Acceleration Simulation of PEFP RCS for a 1-GeV Extraction

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1. Introduction

The conceptual design of an RCS (rapid cycling synchrotron) is under progress as an extension plan of the PEFP (proton engineering frontier project). The 100-MeV linac of the project becomes the injector of the synchrotron whose main purpose is a spallation neutron source. In the initial stage, the beam power is 60 kW and the injection and extraction energies are 100 MeV and 1 GeV, respectively. They become 200 MeV and 2 GeV for the beam power of 500 kW after 3-step upgrade. For the research in the basic science and medical area, the machine also includes a slow extraction option for the energy range up to 450-MeV. This work focuses on the acceleration simulation of the RCS in 1-GeV operation. The ORBIT code was used for the beam dynamics simulation. We found that the capture rate is larger than 99.9 % if the initial RF voltage is 18.7 kV and the maximum voltage is 75 kV.

2. PEFP RCS

There are three ways for a beam power upgrade in the PEFP RCS. One is increasing the injection energy form 100 MeV to 200 MeV. Another is doubling the repetition rate from 15 Hz to 30 Hz. The other is increasing the extraction energy from 1 GeV to 2 GeV. Through these upgrade steps, the beam power is increased from 60 kW to 500 kW (Table 1). This work focuses on the acceleration simulation in the initial stage.

Table 1. Upgrade path of PEFP RCS

	Injection Energy [MeV]	Injection Energy [MeV]	Rep. Rate [Hz]	RF [kV]	Beam Power [kW]
Initial	100	1	15	75	60
1	100	1	30	140	120
2	100	2	30	260	250
3	200	2	30	250	500

2.1 Linac and RCS beams

The RF harmonic is two and there are two bunches in a synchrotron pulse. Because we used a non-adiabatic capture scheme in the injection and acceleration period, the linac beam has to be chopped in order to reduce beam losses in the capture and acceleration process. Fig. 1 shows the time structures of the linac beams just before injection. In the 15-Hz operation, one macro-pulse of linac beams includes 400 mid-pulse with the pulse width of 500 ns. It corresponds to the chopping factor of 57%. In the RCS, there are two bunches in a pulse as shown in Fig. 2. After a injection period, 200 linac pulses are injected into each bucket. The proton number in a synchrotron pulse is 2.5×10^{13} . The particle distribution of each linac pulse and the RF bucket are given in Fig. 3 in the longitudinal phase space. We assumed a uniform distribution on the phase axis and a Gaussian distribution on the energy axis with σ_E = 0.2 MeV. Fig. 4 and Fig. 5 show the simulation result of the distribution.

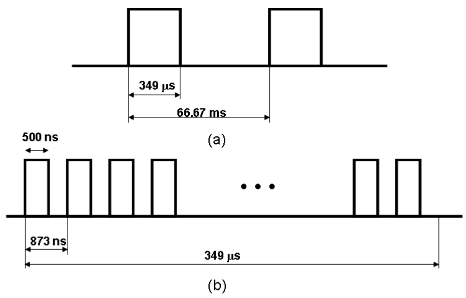

Fig. 1. Time structure of linac beam for (a) macro-pulses and (b) mid-pulses (15Hz operation).

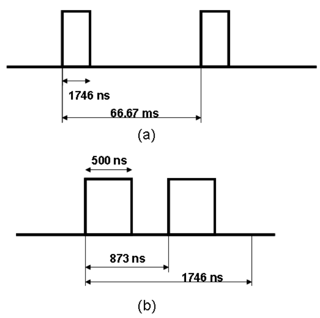

Fig. 2. Time structure of RCS injected beam for (a) pulses and (b) bunches (15Hz operation).

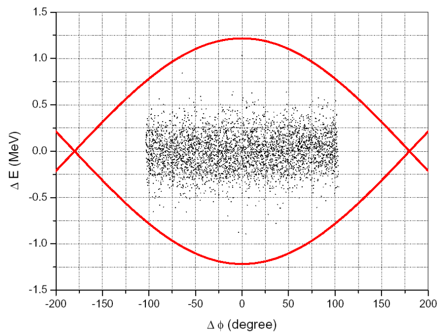

Fig. 3. Particle distribution of one linac pulse in a RF bucket.

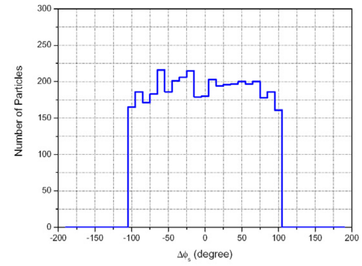

Fig. 4. Simulation result of the particle distribution on phase axis.

