PHYSICS DESIGN OF THE PEFP RCS*

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Abstract

The proton engineering frontier project (PEFP) is designing a rapid cycling synchrotron (RCS) whose main purpose is the spallation neutron source. In the initial stage, an output energy and a beam power are 1 GeV and 60 kW, respectively. The final goal is 500 kW of beam power through increasing an injection energy, an extraction energy, and a repetition rate. Based on the lattice design of the RCS, this article focuses on the transverse injection painting and acceleration simulation of the synchrotron.

INTRODUCTION

Proton Engineering Frontier Project (PEFP) is the 100-MeV proton linac development project which was launched at 2002 and will be finished at 2012 [1]. As an extension plan of the linac, we are considering a rapid cycling synchrotron (RCS). The main purpose of the RCS is a spallation neutron source which can be used in the fields of the material science, bio technology, chemistry, etc.

The basic design concepts of the PEFP RCS are as follows,

- The 100-MeV linac is the injector of the RCS.
- At the initial stage, the extraction energy is 1GeV and the beam power is 60 kW.
- The RCS should be upgradable in an injection energy, an extraction energy, and a repetition rate.
- The beam extraction methods includes both a fast extraction for the spallation neutron source and a slow extraction for the other purposes including medical research and RI production.
- The uncontrolled beam loss should be less than 1 W/m for hands-on maintenance.

The upgrade path of the RCS is summarized in Table 1. The beam power of the RCS is 60 kW in the initial stage and finally becomes 500 kW through the three-step upgrade.

Table 1: Upgrade plan of PEFP RCS

Stage	Injection Energy	Extraction Energy	Repetition Rate	Beam Power
Initial	100 MeV	1 GeV	15 Hz	60 kW
1	100 MeV	1 GeV	30 Hz	120 kW
2	100 MeV	2 GeV	30 Hz	250 kW
3	200 MeV	2 GeV	30 Hz	500 kW

The results on the lattice structure and the injection and extraction schemes were reported [2]. The lattice structure of the RCS is given in Figure 1. Table 2 summarizes the basic parameters of the PEFP RCS.

This work focused on the beam dynamics study of the transverse injection painting and acceleration process in the initial stage operation.

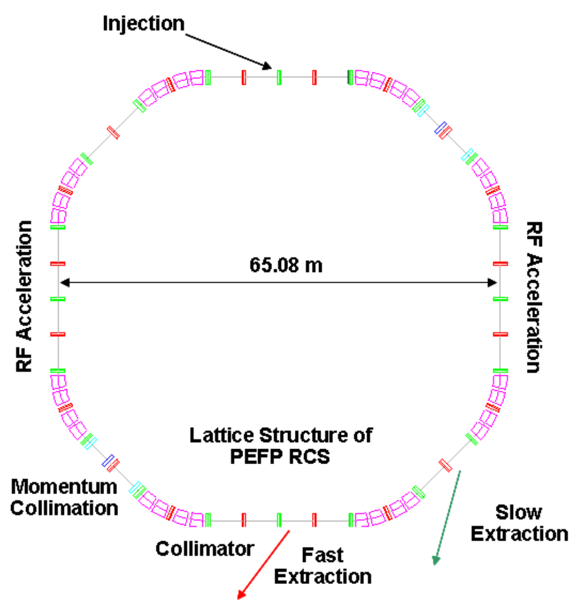

Figure 1: PEFP RCS lattice.

Table 2: Design parameters PEFP RCS in the initial stage

Injected Particle	H-
Lattice Structure	FODO
Super-period	4
Number of Cell	20
Number of Dipoles	32
Machine Tune [Qx /Qy]	4.39 / 4.29
Transition γ	4.4
Circumference [m]	224.16
RF Harmonic	2
RF Voltage	75 kV

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TRANSVERSE INJECTION PAINTING

The PEFP RCS injection system is located in the dispersion-free straight section as shown in Figure 1. It is based on H- charge exchange injection with a transverse painting. The injection system consists of a chicane magnet which deforms the horizontal DC orbit up to 105 mm and the four ferrite cored magnets which are used for the fast change of the painting bump in the horizontal and vertical directions. The overall scheme of RCS injection is illustrated in Figure 2. The DC chicane is located between two quadrupole magnets, AQD1 and AQF2. The rapid deflecting magnets for the injection painting are located after AQF1 and after AQF2 quadrupole magnets. The location of the stripping foil is 2.49 m downstream from the center of quadrupole magnet AQD1. We studied the correlated painting scheme in the transverse phase space. Table 3 lists the relevant parameters for the injection study. The orbit bump functions in the horizontal and vertical directions are $f_h(t) = 1-(t/t_{inj})^{0.45}$ and $f_v(t) = 1-(t/t_{inj})^{0.25}$, respectively.

