Fermi National Accelerator Laboratory

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PIP-II Project

Power Requirements and Calculations for PIP2IT SRF RF Distribution

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Revision History

Version #	Date	Author	Comment
0.0	May 20 2019	James Steimel	Initial Version of the document
			Changes / revisions

1. Purpose

The purpose of this document is to derive the power requirements for the PIP2IT SRF RF distribution. These derived requirements will be based on the SRF cavity parameters, cavity coupler coupling factors, expected peak beam current, and expected microphonics. The RF distribution must be able to handle the power of the forward and reflected waves at the cavity input coupler while protecting the RF power amplifiers.

2. Scope

The scope of this document includes the RF distribution and cavity operation for the HWR and SSR1 cryomodules that will accelerate beam in PIP2IT.

3. Acronyms

RF, HWR, SSR1, PIP2IT

4. Reference Documents

Estimates of Heat and Electrical Load from SS RF Amplifiers, Preliminary Design Report

5. Overview

The power requirements for the PIP2IT RF distribution can be broken down into three sections related to different operating modes of the cryomodules. The first mode deals with accelerating beam through the cavity. This mode dictates the required peak forward power that the RF distribution will deliver to the cavity coupler. The power will compensate for beam loading while performing RF manipulations and microphonics corrections. The second mode deals with maintaining the cavity field in the absence of beam. This mode dictates the required average power handling specification of the RF distribution. The third mode deals with cavity field decay after RF power interruption. This mode dictates the required peak reverse power that the RF distribution must be specified to handle.

6. Required Peak Power Calculations

The equation below is used to calculate the required power at the cavity input coupler to maintain the field in the cavity. This equation assumes that the cavity resonance is detuned to create the best impedance match when operating 2mA of beam current through the cavity. The following table shows the parameter values for each of the cavity types.

$$P_g = \frac{V^2(1+\beta)^2}{4\beta Q_0(r/Q)}\left[\left(1+\frac{I_{Re}(r/Q)Q_0}{V(1+\beta)}\right)^2+\left(\frac{Q_0}{1+\beta}\frac{2\delta f}{f}\right)^2\right] \quad [1]$$

Table 1: PIP2IT SRF Cavity and Beam Parameters

	HWR	SSR1

V (MV)	2	2.05
β	1835	1598
Q_0	$5*10^9$	$6*10^9$
r/Q (Ohms)	272	242
I_{Re} (mA)	2	2
δf (Hz)	20	20
f (MHz)	162.5	325

The equation includes the power necessary to compensate for beam loading and microphonics. The table below shows the power required at the input coupler for each style of cryomodule cavity in PIP2IT. To insure enough room for RF manipulations, the final figure is increased by 25% in the final RF power specifications. The table also shows the power required with the extra contingency.

Table 2: Results of Required Peak Forward Power Calculations

	HWR	SSR1
Required Peak Power at Cavity Coupler (kW)	4.7	4.4
Required Peak Power at Cavity with 25% Contingency (kW)	5.9	5.5

The power levels in the second row represent the required peak power that the RF distribution system must be capable of delivering to the cavity input couplers.

7. Reflected Power Calculations

The matched conditions described above will only occur when the proper intensity of beam flows through the cavity. Beam tests at PIP2IT will be limited to 1% duty cycle (20Hz, 500us) which is the beam intensity specifications for the PIP2IT beam dump. When the beam is off, very little power is required to maintain the field in the cavities (~60W for HWR and ~80W for SSR1). Most of the power used to maintain the cavity field while beam is off will be reflected back to the power source.

The equation above can be used to calculate the power required to maintain the cavity field without beam by setting the beam current to zero. We can assume that most of this power is reflected to the source. The table below shows the results of the no beam power requirement for the cavities.

Table 3: Results of Required Forward Power Calculations without Beam

	HWR	SSR1

Required Power at Cavity Coupler without beam (kW)	2.0	1.4
Required Power at Cavity without beam, with 25% Contingency (kW)	2.4	1.8

The power levels in the second row represent the average power that the distribution must withstand. Components downstream of the circulator must be capable of transmitting the power in two directions (forward and reflected) without overheating. The circulator load must be specified to handle this average power.

8. SRF Cavity Decay Pulse

When the RF drive to the cavity is disabled quickly, the energy stored in the SRF cavity is released through the over-coupled coupler. This creates a large amplitude, reverse pulse through the RF distribution to the circulator. This pulse will have an initial amplitude that is twice the forward voltage (4x the power) required to maintain the field in the cavity and has an exponential decay time constant of 4-5ms. The input coupler, RF distribution, and circulator must be specified to handle this short burst of power without breakdown.

The stored energy in the cavity is a function of the field amplitude, which is tightly regulated by the LLRF system during cavity operations. It will remain relatively constant regardless of beam current, microphonics, or RF manipulations (used to maintain the cavity field amplitude). The reverse pulse amplitude is a function of the forward drive amplitude required without beam loading, microphonics compensation, or RF manipulations contingency. The table below shows this required forward drive derived from the equation and the expected peak amplitude of the reverse wave.

Table 4: Results of Peak Reverse Power Calculation from Cavity Decay

	HWR	SSR1
Required Minimum Power at Cavity Coupler to Maintain Field (kW)	1.0	1.0
Expected Reverse Pulse Peak Amplitude (kW)	4.0	4.0