CRYOMODULE DESIGN FOR 325 MHZ SUPERCONDUCTING SINGLE SPOKE CAVITIES AND SOLENOIDS*

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Abstract

The low-beta section of the linac being considered for Project X at Fermilab contains several styles of 325 MHz superconducting single spoke cavities and solenoid based focusing lenses, all operating at 2 K. Each type of cavity and focusing lens will eventually be incorporated into the design of cryomodules unique to various sections of the linac front end. This paper describes the design of a multiple-cavity and solenoid cryomodule being developed to test the function of each of the main cryomodule systems – cryogenic systems and instrumentation, cavity and lens positioning and alignment, conduction-cooled current leads, magnetic shielding, cold-to-warm beam tube transitions, interfaces to interconnecting equipment and adjacent modules, as well as evaluation of overall assembly procedures.

INTRODUCTION

The entire accelerator lattice for Project X consists of six distinct sections, each with a different style of cavity and cryomodule. The low-beta section is comprised of three single spoke resonator types, SSR0, SSR1, and SSR2, housed in different cryomodule configurations. The medium and high-beta sections all contain elliptical cavities. Table 1 summarizes each of these six sections. The last column indicates the total number of cavities, magnets, and cryomodules in the respective sections. There are a total of 82 low-beta single spoke resonators in 7 cryomodules and 194 medium-beta cavities in 30 cryomodules. Fig. 1 is a graphical form of the lattice detailed in Table 1. The 1.3 GHz pulsed high-beta section is not shown in Table 1 or Fig. 1.

Table 1: Cavity and Cryomodule Configurations

Section	β	f (MHz)	E (MeV)	Cav/Mag/CM
SSR0	0.11	325	2.5-11.4	18/18/1
SSR1	0.22	325	11.4-43	20/20/2
SSR2	0.4	325	43-179	44/24/4
LB650	0.61	650	179-559	42/28/7
HB650	0.9	650	559-3000	152/38/19

SSR CRYOMODULE DESIGN

The design of the SSR cryomodules is in-process with work concentrated on the development of a 4-cavity, 4-solenoid prototype compatible with either SSR0 or SSR1 cavities. All of the SSR cryomodules are similar in that they consist of an alternating sequence of cavities, magnets, and beam position monitors. Cavity to cavity spacing is 610 mm, 800 mm, and 600 mm for SSR0, SSR1, and SSR2 respectively. The SSR2 lattice is different than SSR0 and SSR1 in that there are two cavities for every solenoid so adjacent cavities can be closer together. Some details of individual cryomodule components are described in the following sections.

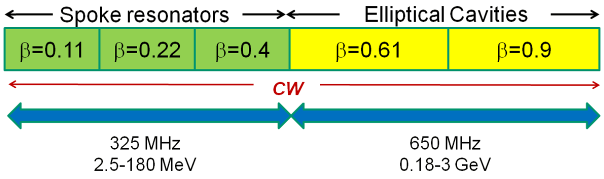

Figure 1: Graphical summary of the Project X lattice.

Segmentation

Segmentation refers to the way in which the cryogenic system and various beamline components are divided along the length of the accelerator. Coarse segmentation refers to systems in which the insulating vacuum and cryogenic circuits inside individual cryostats are more or less continuous for long lengths, at least over the length of several cryomodules. Most accelerator magnet systems are configured this way as are the cryomodules in the system envisioned for the ILC and the XFEL at DESY. Fine segmentation refers to systems in which the insulating vacuum and the cryogenic circuits are confined to an individual cryomodule, the only connection between modules being the beam tube connection. The cryomodules for the SNS are one example of fine segmentation. Fine segmentation is the configuration choice for all the SSR sections in Project X. Each individual vacuum vessel will be closed at both ends and the cryogenic circuits will be fed through connections at each cryomodule. Also, each cryomodule will have its own 2 K heat exchanger and pressure relief line exiting near the middle of the module. This configuration provides flexibility in terms of cryomodule replacement, and cooldown and warm-up time at the expense of requiring more individual cryogenic connections, cold-to-warm transitions at each end of each cryomodule, and extra space at each interconnect to close off each cryomodule.

Vacuum Vessel

The vacuum vessel serves to house all the cryomodule components in their as-installed positions, to provide a secure anchor to the tunnel floor, to insulate all cryogenic components in order to minimize heat load to 80 K, 4.5

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K, and 2 K, as well as maintain the insulating vacuum. It is 48 inches (1.219 m) and manufactured from 300-series stainless steel.

Magnetic Shield

Just inside the vacuum vessel, virtually in contact with the inner wall of that vessel, is a magnetic shield to shield the cavities and magnetic elements from the earth's magnetic field. Preliminary tests show that a 1.5 mm-thick mu-metal shield at room temperature reduces the residual field inside the cryostat to less than 10 µT. It is likely that a separate magnetic shield will be installed around each individual magnetic element to further reduce the potential for trapped fields in the superconducting cavity structures.

