Dynamic Aperture of PEFP RCS

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1. Introduction

One of plausible extension options of the PEFP (proton engineering frontier project) linac is an RCS (rapid cycling synchrotron) for a spallation neutron source. The beam power is designed to be 500 kW with the injection energy of 200 MeV and the extraction energy of 2 GeV after a 3-step upgrade. In the initial stage, the injection and extraction energies are 100 MeV and 1 GeV, respectively. The PEFP 100-MeV linac becomes the injector of the RCS in this stage. The initial beam power is 60 kW. This work focuses on the dynamic aperture simulation of the RCS in 1-GeV operation. We found that the orbit distortion by magnet errors causes a serious reduction of the dynamic aperture. After orbit correction, the dynamic aperture becomes larger than a stable beam region.

2. Dynamic Aperture of PEFP RCS

In a synchrotron, the physical aperture is fixed by the vacuum pipe of the ring. A stable beam region is determined to be smaller than the physical aperture. The charged particles are oscillating around the ideal orbit which is the center of the vacuum pipe. The amplitude of the betatron oscillation is changed by several effects including the particle energy deviation from a synchronous particle, magnet misalignment, magnet multi-pole, etc. These are the potential sources limiting a dynamic aperture. The dynamic aperture should be larger than a stable beam region in order to reduce beam loss.

In this work we studied the dynamic aperture of the PEFP RCS in the initial operation. In this stage, the injection and extraction energies are 100 MeV and 1 GeV, respectively. The beam power will be 50 kW under the 15 Hz operation. The main focuses are the effects of the fractional momentum spread, magnet misalignment, magnet amplitude errors and magnet multi-pole components of dipole magnets. For the simulation, we used the DYNAP routine in MAD8 [1].

2.1 Stable Beam Region

The stable beam region is defined as follows,

$$\sqrt{\frac{2\beta\varepsilon}{\pi}}+\eta\frac{\delta p}{p}+cod\,,$$

where β and ε represent the beta function and beam emittance. The parameter η is the dispersion function of the ring. The cod represents the closed orbit distortion which is less than 1 mm after the orbit correction. Figure 1 shows the resulting stable beam region.

First, we checked with the DYNAP routine by studying how the dynamic aperture depends on the initial beam condition. Figure 2 shows the parameters determining the initial particle coordinates. The results are summarized in Figure 3. The different lines imply the different values of the starting azimuthal position. The horizontal axis describes the initial divergence. The vertical axis is proportional to the dynamic aperture. As shown in Figure 2, the dynamic aperture for a smaller value of the angle ϕ becomes smaller because of a larger initial amplitude. The dynamic aperture is also reduced when the initial divergence becomes larger.

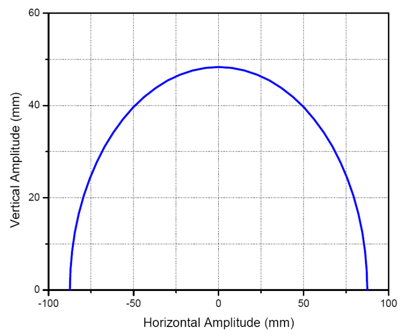

Fig. 1. Stable beam region.

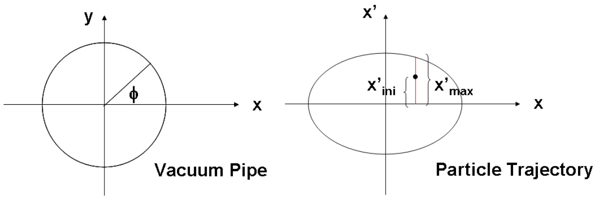

Fig. 2. Parameters of the initial beam condition to study the DYNAP routine.

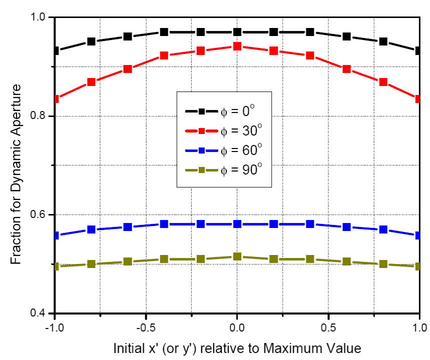

Fig. 3. Dynamic aperture depending on the initial angular position and divergence.

2.2 Results

Because the maximum value of the fractional momentum deviation is 0.7 % in the injection and acceleration simulation [2], we studied its effects on the dynamic aperture by varying from 0.0% to ±0.7%. In this study, we used both the TRANSPORT method (Figure 4) and the LIE algebra method (Figure 5) for particle tracking. As expected the figures show that the dynamic aperture is reduced as the fraction momentum spread increases. Yet the dynamic aperture is still larger than the stable beam region even when the deviation becomes ±0.7%. In the following analysis we will use the LIE algebra tracking only.

