SSR1 CRYOMODULE DESIGN FOR PXIE*

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Abstract

Project X is a proposed proton accelerator complex intended to support Fermilab's role in intensity frontier research over the next several decades. It will replace the existing 40-year-old injector complex and add powerful new capabilities to support a large number of experiments in the energy range from 1 to 120 GeV.

Fermilab is planning a program of research and development aimed at testing of critical components. This program, known as the Project X Injector Experiment (PXIE), is being undertaken as a major element of the ongoing Project X R&D program.

PXIE contains two superconducting cavity cryomodules, one utilizing half-wave resonators (HWR), and the other, single spoke resonators (SSR). The first SSR cryomodule, known as SSR1 contains eight cavities and four solenoids in the following order: C–S–C–C–S–C–C–S–C–C–S–C, as well as active steering elements.

This paper describes the design of the SSR1 cryomodule and includes discussions of the system interfaces, vacuum vessel, magnetic and thermal shields, insulating and support systems, cavities, tuners, input couplers, focusing elements, and current leads.

INTRODUCTION

The SSR1 cryomodule will operate with continuous wave (CW) RF power and support peak currents of 5 mA chopped with varying patterns to yield an average beam current of 1 mA. The RF power per cavity at 1 mA average current and 2.2 MV accelerating voltage (β=0.22) should not exceed 4 KW with an overhead reserved for microphonics control.

The current beam optics design for Project X requires that the SSR1 cryomodule contains eight cavities and four solenoids in the following order: C–S–C–C–S–C–C–S–C–C–S–C. Horizontal and vertical dipole correctors are located inside each solenoid. A four-electrode beam position monitor (BPM) is located at each solenoid.

The intent is that this cryomodule has all external connections to the cryogenic, RF, and instrumentation systems made at removable junctions at the cryomodule itself. The only connection to the beamline is the beam pipe itself which will be terminated by "particle free" valves at both ends. Minimizing mean time between failure and repair and in-situ repair of some internal systems are important design considerations in the cryomodule design.

Figure 1 shows the linac layout including the location of the SSR1 cryomodule.

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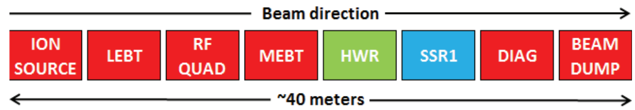

Figure 1: PXIE layout.

CRYOMODULE DESIGN

Eventually, Project X will require several different cryomodule designs for cavities operating at 162.5, 325, 650, and 1300 MHz. The SSR1 for PXIE is the first of these being developed at Fermilab. Details of individual cryomodule components are described below.

Cryogenic Systems and Vacuum Interfaces

There are two ways that cryogenic and vacuum systems are distributed to individual modules in superconducting magnets or cavity strings. Coarse segmentation refers to systems in which the cryogenic circuits and insulating vacuum inside individual cryostats are more or less continuous for long lengths, at least over the length of several cryomodules. 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 at beam tube. Fine segmentation is the configuration choice for Project X and PXIE cryomodules. Each individual vacuum vessel will be closed at both ends and the cryogenic circuits will be fed through bayonet connections at each cryomodule. Each cryomodule will have its own connection to the insulating vacuum pumping system. 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 times 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 the beam tube.

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 K, and 2 K, as well as maintain the insulating vacuum. It is 1.219 m (48 inches) in diameter.

Magnetic Shield

Just inside the vacuum vessel, nearly in contact with the inner wall, is a magnetic shield to shield the cavities from the earth's field. Preliminary tests show that a 1.5 mm-thick mu-metal shield at room temperature reduces

ISBN 978-3-95450-138-0

the residual field inside the cryostat to less than 10 μT. It is likely that separate magnetic shields will be installed around individual magnetic elements to further reduce trapped fields in the superconducting cavities.

