Top-Level Specification for Deflecting-Mode Cavities of the Short-Pulse X-rays Project

—

V. Sajaev, L. Emery, M. Borland, and A. Nassiri—26/04/2010

—

Accelerator Operations Division, Advanced Photon Source

1 Introduction

Several specifications for buidling the rf cavities for the short-pulse X-rays are listed here. The specifications result from calculations or complex simulations to ensure that the correct deflection is applied to the beam for sector 7 users, that no other users will be affected, that the beam will be in general stable during operation of the rf cavities and also during non-operation of the cavities. The project consists of several parts:

- RF system
- LSS related magnet modifications
- Diagnostics
- Controls
- Undulators and beamlines

2 Goals

The goal of the project is to deliver x-ray pulse with 70% length of 1ps at 10 keV photon energy using Undulator A with intensity of about 1% of the non-chirped APS intensity. The cavities will operate only in 24 singlets mode.

Specification name	Goals	Acceptable
Pulse length (70% of the beam)	1 ps	4 ps
Pulse length fluctuation	10%	10%
Pulse intensity fluctuation	1%	10%
Pulse timing jitter (fraction of pule length)	10%	10%

3 Layout

The first deflecting cavity cryomodule will be located in the ID6 straight section. The second cryomodule will be located in the ID8 straight section. Exact location of the cryomodules in the straight sections will be defined later. Both ID6 and ID8 straight sections will be Long Straight Sections (LSS). LSS increases useful length of the straight section from 5 m to about 8 m. ID7 straight section will remain 5 m long.

4 RF system

4.1 Main parameters

Specification name	Value
Current	202 mA
Energy	7 GeV
Revolution frequency	271.55 kHz
RF Voltage (stage 1)	2 MV
Number of cells (stage 1)	4
RF Voltage (stage 2)	4 MV
Number of cells (stage 2)	8
RF Frequency	2815.44 MHz
Cavity tunability	271 kHz
Source tunability	2 kHz

4.2 Cryogenic parameters

Specification name	Value
Cryomodule length	?? m
Cryomodule width	?? m
He temperature	2 K

4.3 RF Phase and Amplitude Tolerances

The rf phase and ampllitude have to be controlled to sufficient accuracy to prevent trajectory leakage to the outside of the cavity bump. This table is for constant errors.

Specification name	Peak Value	Driving requirement
Common-mode voltage amplitude variation	< 1 %	Keep intensity and pulse length variation under 1%
Common-mode phase variation	< 7 deg	Keep intensity variation under 1%
Voltage amplitude mismatch error between cavities	< 0.5 %	Keep emittance variation under 10 % of nominal 35 pm
Voltage phase mismatch error between cavities	< 0.03 deg	Keep beam motion under 10 % of beam size/divergence

Orbit motion due to phase mismatch in the low frequency range can be corrected by the orbit feedback. The feedback correction effectiveness is shown below. Also, when the excitation frequency aproaches the betatron frequency, the orbit motion exhibits the resonance behaviour.

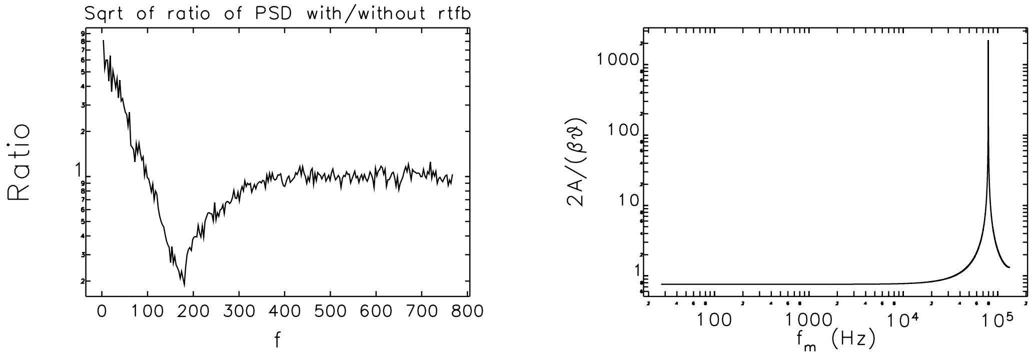

Figure 1: Left: Orbit feedback correction effectiveness. Right: Frequency dependence of the orbit response to a sinusoidally-varying dipole kick.