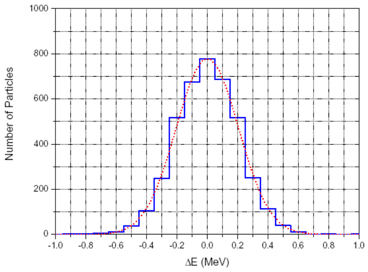

Fig. 5. Simulation result of the particle distribution on energy axis. Red (dotted) line is a Gaussian curve with $\sigma_E = 0.2$ MeV.

2.2 Acceleration Simulation

The magnetic filed is ramped in a cosine wave-form as shown in Fig. 6. The corresponding profiles of the RF voltage and the synchronous phase are given in Fig. 7 and Fig. 8, respectively. The initial voltage is 18.7 kV and the maximum voltage is 75 kV. The initial voltage profile was obtained by using the RAMA code [1].

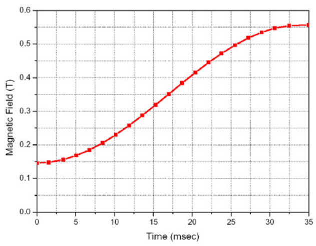

Fig. 6. Magnetic field ramping in acceleration period.

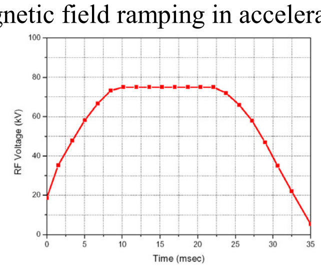

Fig. 7. RF voltage profile in acceleration period.

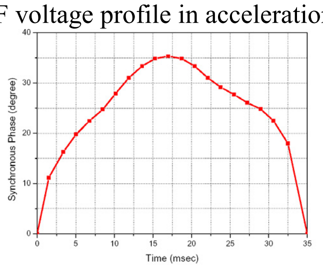

Fig. 8. Synchronous phase profile in acceleration.

In this ORBIT simulation [2], we used 40,000 macro-particles and included both transverse and longitudinal space charge effects. After 200 injection turns, the capture rate is 100% and the particle distribution is given in Fig. 9. The synchrotron tune of the RCS is 5.06×10^{-3} and the initial particles complete one rotation in the longitudinal phase space (Fig. 9).

We found that the particle loss is less than 0.1% in the acceleration period. That mainly happens in the initial ramping period of the RF voltage. The final particle distribution after acceleration is given in Fig. 10. The final energy is 1.003 GeV and the capture rate is 99.91%.

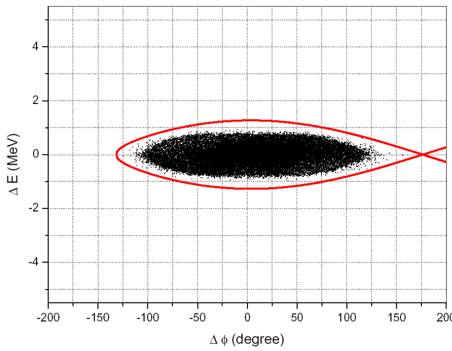

Fig 9. Particle distribution after injection.

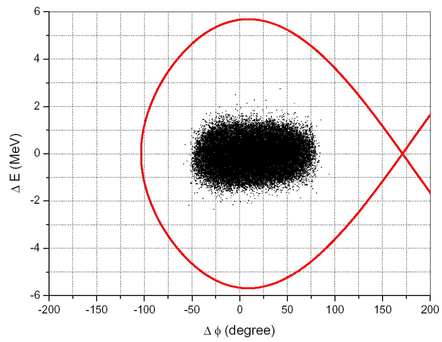

Fig 10. Particle distribution after acceleration.

3. Conclusions

This work summarized the acceleration simulation result of the PEFP RCS for a1-GeV extraction with a 15 –Hz operation. With the proposed magnetic field and RF voltage profiles, we achieved a capture rate larger than 99.9% with a final energy of 1.003 GeV. We will study the longitudinal painting method in the near future.

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REFERENCES

[1] R. Baartman et al., A Computer Code Useful for Designing Synchrotrons, TRI-DN-86-15, 1986.
[2] J. D. Galambos, et al., ORBIT User Manual, Version 1.0, 1999.