Fermilab

Project X
SSR1 Cryomodule
Functional Requirements Specification

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Revision History

Revision	Date	Section No.	Revision Description
0	10/9/2011	All	Initial Draft

INTRODUCTION AND SCOPE

The goals and functional requirements for Project X are outlined in the Project X functional requirements document. The second superconducting cavity cryomodule will contain a series of superconducting RF accelerating structures consisting of single spoke resonators (SSR) operating at 325 MHz, beam focusing elements and instrumentation and is intended to accelerate H- ions from 10 MeV to about 25 MeV.

This specification addresses the functional requirements of the Project X SSR1 cryomodule. It includes physical size limitations, cryogenic system requirements and operating temperature, instrumentation, cavity and lens sequence and alignment requirements, magnet current leads, and interfaces to interconnecting equipment and adjacent modules.

SSR1 CRYOMODULE REQUIREMENTS

The cryomodule will operate with continuous wave (CW) RF power and support peak currents of 5 mA chopped with arbitrary patterns to yield an average beam current of 2 mA. The RF coupler design employed should support a future upgrade path with currents as high as 5 mA average. The RF power per cavity at 2 mA average current and 2.2 MV accelerating voltage (β=0.11) should not exceed 6 KW with an overhead reserved for microphonics control. The RMS normalized bunch emittance at the CM exit should not exceed 0.25 mm mrad for each of 3 planes.

The current Project X beam optics design for Project X requires that the SSR1 cryomodule contains 8 identical cavities and 4 focusing solenoids in the following order: C–S–C–C–S–C–C–S–C–C–S–C (beam direction). The solenoids will be bath-cooled to 2 K and employ active shielding. Two dipole correctors (horizontal and vertical) are embedded in each solenoid. The beam tube and four-electrode beam position monitor will be integral parts of the magnet assembly.

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” beam vacuum valves at both ends. Mean-Time-Between-Failure and Mean-Time-to-Repair are important design considerations for the cryomodule. It is desirable that some maintenance operations be possible “in situ”, namely without removing the cryomodule from its installed position.

Alignment of cavities and solenoids will be accomplished using optical targets installed on the internal assemblies translated to fiducials installed on the vacuum vessel. Changes in alignment due to shipping and handling or during cooldown and operation will be monitored using a series of wire targets on each cavity and solenoid, viewed through optical windows in either end of the cryomodule assembly.

The general requirements for the cryomodule are outlined in the tables below. This specification does not set exact sizes of the cryomodule and types of all its connections. However they will be determined in the technical specifications developed as part of the design process.

GENERAL REQUIREMENTS

General		
	Physical beam aperture, mm	30
	Overall length (flange-to-flange), m	≤5.4
	Overall width, m	≤1.6
	Beamline height from the floor, m	1.3
	Cryomodule height (from floor), m	≤2.00
	Ceiling height in the tunnel, m	3.20
	Maximum allowed heat load to 70 K, W	250
	Maximum allowed heat load to 5 K, W	80
	Maximum allowed heat load to 2 K, W	50
	Maximum number of lifetime thermal cycles	50
	Intermediate thermal shield temperature, K	45-80
	Thermal intercept temperatures, K	5 and 45-80
	Cryo-system pressure stability at 2 K (RMS), mbar	~0.1
	Environmental contribution to internal field	15 mG
	Transverse cavity alignment error, mm RMS	<1
	Angular cavity alignment error, mrad RMS	≤10
	Transvers solenoid alignment error, mm RMS	<0.5
	Angular solenoid alignment error, mrad RMS	<1[i]
Cavities		
	Number, total	8
	Frequency, MHz	325
	β[ii]	0.22
	Operating temperature, K	2
	Operating mode	CW
	Operating energy gain at β=0.22, MV/cavity	2[iii]
	Coupler type – standard coaxial with impedance, Ω	105
	Coupler power rating, KW	>20
Solenoids		
	Number, total	4
	Operating temperature, K	2
	Current at maximum strength, A	≤100
	$\int B^2 dL$, T^2m	4.0
	Maximum fringe field at the cavity walls, mT	10
	Each solenoid has independent powering	

