Functional Requirements Specification PXIE (Project X Injector Experiment) Linac front-end integrated systems test

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Revision History

Revision	Date	Section No.	Revision Description
0	11/18/11	All	Initial Draft Release.

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1. Introduction:

Project X is a high intensity proton facility conceived to support a world-leading physics program at Fermilab.[1] Project X will provide high intensity beams for neutrino, kaon, muon, and nuclei based experiments and for studies supporting energy applications.

The Project X Injector Experiment (PXIE) will be an integrated systems test for the Project X front end linear accelerator.[2][3] It is part of the broader program of research and development aimed at key components of the Project X. The successful completion of this test will validate the concept for the Project X front end, thereby minimizing the primary technical risk element within Project X. Successful systems testing will also demonstrate the viability of novel front end technologies that will find applications beyond Project X in the longer term.

2. Scope:

PXIE will be located in a newly constructed addition to the existing Cryomodule Test Facility (CMTF) located near New Muon Laboratory (NML) and will utilize all available existing infrastructure. The PXIE accelerator will include the following eight subsystems shown in Figure 1:

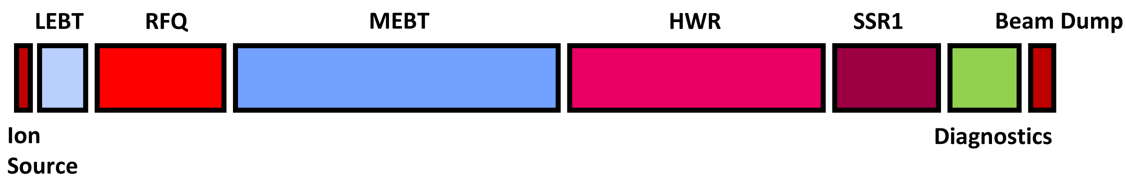

FIGURE 1: Major Subsystem in the PXIE Linac

The major subsystems included in the scope of PXIE are:

- A DC H- ion source capable of delivering 5 mA (nominal) at 30 keV[4].
- A Low Energy Beam Transport (LEBT) section with beam pre-chopping[5].
- A CW Radio Frequency Quadrupole (RFQ) operating at 162.5 MHz and delivering 5 mA at 2.1 MeV[6].
- A Medium Energy Beam Transport (MEBT) section with integrated fast programmable wideband beam chopper and 10 kW beam absorber capable of generating arbitrary bunch patterns at 162.5 MHz from the 5 mA RFQ beam[7].
- Two low-beta superconducting cryomodules capable of accelerating 1mA of beam to greater than 15 MeV[8] [9].
- A beam diagnostic section capable of measuring particle distribution including tail distributions and the extinction ratio of removed bunches at a 10^{-9} level.
- A beam dump capable of accommodating maximum beam power of 50 kW with energies of up to 30 MeV for extended periods.

PXIE Goals

Validate critical technologies required to support the Project X Reference Design concept.

- Provide a platform for demonstrating operations of Project X front end components at full design parameters
- Integrated systems test goals:
  - 1 mA average current with 80% bunch-by-bunch chopping of beam delivered from the RFQ
  - Efficient acceleration with minimal emittance dilution through at least 15 MeV

3. Key Assumptions, Interfaces & Constraints:

The new addition to CMTF is assumed to have the following parameters so that PXIE can function as intended:

- The PXIE Linac will be located on a concrete pad with a maximum size of 50 feet wide (east-west) by 188 feet long (north-south). This envelope is determined by the existing CMTF buildings located to the south and east and the curved access road on the other sides.
- The load rating of the concrete pad is being designed to support the load of the concrete shielding blocks that will create the PXIE Linac housing.
- Labyrinths for personnel access will be located both upstream and downstream of PXIE.
- The heaviest shielding block that will need to be manipulated inside the PXIE enclosure is an “H” block, measuring 6 tons.
- The design of the concrete pad is independent of where the PXIE cave is located on the pad.
- Footing for the concrete pad will go below the frost line to prevent seasonal movement of the concrete pad.
- There is sufficient space on the pad to house both the concrete shielding for the test cave and the PXIE RF equipment outside the cave.
- Personnel access will be available on both sides of the beam line inside the test cave.
- The minimum width of the test cave should allow for the two largest components to pass by each other during installation and maintenance.