4.4 RF Phase and Amplitude Control

Adjustment range:	
RF source amplitude	> X dB
RF source phase	> 400 deg
Adjustment rate:	
RF source amplitude	Full range in < 10 s
RF source phase	Full range in < 10 s
Cavity-to-cavity controls:	
Amplitude error adjustment range	> 10 %
Amplitude error adjustment step	< 0.1 %
Amplitude error adjustment rate	Full range in < 10 s
Phase error adjustment range	> 5 deg
Phase error adjustment step	< 0.005 deg
Phase error adjustment rate	Full range in < 10 s
Group-to-group:	
Amplitude error adjustment range	> 10 %
Amplitude error adjustment step	< 0.1 %
Amplitude error adjustment rate	Full range in < 10 s
Phase error adjustment range	> 5 deg
Phase error adjustment step	< 0.005 deg
Phase error adjustment rate	Full range in < 10 s

4.5 HOM requirements

Requirements are calculated taking bunch form factor into account and assuming synchrotron radiation damping rate only.

Quantity	**Limit on Quantity**
$(R_s f_{HOM})$ for one monopole HOM	0.50 MΩ-GHz
R_s for one monopole HOM at 2 GHz	0.25 MΩ
R_t for one x-plane HOM	1.5 MΩ/m
R_t for one y-plane HOM	4.5 MΩ/m

5 Lattice and magnet modification

ID7 SS will not be modified. ID6 and ID8 will be made longer. LSS design is described separately. Important: the distance between the beam orbit and the photon trajectory in the BM beamline is only about 0.35m at the beginning of the SS - puts limit on the cryostat size if it is located in the upstream part of the SS.

6 Diagnostics

Diagnostics needs to

- ensure that the beam is at the center of the cavities and keep the beam there within 100 μm;
- characterize the chrip inside and outside the cavity system. The vertical beam tilt inside the dipole is about $\frac{\pm 2mm}{\pm 12mm}$ (1 sigma). Outside the cavity system the possible beam size increase is ±5% which means the beam tilt is $\frac{\pm 2\mu m}{\pm 12mm}$;
- ensure the beam outside of the cavities is not disturbed (orbit, beam size, and tilt).

Resolution of straight section bpm

One-sec average	1 μm
Single pass	10 μm

7 Alignment

Cavity electric center alignment within cryostat: ±0.3 mm.

Cell tilt inside the crystat: ±5 mrad (increase horizontal emittance by 5%).

Cryostat alignment relative to the SR magnets: ??

8 Undulators and beamlines

8.1 ID gap perturbation

The trajectory of the beam in the rf cavities should be controlled close to a zero value. Once this is done, the insertion device (ID) should not move the orbit significantly. The first and second integral error tolerances depend on the DC corrector layout.

ID error over operating gap range

First integral error	1 μrad
Second integral error	10 μm

9 Effect on/of the beam

9.1 Beam emittance

The beam emittance should not be degraded as a result of operating the deflecting mode cavity. Based on an unnperturbed emittance, the maximum beam emittance allowed for the beam is listed below.

Maximum beam emittance

ϵ_x (unperturbed)	2.7 nm-rad
ϵ_y (unperturbed)	35 pm-rad
ϵ_y (with cavities on)	50 pm-rad

9.2 Orbit stability

A large orbit in the cavities will generate an unwanted voltage for deflecting modes.

Maximum allowed orbit in deflecting cavity

With cavities on	100 μm
With cavities off	100 μm

Orbit stability inside the ID7 undulator - orbit angle gives timing jitter for the experiment. Slits in the user beamline let radiation throught only for the beam slice that raidates at zero angle. Changing vertical orbit angle will change the slice of the beam which radiates at zero angle.

$$\Delta t = \frac{E}{V_0}\frac{\alpha}{\omega} \tag{1}$$

Timing jitter of 10% of the pulse length is achieved at orbit angle value of 1 μrad.

10 Machine Protection system

Beam missteering inside the cavities: 100 μm (protection of cavities against power generated by off-center beam).

Orbit in the dipole upstream of the cavity – protection of the cavity iris from upstream synchrotron radiation. The electron beam size at the exit of the dipole $\pm 3\sigma$ is ± 3 mm, the beam is converging so the photon beam in the middle of the ID straight section is ± 1.5 mm.

Orbit inside dipoles between cavities – protection of vacuum chamber downstream. The electron beam size inside the dipole $\pm 3\sigma$ is ± 5 mm, while the slot size for synchrotron radiation inside the dipole vacuum chamber is 10 mm only.

Orbit inside the undulator in ID7 – protection of vacuum chambers downstream from ID7 undulators from the synchrotron radiation. Photon beam size $\pm 3\sigma$ at 10 m from the undulator is ± 5 mm, while the slot size inside the dipole vacuum chamber is 10 mm only.