Thermal Shield and Multi-Layer Insulation

Each cryomodule will have a single thermal shield cooled with helium gas, nominally at 45-80 K. It is currently envisioned to be aluminum with cooling channels on both sides. 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 1.5 W/m^2. A 5 K circuit will be available to intercept heat on the input couplers and current leads, but there is no plan to install a full 5 K thermal shield.

Support System

All of the cavities and solenoids will be mounted on individual support posts which are in turn mounted to a full-length strongback located between the vacuum vessel and 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. Presently, the strongback is aluminum, but stainless steel is an option. Maintaining the strongback at room temperature helps minimize axial movement of the cold elements during cooldown, reducing displacement of couplers, current leads, and many other internal piping components.

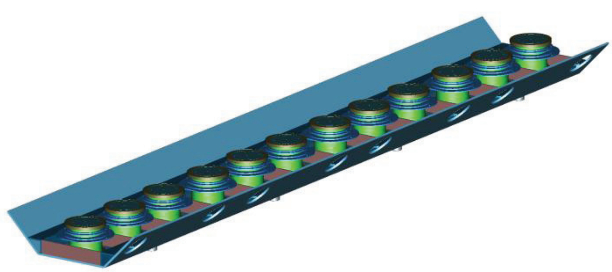

Figure 2: Strongback assembly.

The support posts are similar 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 the intermediate thermal intercepts are all assembled using a shrink-fit technique in which the composite tube is sandwiched between an outer metal ring and inner metal disk [1]. The strongback and support posts are shown in Fig. 2. All the cavities and solenoids are mounted to the support posts using adjustable positioning mechanisms.

Cavity and Tuner

The cryomodule contains eight single spoke, β=0.22, 325 MHz cavities operating in CW mode at 2 K in stainless steel helium vessels. Each has integral coarse and fine tuners that operate through a lever system and push on the cavity end wall. For ease of maintenance, tuner access covers are incorporated into the helium vessel design. The cavity and tuner system is shown in Fig. 3 and described more completely in [2].

Figure 3: Dressed cavity and tuner.

Input Coupler

The input coupler is a 105-ohm coaxial design that supplies approximately 2 kW CW to each cavity in PXIE and ultimately up to 18 kW CW in Project X. The coupler contains a single warm ceramic window. During cryomodule fabrication, the cold section is installed on the cavity in the cleanroom prior to assembly of the string. The warm section is installed from outside the vacuum vessel during final assembly. The inner conductor is solid copper with copper plated bellows to accommodate motion due to misalignment and thermal contraction. The cold end of the outer conductor is 316L-stainless steel. The warm end is copper with copper plated bellows. Heat load estimates don't suggest a significant penalty for not copper plating the outer conductor. A forced-air cooling tube is inserted into the inner conductor after assembly that supplies air to cool the coupler tip. Fig. 4 shows the current coupler design. The input coupler design is described more thoroughly in [3].

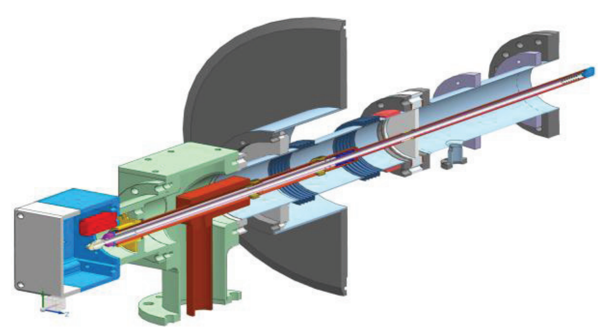

Figure 4: Input coupler assembly.

Current Leads

Each solenoid package contains three magnet coils, the main solenoid, operating nominally at 100 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 PXIE [4]. Fig. 5 illustrates the conceptual design for the lead assembly. Thermal intercepts at 45-80 K and 5 K 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 lead assembly for each magnetic element.