The CMTF Facility imposes the following FIXED constraints on the PXIE Linac:

- The available cryogenic supply from the Superfluid Cryogenic Plant (SCP) has a maximum capacity as listed in Table 1:

TABLE 1: CMTF SCP Cryogenic Capacity

Temperature Level	Capacity
2 K	500 W
5 to 8 K	600 W
40 to 80 K	4,100 W

- NL15D is the dedicated transformer for the CMTF facility and has an output of 480 V 3Ø with 1200 A available for CMTF and PXIE RF loads. The remainder of NL15D capacity is allocated for CMTF lighting, plug power, controls hardware, etc.

The CMTF Facility imposes the following VARIABLE constraints on the PXIE Linac:

- The cryogenic distribution system has to allow for the ability to operate both the Cryomodule Test Stand 2 (CMTS2) and the PXIE Linac. The configuration will depend on actual cavity heat loads, quench recovery needs, cooldown capacity and other factors.
- The electrical distribution system could utilize three "noisy" feeders that have additional capacity in addition to NL15D and could be used if needed for the PXIE Linac if needed. These three transformers are powering the CMTF compressor building and each have multiple Variable Frequency Drives (VFD) which can produce electrical noise. On NL15E and NL15F transformers, there is an additional 600 A of capacity and on NL15G there is an additional 400 A of capacity.
- The current building HVAC has a capacity of 246 kW. The current estimate for process load (engines, relay racks, computers, etc…) is 48 kW. The empty CMTF building requires 144 kW. The PXIE Linac may use the CMTF HVAC or may require a separate unit.
- The PXIE Linac will require Low Conductivity Water (LCW), however no LCW system is currently installed at CMTF. The NML LCW system could be duplicated for CMTF including PXIE if it has sufficient capacity. The estimated requirement for CMTS1 and CMTS2 infrastructure is 456 gal/min. For reference, the NML system has 1000 gal/min flow capacity at 90 ^{o}F ± 1 ^{o}F. This is accomplished with three VFD pumps (2 online and 1 spare) and a 180 ton capacity chiller.
- The compressed air capacity of CMTF will be 160 ft^3/min once the current NML system is moved to the CMTF building. The estimated load from the CMTF pneumatic control valves is 56 ft^3/min.

4. Requirements

Technical Requirements:

Project X is based on a 3 GeV continuous-wave superconducting H- linac. PXIE represents the Project X front end and is therefore required to generate and deliver the same quality beam as Project X but at a reduced energy. The PXIE functional requirements are listed in Table 2

TABLE 2: PXIE FRS

Functional Requirements Specification - PXIE		
L1	Delivered Beam Energy, Minimum/Maximum	15/30 MeV
L2	Average Beam Power	≤ 30 kW
L3	Nominal Ion Source and RFQ current	5 mA
L4	Average Beam Current (averaged over >1 μsec)	1 mA (at MEBT end)
L5	Beam Normalized Transverse RMS Emittance*	< 0.25 mm-mrad
L6	Beam Normalized Longitudinal RMS Emittance&	< 1 eV-μs
L7	Maximum Bunch Intensity (ppb)	1.9×10^8
L8	Minimum Bunch Spacing	6.2 nsec (1/162.5 MHz)
L9	The MEBT Shall Include A Wideband Chopper Capable Of Removing Bunches In Arbitrary Patterns At 162.5 MHz	<5% beam loss in unremoved bunches; <0.01% residual beam in removed bunches at MEBT end
L10	Individual Components Should Meet Project X FRS - Ion Source, LEBT, RFQ, MEBT, HWR & SSR1	
L11	The MEBT Will Be Capable of Disposing of 100% Of The Beam Incoming From The RFQ	
L12	The Tunnel Enclosure Shall Be Constructed With Similar Dimensions As The Project X Enclosure	Beam height: 1.3 m above floor
L13	Shielding Shall Be Established Sufficient For An Unlimited Occupancy Designation, As Defined By FESHM, Outside The PXIE Enclosure	
L14	Appropriate Diagnostic Systems Shall Be Developed, Installed and Commissioned to Verify and Quantify all of PXIE Requirements in this Document	

