.1 m tall; this is greater than the cold box room ceiling height which requires a very careful installation of this module.

| Line                  | Size          |
|-----------------------|---------------|
| Guard vacuum          | 4 NPS SCH-10  |
| Cool down             | 3 NPS SCH-10  |
| Lead flow return      | 2 NPS SCH-10  |
| 4 K relief header     | 2 NPS SCH-10  |
| 3 atm helium purge supply | 1 NPS SCH-10 |

Some special-purpose segments of transfer line exist within the cryogenic distribution to bridge long gaps between cryomodules, terminate the ends of the lines with cool down valves and anchor points, and adapt to branch lines serving the 4 K superconducting folding magnets.

### 3.4. Instrumentation

Temperature and pressure instrumentation for each of the linac segments is located within the “T” transfer line sections. Redundant Cernox cryogenic temperature sensors are surface-mounted to the process lines and are arranged to record the temperatures of the primary and shield supply lines as well as each component of the primary and shield return flows: i.e. the component from the west portions of the linac segment, the component from the east, and the combined flow returning to the cold box room. The pressures of the 2 K return lines are also monitored at the “T” locations by pressure transducers; these pressure signals will be used to control the operating conditions of the cryomodules.
Figure 5. Layout of shaft bayonet boxes within cold box room. Visible are three pairs of 9-1/4” female bayonets, with their vacuum gate valves, for the subatmospheric return to the 2K cold box. There are also 15 pairs of smaller female bayonets for positive-pressure operation; all of these bayonets are arrayed such that each group of bayonets supports the operation of each linac section. On the skids beneath the bayonet cans, the ASME relief valves are seated on diverter valves for easy recalibration and replacement and are vented to atmosphere through a large exhaust header.

4. Prototype standard transfer line sections

A fixture was developed at JLab to facilitate the various stages of fabrication and in-process testing of the transfer line sections. A nearly completed transfer line section in the fabrication fixture is shown in figure 6. Using this fixture, two prototype sections of transfer line were built at JLab and supplied to MSU for combined testing together with a prototype FRIB cryomodule in the ReAccelerator (ReA) area. Lessons learned from this prototype transfer line fabrication experience were incorporated into the final design package which was provided to the industry.

5. Cold box room

The layout of the MSU-FRIB main cold box room is given in figure 7. The location of the distribution system relief devices and linac disconnects in the refrigerator room, similar to JLab and SNS, eases maintenance and improves safety conditions as described previously [1]. An overhead crane is available to assist the installation and removal of large U-tubes.

The majority of pressure relief valves which protect the MSU-FRIB cryogenic distribution system are located in the cold box room near the vertical chase. The relief exhausts are collected in a header and vented to the outdoors through a penetration in the roof of the cold box room. Relief valves on positive-pressure cryogenic systems are connected to the system through diverter valves. Although only one relief is provided on each diverter valve to enable plant operations, a small number of spares are planned to be kept on-hand for relief changeover operations which may be necessitated by a scheduled calibration cycle or a leaky valve.
To minimize the risk of air contamination into the subatmospheric 2 K return line, its relief valves are captured within a secondary enclosure which is itself protected by a parallel plate relief device. During normal operation the enclosure is isolated from guard vacuum so that a pressure indicator may be used to determine the integrity of the relief valve within.

Figure 6. The fixture for the production of the Standard Transfer line section. The fixture is designed to allow the vast majority of assembly and testing steps to be accomplished before the transfer line is withdrawn. The multifunctional assembly which includes the rectangular plate at the top of the diagram is used for (1) precise placement of the valves and bayonets with respect to the rest of the transfer line, (2) suspension of portions of the copper shield, (3) suspension of portions of the insulating vacuum jacket, (4) vacuum leak check of the final assembly, and (5) pneumatic pressure test of the final assembly.

Figure 7. Planned layout of the above ground FRIB cold box room, a floor space of approximately 40 m x 11.5 m. From left to right and top to bottom, the primary components of this layout include: (1) the horizontal 60–4 K Lower Cold Box, approximately 11.2 m in length; (2) the vertical 10 kL liquid helium storage dewar; (3) a conceptual model of the 2 K cold box; and (4) the arrangement of bayonet cans supporting the independent operation of the three linac segments. Beneath the bayonet cans are the racks for the cryogenic distribution system relief valves. At the top right of the diagram, a short section of the warm helium piping is visible; this piping connects the helium compressors to the 300–60 K Upper Cold Box. At the bottom of the diagram are the two purifier cold boxes for helium recovery.
6. Fabrication and procurement status
To support the production of the standard transfer line sections, three manufacturing fixtures have
been fabricated. In addition, two customized fixtures have been developed for the production of the
connecting transfer lines between the linac segments and the cold box room. Production of the
transfer lines is proceeding as given in table 3.

Table 3. Production status and outlook for the cryogenic transfer lines to support initial
cryomodule 4 K operations.

| Transfer line                     | Number of units | Status       | Expected delivery of first batch | Expected delivery of final batch |
|-----------------------------------|-----------------|--------------|----------------------------------|---------------------------------|
| Standard cryomodule transfer lines| 49              | In production| Sep 2015                         | Dec 2016                        |
| Shaft transfer lines              | 3               | In production| Aug 2015                         | Apr 2016                        |
| Shaft bayonet cans                | 3               | In design    |                                  | Jun 2016                        |
| 4 K cold box bayonet cans         | 3               | In design    |                                  | Aug 2016                        |

7. Conclusions
The FRIB cryogenic distribution system design is based on the experience gained at JLab and SNS.
The procurement of the key sub systems are progressing as outlined above. There are no major
changes to the plans outlined previously [1].

Acknowledgements
The authors would like to express their appreciation and thanks to the TJNAF and FRIB management
and to their colleagues for their support. This work was supported by Jefferson Science Associates,
LLC under the U.S. Department of Energy contract no. DE-AC05-06OR23177. This material is based
upon work supported by the U.S. Department of Energy Office of Science under Cooperative
Agreement DE-SC0000661. Michigan State University designs and establishes FRIB as a DOE Office
of Science National User Facility in support of the mission of the Office of Nuclear Physics. The
FRIB/JLab collaboration is supported by Work for Others Agreement No. JSA 2012W003 between
JSA and MSU.

References
[1] Ganni V, Dixon K, Laverdure N, Knudsen P, Arenius D, Barrios M, Jones S, Johnson M and
Casagrande F 2014 FRIB cryogenic distribution system Adv. Cryo. Eng. 59A (New York:
American Institute of Physics) pp. 880-886.
[2] Ganni V, Knudsen P, Arenius D and Casagrande F 2014 Application of JLab 12 GeV helium
refrigeration system for the FRIB accelerator at MSU Adv. Cryo. Eng. 59A (New York:
American Institute of Physics) pp 323-328
[3] Dixon K, Wright M and Ganni V 2014 Linac cryogenic distribution system maintainence and
upgrade at JLab Adv. Cryo. Eng. 59A (New York: American Institute of Physics) pp 900-904
[4] Ganni V and Knudsen P 2014 Helium refrigeration considerations for cryomodule design Adv.
Cryo. Eng. 59B (New York: American Institute of Physics) pp 1814-1821
[5] Laverdure N, Creel J, Dixon K, Ganni V, Martin F Norton R and Radovic S 2014 The Hall D
solenoid helium refrigeration system at JLab Adv. Cryo. Eng. 59A (New York: American
Institute of Physics) pp 329-336.