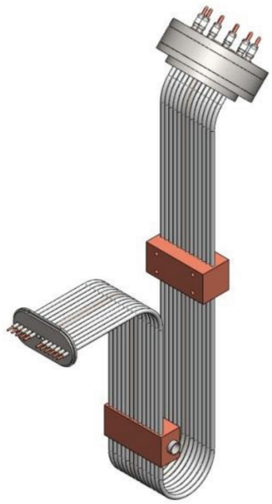

Figure 5: Conduction cooled current lead assembly.

Solenoid and Beam Position Monitor

The four magnet packages in the cryomodule each contain a focusing solenoid and two dipole correctors all operating in a helium bath at 2 K. The Project X lattice provides little room along the beamline for diagnostics either inside individual cryomodules or between adjacent modules. To conserve axial space along the beamline a button-type BPM has been chosen for installation in the SSR1 cryomodules. A total of four will be installed in the cryomodule and tested in PXIE, one at each solenoid. These devices are compact and lend themselves well to incorporation into the solenoid magnet package as shown below in Fig. 6. The bellows at either end of the beam tube allow independent adjustment of each magnet.

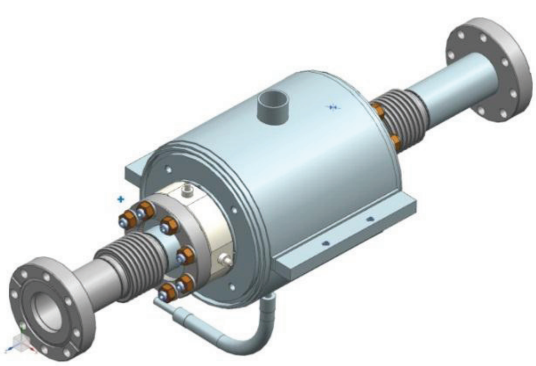

Figure 6: Focusing solenoid and BPM.

Final Assembly

The final assembly of the SSR1 cryomodule for PXIE is shown in Fig. 7.

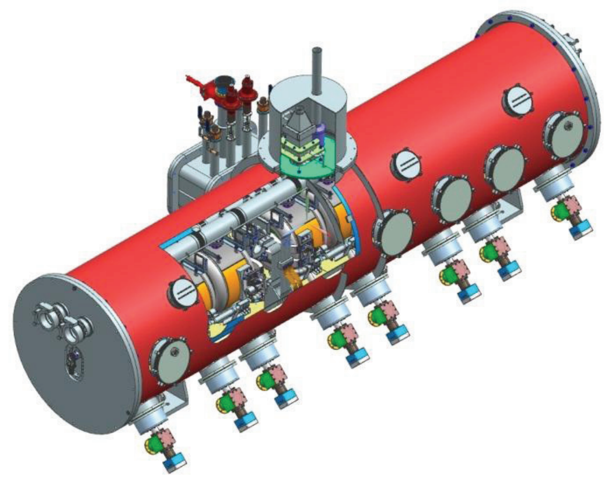

Figure 7: Final assembly.

HEAT LOAD ESTIMATE

Table 1 summarizes the estimated static and dynamic heat loads to each temperature level in the cryomodule assembly from the primary sources.

Table 1: Heat Load Summary for PXIE Cryomodule (W)

SSR1 (8 cav, 4 sol)	70 K	4.5 K	2 K
Input coupler static	42.88	22.56	4.00
Input coupler dynamic	0.00	0.00	2.00
Cavity dynamic load	0.00	0.00	14.24
Support post	33.12	4.32	0.60
Conduction lead assy	85.60	43.60	5.92
MLI (total 70 K + 2 K)	30.54	0.00	1.42
Cold to-warm transition	1.44	0.16	0.02
Total	**193.6**	**70.6**	**28.2**

SUMMARY

The design and modeling of the SSR1 cryomodule for PXIE is nearly complete and detailed drawings for the strongback, supports, and vacuum vessel are ready for procurement. In the coming months further details will be completed with the goal of beginning production of this first 325 MHz SSR1 cryomodule in FY14 [5].

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ISBN 978-3-95450-138-0