* The normalized rms emittance is defined using the moments of the particle distribution in phase space (e.g. $x - x'$) as follows: $\varepsilon_x = \beta\gamma\left(\overline{x^2}\,\overline{x'^2} - \overline{xx'}^2\right)^{1/2}$. For Gaussian beams, it is based on 100% of particles; both in modeling and in experiments, it may be based on a truncated number of particles (95-100%) to reduce the effect of far tails on the calculated emittance value.

& To express the longitudinal rms emittance in mm-mrad, multiply it by $(M_p c)^{-1}$, 0.32 mm-mrad/(μs-eV) for protons and H^- ions.

Fermilab engineering and ES&H policy also imposes the following requirements for the PXIE Linac:

- The engineering design of all aspects of the PXIE Linac is subject to the process detailed in the Fermilab Engineering Manual.[10]
- All sections of the Fermilab ES&H manual shall be adhered to at all times.[11]

Safety Requirements:

The design of the PXIE Linac enclosure should have special attention given to the safety requirements in the following area:

- Radiation safety – the proper design of cave shielding and entrance/exit labyrinths.
- Fire Safety – the proper design of fire detection & suppression systems and proper egress pathways around beamline components
- Oxygen Deficiency Hazard (ODH) Safety – the proper venting of all pressure vessel and cryogenic reliefs as to minimize the ODH classification of the test cave.
- Personnel Protection System – have in place a design that allows for a controlled and supervised access into the test cave.
- Machine protection – a proper monitoring and interlock design to prevent damage to PXIE components.

Commissioning Requirements:

The project requires flexibility to handle a phased commissioning of the accelerator components.

Operational Requirements:

The facility needs to have the capability of continuous and remotely controlled operations. This operation can utilize the Accelerator Division Operations Department (AD/OPS) through the training of Main Control Room (MCR) personnel.

All beam tube components must be properly cleaned to ensure that particulate migration to the cold SCRF cavities does not degrade long term performance.

5. References:

Documents with reference numbers listed are in the Project X DocDB:
http://projectx-docdb.fnal.gov

[1] Project X Functional Requirements Specification
Document #: Project-X-doc-658

[2] General Information Regarding PXIE Project
http://www-bdnew.fnal.gov/pxie/

[3] PXIE White Paper
Document #: Project-X-doc-966

[4] PXIE Ion Source Functional Requirements Specifications
Document #: Project-X-doc-968

[5] PXIE LEBT Functional Requirements Specification
Document #: Project-X-doc-912

[6] PXIE RFQ Functional Requirements Specification
Document #: Project-X-doc-894

[7] PXIE MEBT & Wideband Chopper Functional Requirements Specification
Document #: Project-X-doc-938

[8] PXIE HWR Cryomodule Functional Requirements Specification
Document #: Project-X-doc-967

[9] PXIE SSR1 Cryomodule Functional Requirements Specification
Document #: Project-X-doc-931

[10] Fermilab Engineering Manual
http://www.fnal.gov/directorate/documents/FNAL_Engineering_Manual_REVISED_070810.pdf

[11] Fermilab ES&H Manual
http://www-esh.fnal.gov/pls/default/esh_home_page.page?this_page=15053