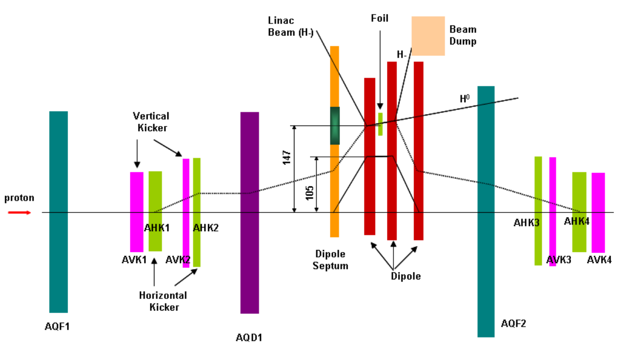

Figure 2: Layout of the injection system for PEFP RCS.

Table 3: Injection parameters

β_X, β_Y [m]	10.08 / 10.08
Linac emittance [π mm-mrad, rms]	1
RCS emittance [π mm-mrad, total]	280
Number of protons	2.50×10^{13}
Foil thickness [μg/cm]	200
Number of injection Turns	200

Figure 3 shows particle distribution in x-y, x-x' and y-y' spaces after finishing injection. In this simulation we used ORBIT code [3] with 40,000 macro particles. The particle distributions in x- and y-axis are given in Figure 4 which shows the parabolic distribution as expected in a uniform painting in the transverse phase space. The emittance variations are given in Figure 5 as a function of injection turns in the horizontal and vertical directions. The figures include 90%, 95%, 99%, and 99.9% emittance values. The 99.9% emittance becomes about 300 π mm-mrad.

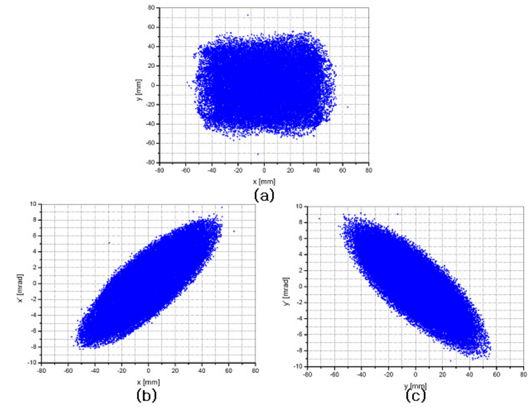

Figure 3: Particle distribution after injection in (a)x-y space, (b) x-x' space, and (c) y-y' space.

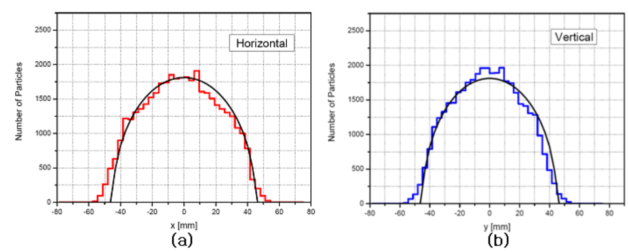

Figure 4: Particle distribution in (a) horizontal and (b) vertical directions.

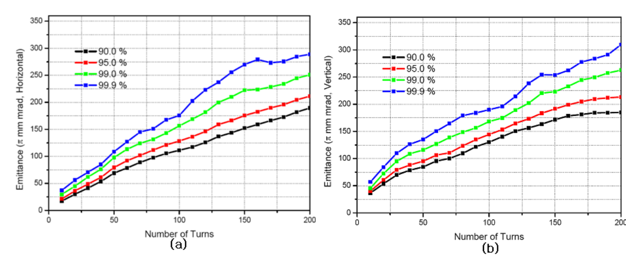

Figure 5: Emittances as a function of injection turns in (a) horizontal and (b) vertical directions.