Thermal Shield and Multi-Layer Insulation

Each cryomodule will have a single thermal shield cooled with helium gas, nominally at 70-80 K. It is currently envisioned to be made from 6000-series aluminum with a single cooling channel on one side. Two 15-layer blankets of multi-layer insulation, between the vacuum vessel and thermal shield will reduce the radiation heat load from the room temperature vacuum vessel to approximately 1 W/cm^2. There will be 4.5 K intercepts on the input coupler and conduction cooled current leads, but there is no plan to install a full 4.5 K thermal shield inboard of the 70-80 K shield.

Strongback

All of the cavities and solenoids will be mounted in pairs on support posts which are in turn mounted to a full-length strongback inside the vacuum vessel, but outside the thermal shield. This enables the entire cavity string to be assembled and aligned as a unit then inserted into the vacuum vessel during final assembly. The strongback is currently envisioned to be fabricated from aluminum, but stainless steel is also an option. Maintaining the strongback at room temperature helps to minimize axial movement of the cold elements during cooldown, reducing displacement of couplers, current leads, and many of the internal piping components. The strongback is shown as part of the assembly in Fig. 5.

Support Post

Each cavity, solenoid, and beam position monitor sub-assembly is mounted on an individual support post similar in design to supports utilized in SSC collider dipole magnets and ILC and XFEL 1.3 GHz cavity cryomodules. The main structural element is a glass and epoxy composite tube. The tube ends and any intermediate thermal intercepts are all assembled using conventional shrink-fit assembly techniques in which the composite tube is sandwiched between an outer metal ring and inner metal disk [1]. The support post is also shown in Fig. 5. All of the magnetic elements are mounted to the support post through an adjustable positioning mechanism.

Input Coupler

The input coupler is a 50-ohm coaxial design with inner and outer conductor diameters of 33.4 and 78.4 mm respectively and supplies 250 kW peak and 750 W average pulsed power to each cavity. The coupler contains two ceramic windows, one warm, one cold, which protect the integrity of the interior of the cavity and which enable separating the coupler into warm and cold sections. During cryomodule fabrication, the cold section can be installed on the cavity in the cleanroom prior to assembly of the string. The warm section can then be installed from outside the vacuum vessel during final assembly. The inner conductor is solid copper. The outer conductor is 304-stainless steel. A short section of hydro-formed bellows in the cold section of the outer conductor allows a small amount of tuning – 1 to 2 mm – to be performed from outside the vacuum vessel. Initial heat load estimates don't suggest a significant penalty for not copper plating the outer conductor so to preclude potential problems with copper plating the bellows, the outer conductor will not be plated. Fig. 2 shows the current coupler design.

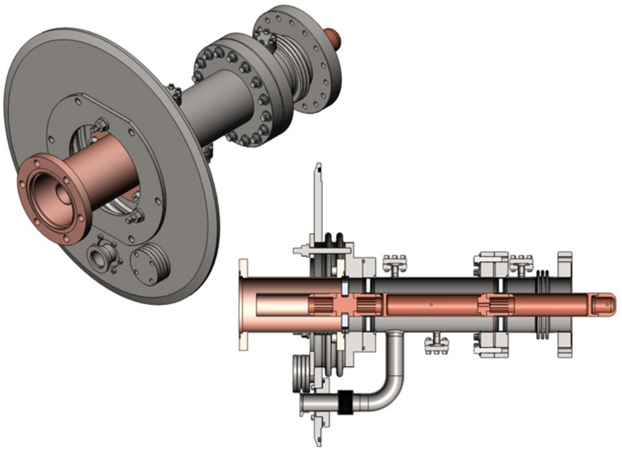

Figure 2: 325 MHz cavity input coupler.

Current Leads

Each focusing element package contains up to three magnet coils, the main solenoid, operating nominally at 200 A and two steering correctors each operating nominally at 50 A. A conduction cooled current lead design modeled after similar leads installed in the LHC at CERN is being developed for use in Project X [2]. Fig. 3 illustrates the conceptual design for the SSR cryomodule lead assembly. Thermal intercepts at 70-80 K and at 4.5 K help reduce the heat load to 2 K, nonetheless, these current leads represent a significant source of heat at the low temperature end. There will be one such lead assembly for each magnetic element.