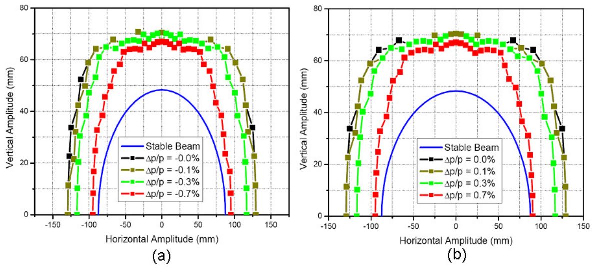

Fig. 4. Fractional momentum deviation and dynamic aperture in the TRNSPORT tracking method: (a) 0 ~ -0.7 %, (b) 0 ~ 0.7%.

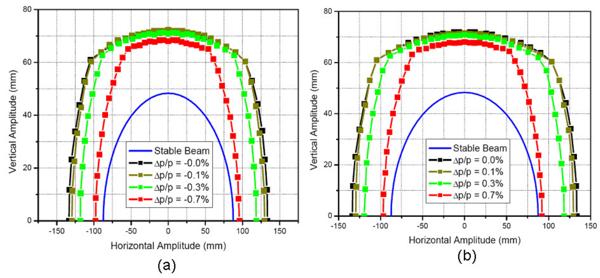

Fig. 5. Fractional momentum deviation and dynamic aperture in the LIE algebra tracking method: (a) 0 ~ -0.7 %, (b) 0 ~ 0.7%.

We also studied how the orbit distortion by magnet errors affects the dynamic aperture. We assumed that the displacement and rotation errors of the magnets are less than 300 μm and 1 mrad, respectively. The magnet field errors are less than 10^{-4}. The fractional momentum deviation is fixed to the worst case of 0.7%. Figure 6 shows the result of the closed orbit distortion and its correction in both horizontal and vertical directions. The corrector magnets and scheme worked satisfactorily. The dynamic aperture is given in Figure 7 under the condition of the orbit distortion and its correction. In this study, we reflected the physical aperture of the quadrupole magnets as a circular pipe in each quadruple center. The particle is considered lost if it is found outside the pipe. We found that the dynamic aperture is reduced to be smaller than the stable beam region without the orbit correction. However the dynamic aperture moves to outside of the stable region after the orbit correction.

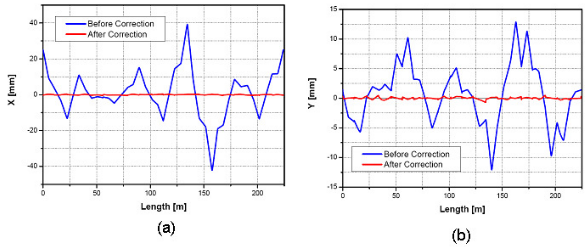

Fig 6. Closed orbit distortion and its correction in (a) horizontal and (b) vertical directions

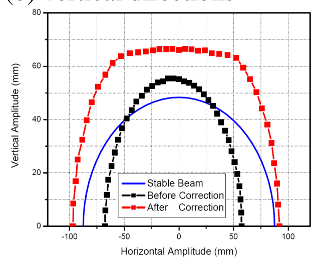

Fig 7. Orbit distortion and dynamic aperture.

Finally we studied the dynamic aperture variation by the multi-pole components of the bending magnet. The errors include quadrupole, sextupole, and octupoles which are assumed to be less than 10^{-4} of the dipole amplitude. Figure 8 shows the result. We found that the multi-pole error effects are negligible.

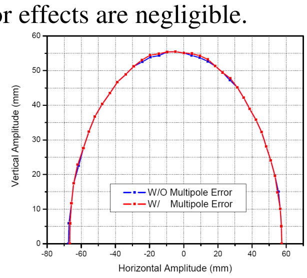

Fig 8. Multi-pole errors of dipole magnets and dynamic aperture.

3. Conclusions

We studied the dynamic aperture of PEFP RCS in 1-GeV operation. The most serious effects are generated by the orbit distortion. The dynamic aperture is too large to cover the stable beam region under the magnet error effects. However we found that the dynamic aperture is increased to be larger than the stable beam region after orbit correction.

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REFERENCES

[1] H. Grote and F. C. Iselin, The MAD Program: Users Reference Manual, Version 8.19, CERN/SL/90-13.
[2] J. H. Jang, Y. S. Cho, H. J. Kwon, Y. Y. Lee, Acceleration simulation of PEFP RCS for a 1-GeV operation, KNS spring meeting 2009.