Fermi National Accelerator Laboratory

Fermilab

Booster RF Cavities for PIP-I+ and PIP-II Functional Requirements Specification

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Document Approval

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Revision History

Revision	Date of Release	Description of Change
A		Initial release

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1. Purpose

This document outlines functional requirements for 22 new wide bore RF cavities tunable in the frequency range of 37 – 53 MHz that replace the current 50-year-old refurbished RF cavities in the Booster ring. This upgrade is to reduce losses around the ring at the entrance of the RF cavities and to provide required accelerating RF power to the high intensity beam in the Booster during PIP-I+ era (at 15 Hz) and PIP-II era (at 20 Hz).

2. Scope

This FRS addresses the functional requirements of

i. HLRF that includes 22 newly built wide aperture RF cavities operating in the frequency range of 37 – 53 MHz for the Fermilab Booster to handle high intensity beam from injection energy at 400 MeV (during PIP-I+ era) and 800 MeV (during PIP-II era) and accelerate it to 8 GeV. The scope of this project includes design of the cavities, ferrite tuner and passive & active dampers, fabrication, assembly on a test bench, attachment of the amplifiers for power testing (with changes as needed), vacuum certification, measurements on fundamental and higher order resonance modes of the cavity and their suppression as required by beam physics modeling and beam measurements.

ii. Refurbish 11 girders that support the RF cavities in the Booster ring, installation of the completed 22 RF cavities in the ring without affecting the Booster lattice, attaching LCW cooling and vacuum pumps as needed and testing, that includes design, modifications to all fixtures, cavity phase adjustments and vacuum certification. Commissioning of the cavity assembly with high intensity proton beam after integrating it with Booster LLRF.

iii. These cavities should operate at 15 Hz during PIP-I+ era and at 20 Hz during PIP-II era.

iv. For intensities beyond the design goal of PIP-II we need the development of beam loading compensation for the RF system which is beyond the scope of this project.

3. Acronyms

FESHM	Fermilab ES&H Manual
FRCM	Fermilab Radiological Control Manual
FRS	Functional Requirements Specification
PIP	Proton Improvement Plan
PIP-I+	Proton Improvement Plan I+ AIP
PIP-II	Proton Improvement Plan -II
2SC	Two Stage Collimator
CHG0	Charge zero detector
DCCT	Direct current Transformer
SCD	System Configuration Document
HLRF	High Level RF

LLRF	Low Level RF
HEP	High Energy Physics
ppp	protons per pulse
TC	Teamcenter
WBS	Work Breakdown Structure

4. Reference

#	Reference	Document #
1	PIP Design Handbook	Beams-docs-4053 (2012)
2	Fermilab Engineering Manual	NA
3	Fermilab Environmental Safety and Health Manual	NA
4	Fermilab Radiological Control Manual	NA
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5. Key Assumptions

Conventional utilities (painting, lighting, fire protection, sump/drainage, impediments) cable trays and work on penetrations, LCW line and vacuum pumps will be outside the scope of this FRS and be completed/precured prior to cavity installations in the Booster ring. But, the FTE and M&S cost related to refurbishing the existing girder at each cavity location is part of this WBS. Any M&S cost related to acquire new computers/computer software for cavity design are outside the scope of this FRS.

6. Functional Requirements

i. Inject 5.2E12 proton at 15 Hz from the current 400 MeV LINAC by multi-turn injection and capture the beam adiabatically, accelerate to 8 GeV using the newly installed RF cavities and extract 5E12ppp from the Booster with longitudinal emittance of ~0.1 eVs at the completion of PIP-I+.

ii. Be capable of providing the necessary RF bucket at the injection energy of 800 MeV for direct beam transfer from PIP-II LINAC by multi-turn injection (up to 400 turns) for more than 6.7E12ppp at injection, accelerate to 8 GeV and extract 6.5E12ppp from the Booster at 20 Hz with longitudinal emittance of ~0.1 eVs at the completion of PIP-II.

iii. Currently, ~4.3E12 ppp is extracted at 15 Hz from the Booster. The current RF cavities have a bore size of 2.25” and are installed downstream of the de-focusing magnets with physical vertical aperture of 2.25”. Operationally the full ring beam loss is localized at the entrance of cavity pairs. Any additional beam loss at the entrance of the RF cavity results in cavity trips that immediately inhibits beam acceleration and causes the beam to be dumped in the ring. Such cavity trips are expected to increase by ~16% during PIP-I+ era due to higher intensity

and another 33% from the increased repetition rate from 15 Hz to 20 Hz for PIP-II. This type of RF trips will be mitigated by increasing the cavity bore size from 2.25” to 3”.

iv. Due to increase in the Booster repetition rate from PIP-I+ to PIP-II the heat load of the fully loaded cavity will go up by ~33% which requires adequate LCW cooling.

v. As the beam power goes up, beam loading will also go up linearly. The existing HLRF system cannot provide the required minimum accelerating RF voltage of 1.32 MV for PIP-II operation of the Booster. So, the newly proposed 22- RF cavities with 60 kV each will provide the needed RF power for both PIP-I+ as well as PIP-II design beam intensities.

vi. During PIP-I+, the newly installed wide bore RF cavities will be fully tested with high intensity beam to a) identify beam loss pattern and develop mitigation techniques, 2) understand longitudinal beam dynamics, c) RF related beam instabilities, and develop mitigation and prepare Booster RF system for PIP-II type intensity by beam studies as stated in beam physics FRS.

7. Safety Requirements

Engineering, design, fabrication, assembly and tests of the given system shall abide by Fermilab ES&H (FESHM) and all Fermilab Radiological Control Manual (FRCM) requirements.

Any changes in the applicability or adherence to these standards and requirements require the approval and authorization of appropriate authority.

In addition, the following codes and standards in their latest edition shall be applied to the engineering, design, fabrication, assembly and tests of the given system.