Correctors		
	Number, total	8
	Number, per solenoid package	2
	Current, A	≤50
	Strength, T-m	0.0025
BPMs		
	Number, total	4
	Number of plates	4
	Accuracy of electrical center with respect to the geometric center, mm	≤±0.5

SYSTEM PRESSURE RATINGS

System	Warm MAWP (bar)	Cold MAWP (bar)
2 K, low pressure	2	4
2 K, positive pressure piping	20	20
5 K piping	20	20
45-80 K piping	20	20
Insulating vacuum	1 atm external, vacuum inside	Na
Cavity vacuum	2 bar external, vacuum inside	4 bar external, vacuum inside
Beam pipe outside cavities, includes beam position monitors and warm to cold transitions	1 atm external, vacuum inside	1 atm external, vacuum inside

INTERFACES

The cryomodule assembly has interfaces to the following.

- Bayonet connections for helium supply and return.
- Cryogenic valve control systems.
- Cryogenic system interface is via a heat exchanger which pre-cools helium from approximately 5 K to 2 K upstream of the cryomodule liquid level control valve (JT-valve).
- Pumping and pressure relief line connections.
- Cryomodule warm support structures.
- Beam tube connections terminated by a particle free vacuum valve.
- RF cables to the input couplers.
- Instrumentation connectors on the vacuum vessel shell.
- Power supply cables for the solenoid and corrector connections.
- Alignment fiducials on the vacuum vessel shell with reference to cavity positions.

INSTRUMENTATION

Cavity and cryomodule instrumentation will include, but not be limited to the following. Internal wiring shall be of a material and size that minimizes heat load to the internal systems.

- Beam position monitors.
- Cavity field probes.
- Coupler e-probes.
- Diode x-ray detectors.
- Cavity tuner control and diagnostics.
- Input coupler temperature sensors.
- Thermal shield temperature sensors.
- Magnet current lead temperature sensors.
- Cavity helium vessel temperature sensors (externally mounted).
- Cavity helium vessel heater (externally mounted).
- Helium system pressure taps.
- Helium level probes in the 2 K phase separator.
- Helium temperature sensors in the 2 K phase separator.
- Cavity vacuum monitors.
- Insulating vacuum monitors.
- Input coupler vacuum monitors.

ENGINEERING AND SAFETY STANDARDS

All vacuum vessels, pressure vessels, and piping systems will be designed, documented, and tested in accordance with the appropriate Fermilab ES&H Manual (FESHM) chapters. This includes the superconducting cavities and their associated helium vessels which must be designed, manufactured, and tested in accordance with FESHM chapter 5031.6, Dressed Niobium SRF Cavity Pressure Safety. Bellows shall be designed using the requirements of the Expansion Joint Manufacturers Association (EJMA). The cryomodule as a whole shall be designed to be free of frost and condensation when in operation in air with a dew point of 60 F.

QUALITY ASSURANCE

A complete cryomodule traveler is to be developed documenting all stages of materials inspection, cryomodule component fabrication, piping and weld inspection, cryomodule assembly, and test.

TECHNICAL REFERENCES

For purposes of calculating pressure relief requirements, conduction and radiation heat loads, etc., the following numbers should be used.

Worst-case heat flux to liquid helium temperature metal surfaces with loss of vacuum to air shall be assumed to be 4.0 W/cm^2.
Worst-case heat flux to liquid helium temperature surfaces covered by at least 5 layers of multi-layer insulation (MLI) shall be assumed to be 0.6 W/cm^2.
Thermal radiation to the 2 K or 5 K level under a 70 K thermal shield is approximately 0.1 W/m^2.
Thermal radiation to the 70 K thermal shield from room temperature vacuum vessel is approximately 1 W/m^2.

REFERENCES

1. Project X Functional Requirements Specification
2. V. Lebedev, "Major Requirements to PXIE Optics and Design", http://projectx-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=930.

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[i] 1 mrad error of solenoid alignment excites betatron oscillations of about 1.5 mm
[ii] β is determined so that the maximum acceleration is achieved at this velocity
[iii] Beam dynamics limits the maximum voltage to approximately half of the nominal voltage