Fermilab

Project X
650 MHz Beta=0.9 Cryomodule
Functional Requirements Specification

Prepared by: T. Nicol, Lead Engineer	Fermilab TD/SRF	Extension X3441
Approved by: T. Arkan, Fabrication Engineer	Fermilab TD/SRF	Extension X3782
Approved by: V. Yakovlev, Department Head	Fermilab TD/SRF	Extension X3888
Approved by: V. Lebedev, CW Linac Scientist	Fermilab AD/Project X	Extension X2558
Approved by: R. Kephart, SRF Director, PX CW Linac	Fermilab Directorate	Extension X3135
Approved by: S. Nagaitsev, Project Scientist	Fermilab AD/Project X	Extension X4397
Approved by: R. Stanek, Project X Lead Engineer	Fermilab Directorate	Extension X3519
Approved by: S. Holmes, Project X Project Manager	Fermilab APC/Project X Office	Extension X3988
Approved by: M. Kaducak, Project X Project Engineer	Fermilab TD/Project X Office	Extension X5192

Revision History

Revision	Date	Section No.	Revision Description
0	2/6/2013	All	First release.

INTRODUCTION AND SCOPE

This specification addresses the functional requirements of the 650 MHz beta=0.9 cryomodule for Project X as outlined in the project functional requirements document [1]. It includes cavity configurations, physical size limitations, cryogenic system requirements, operating temperatures, instrumentation, alignment requirements, and interfaces to interconnecting equipment and adjacent modules.

650 MHZ BETA=0.9 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 current beam optics design for Project X requires that the 650 MHz, beta=0.9 cryomodule contains 6 identical cavities for cryomodules up to 1 GeV and 8 cavities from 1 to 3 GeV. There are no magnet or beam instrumentation elements inside the cryomodule.

The cavity string components consisting of the qualified dressed cavities, interconnecting beam tube sections, and beam vacuum valves will be specified, fabricated, procured, and prepared for assembly in a manner consistent with final cavity string assembly in a class 10 cleanroom. Strict adherence to the Superconducting RF components cleanroom protocols must be observed.

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.

Cavity alignment will be accomplished using optical targets installed on the internal assemblies translated to fiducials installed on the vacuum vessel.

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.

Note: *Throughout this specification, 2 K refers to the sub-atmospheric, cavity side helium circuit, 5 K refers to the JT-valve side of the helium supply and low temperature thermal* *intercept circuit, and 70 K refers to the intermediate thermal shield and thermal intercept circuit, regardless of their actual operating temperatures.*

GENERAL REQUIREMENTS

General		
	Physical beam aperture, mm	100
	Overall length (flange-to-flange), m (6 cav/8 cav)	9.56/12.50
	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
	Max allowed heat load to 70 K, W (6 cav/8 cav)	300/375
	Max allowed heat load to 5 K, W (6 cav/8 cav)	25/30
	Max allowed heat load to 2 K, W (6 cav/8 cav)	150/200
	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	<10 mG
	Transverse cavity alignment error, mm RMS	<0.5
	Angular cavity alignment error, mrad RMS	≤5
Cavities		
	Number, total per cryomodule up to 1 GeV	6
	Number, total per cryomodule from 1 to 3 GeV	8
	Frequency, MHz	650
	β geometric	0.9
	Operating temperature, K	2
	Operating mode	CW
	Operating energy gain, MV/m	17.7
	Coupler type – standard coaxial with impedance, Ω	105
	Coupler power rating (TW, full reflection), kW	100

SYSTEM PRESSURE RATINGS (all are differential pressures)

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.
- 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.

- Cavity field probes.
- Coupler e-probes.
- Diode x-ray detectors.
- Cavity tuner control and diagnostics.
- Input coupler temperature sensors.
- Thermal shield 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”, Project X Document 658.