Beam Position Monitor

The Project X lattice, especially the low-beta section, provides little room along the beamline for beam diagnostics either inside individual cryomodules or

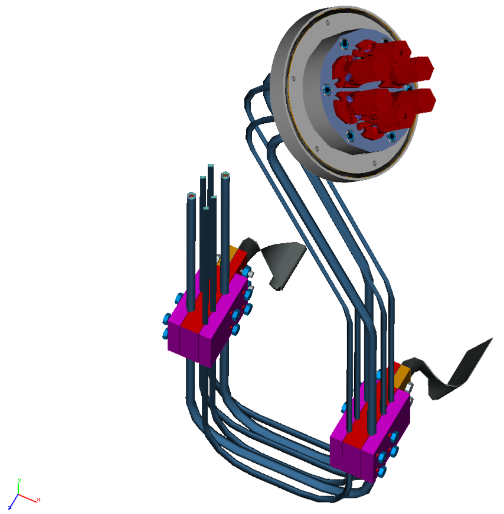

Figure 3: Conduction cooled current lead assembly.

between adjacent modules. A button-type beam position monitor (BPM) has been chosen for installation in all of the SSR cryomodules, one at each magnetic element. These devices are compact and lend themselves well to placement in tight spaces. Fig. 4 shows the design of the unit envisioned for installation in the SSR0 cryomodule. The long beam tube section shown to the left of the BPM in this figure is inside the bore of the solenoid allowing the body of the device to fit very close to the end wall of the solenoid.

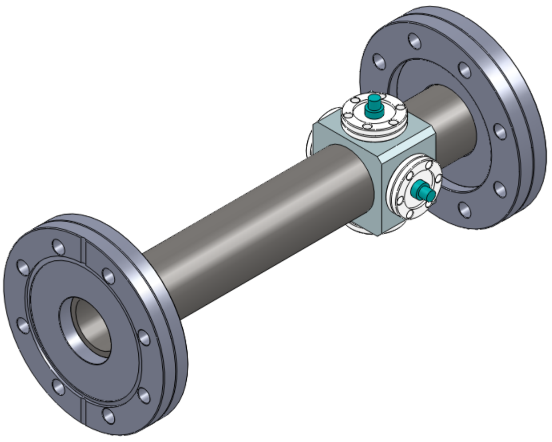

Figure 4: BPM assembly for the SSR0 cryomodule.

Final Assembly

The final assembly of the prototype SSR0 cryomodule is shown in Figs. 5 and 6. Fig. 5 shows the cavity string consisting of the cavities, solenoids, and beam position monitors mounted on support posts which are in turn mounted to the strongback. Fig. 6 shows the entire cryomodule assembly. Bear in mind that the production SSR0 cryomodule will contain 18 cavity and solenoid pairs so will be over four times the length of the prototype shown.

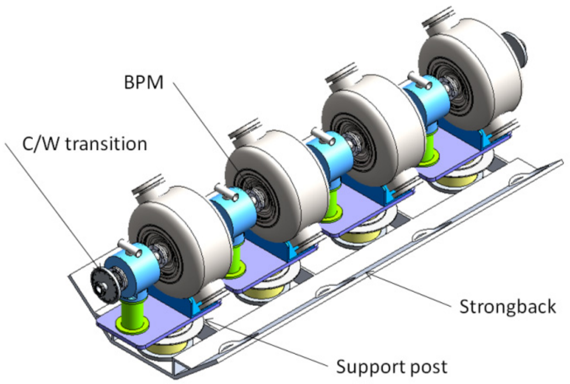

Figure 5: SSR0 cavity string.

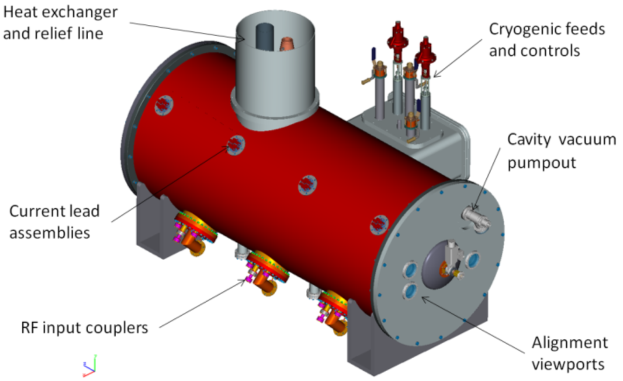

Figure 6: Prototype cryomodule assembly.

STATUS AND PLANS

Fermilab currently has 3 SSR1 cavities in-house. Two of the bare cavities have been successfully tested in a vertical dewar. One is jacketed within a helium vessel and is currently being tested at 4.5 K in a horizontal test cryostat [3]. One has been received as part of a larger order for 10 cavities. The SSR0 design is nearly complete and the plan is to place an order soon. The SSR2 design is in-process. As mentioned, a 4-cavity, 4-solenoid prototype cryostat is being designed to accommodate either SSR0 or SSR1 cavities and will be used to evaluate alignment capabilities, performance of all the internal components, assembly techniques, and cryogenic performance.

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