ACCELERATION SIMULATION

The RF capture in the injection and the initial part of the acceleration process is important because most of beam losses occur in this region. Beam loss during the acceleration process can be prevented by providing large dynamic apertures and by choosing the suitable RF voltage ramping. The RF voltage and synchronous phase should be synchronized with the magnetic field. In this study we used a sinusoidal ramping of the magnetic field. The RF voltage program and the corresponding synchronous phase variation are given in Figure 6 and

Figure 7, respectively. The initial RF voltage is 18.7 kV and the maximum voltage is 75.0 kV. The synchronous phase increases up to about 35 degrees. We used the RAMA program to get the initial ramping of the RF voltage [4].

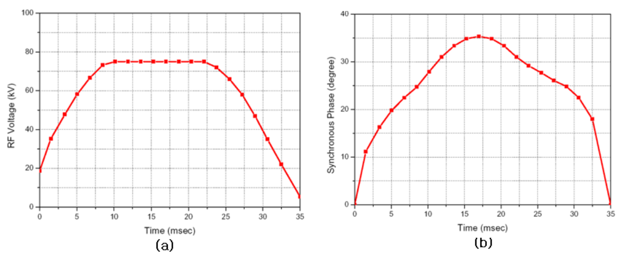

Figure 6: Ramping of (a) RF voltage and (b) the synchronous phase.

The phase space distribution of the incoming Linac beams in the RF bucket is given in Figure 7. In the $\Delta\phi$ space, they are uniformly distributed between ±103 degrees as shown in Figure 8(a). It correspond to the chopping factor of 57%. The particle distribution in the ΔE space is a Gaussian with σ_E= 200 keV (Figure 8(b)). Figure 9 shows the particle distribution in the longitudinal phase space just after injection. We found that there is no beam loss up to 200 injection turns. The particle distribution is given in Figure 10 for 1GeV beams The final energy and capture rate are 1.003 GeV and 99.91%, respectively.

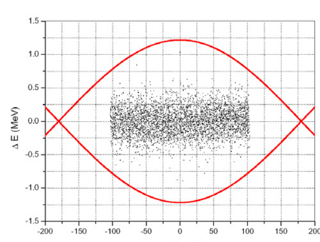

Figure 7: Linac beam distribution in the initial RF bucket.

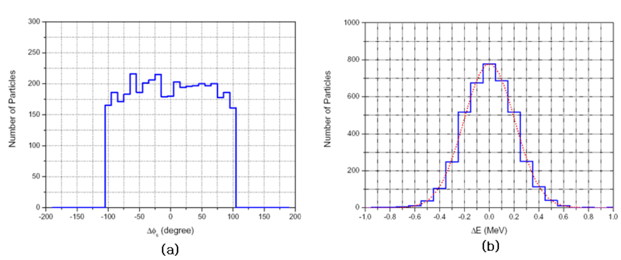

Figure 8: Uniform and Gaussian distribution with σ_E= 200 keV in (a) $\Delta\phi$ and (b) ΔE spaces.

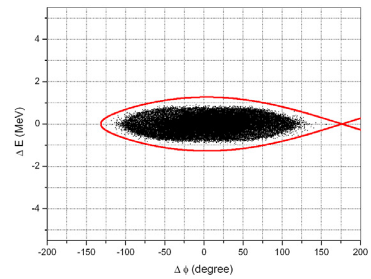

Figure 9: Particle distribution in the RF bucket just after injection process.

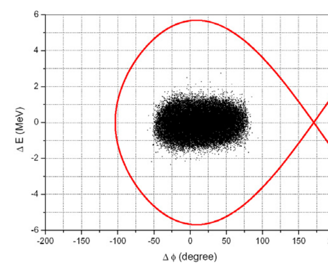

Figure 10: Particle distribution in the RF bucket after acceleration process.

CONCLUSION

This work summarized the results on the injection painting and the acceleration simulation of the PEFP RCS in the initial stage where the beam power is 60 kW with a 15–Hz operation. We found that the particles are uniformly painted in the transverse phase space by the proposed orbit bump function. With the specific ramping of the RF voltage with maximum value of 75 kV, we achieved a capture rate larger than 99.9% in the acceleration process.

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