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XiPAF SYNCHROTRON SLOW EXTRACTION COMMISSIONING*

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Abstract

Xi'an 200 MeV Proton Application Facility (XiPAF) is a project to fulfill the need for the experimental simulation of the space radiation environment. It comprises a 7 MeV H- linac, a 60~230 MeV proton synchrotron, and experimental stations. Slow extraction commissioning for 60 MeV proton beam in XiPAF synchrotron has been finished. After commissioning, the maximal experiment extraction efficiency with the RF-knockout (RF-KO) method can up to 85%. The reason for beam loss has been analyzed and presented in this paper. Besides, an experiment of multiple energy extraction has been conducted in XiPAF synchrotron. The proton beams of 3 different energies were successfully extracted in 1.54 s.

INTRODUCTION

Xi'an 200 MeV Proton Application Facility (XiPAF) is used for the experimental simulation of the space radiation environment. To satisfy the requirements of the experiments, the third-order resonance and RF-KO technology are adopted to realize slow extraction. Slow extraction commissioning for 60 MeV proton beam and multiple energy extraction have been completed. The main design parameters of XiPAF synchrotron related to slow extraction are listed in Table 1.

Figure 1 shows the scheme of the XiPAF synchrotron extraction system [1]. A pair of sextupoles (SR1, SR2) are used for resonance excitation, another pair of sextupoles (SC1, SC2) are used for chromaticity correction. An RF-KO kicker is used for transverse excitation, a electrostatic wire septum (ES) and two septum magnets (MS1, MS2) are used for deflecting the extracted beam.

Table 1: Main Design Parameters for Extraction

Parameters	**Design Value**
Betatron tunes(x/y)	1.678/1.762
Separatrix acceptance	28.2π mm mrad
ES gap width	15 mm
ES wire position	22 mm
ES wire thickness	0.1 mm
Kick angle of ES	11 mrad
RF-KO FM method	dual FM [2]

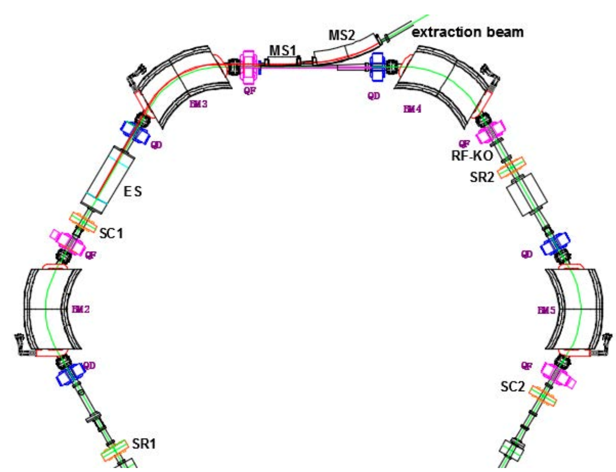

Figure 1: The extraction system scheme for XiPAF synchrotron.

EXPERIMENTAL RESULT

Figure 2 shows a typical result for extraction at an energy of 60 MeV. The beam current in the ring was measured with DCCT and the spill was measured with an ionization chamber (IC). As shown in Fig. 2, there is a sudden drop of the beam current between 380 ms and 440 ms which time corresponding to the sextupoles ramping up. RF-KO was turned on between 700 ms and 1250 ms, and then the beam was extracted during this time by RF-KO.

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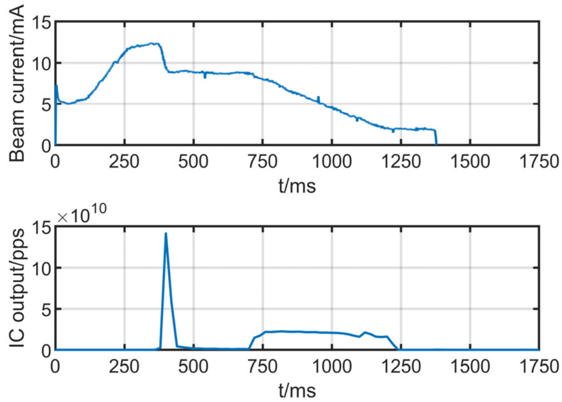

Figure 2: A typical result: beam current measured with DCCT and spill measured with IC.

The beam current drop during the sextupoles ramping up because the beam emittance is larger than the area of the stable triangle, which caused undesired extraction and total extraction efficiency decrease. However, a small area of the stable triangle is necessary for a high extraction efficiency when extraction with RF-KO. So the beam current drop is inevitable unless the beam emittance becomes smaller.

In the following discussion, we only concern about the extraction efficiency during RF-KO turning on stage. The efficiency varying with stable triangle area was measured in the experiment as shown in Fig. 3. In the experiment, the horizontal and vertical betatron tunes measured with sextupoles turning off are 1.6794, 1.7246 respectively, which are somewhat different than the design value. We changed the triangle area by adjusting the sextupoles strength. The stable triangle area was calculated with the horizontal tune (measured with sextupoles turning on) and sextupoles strength. The maximum extraction efficiency in the experiment can up to 85%. The simulation result was also shown in the figure.

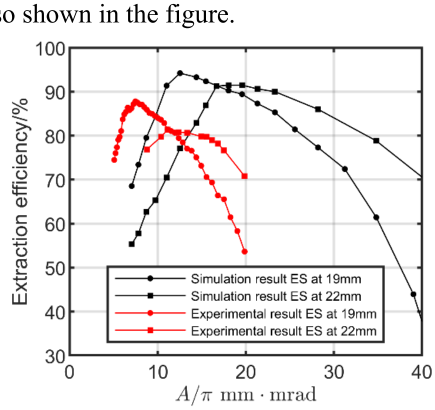

Figure 3: Extraction efficiency vs. the stable triangle area.

BEAM LOSS ANALYSIS

As shown in Fig. 3, the trends of extraction efficiency varying with the stable triangle area in experiment and simulation are similar. So the reasons for beam loss are also similar both in simulation and experiment.

The first reason is beam loss during the last three turns. The trajectory of the last three turns under the design parameters is shown in Fig. 4. The maximum trajectory at MS1 in the last three turns is very close to the vacuum chamber wall. If there has a closed orbit distortion at MS1, particles will probably lose. In another case, if the sextupoles strength is larger than the design value, the spiral step will increase, which means the maximum trajectory at MS1 will be larger and particles more likely to lose.

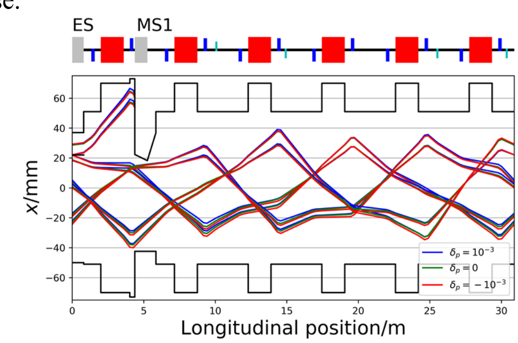

Figure 4: The trajectory of the last three turns and the extracted beam under the design parameters.

The second reason is beam loss at ES inner or outer electrode. The extracted beam phase space distribution for different stable triangle areas is shown in Fig. 5. For a large stable triangle area, the spiral step is small, thus the distribution in the x-direction is concentrated. The influence of ES wire becomes larger, beam loss at ES wire (i.e. ES inner electrode) is larger than the small stable triangle area situation. The spiral step is relatively larger for a small stable triangle area. However, a too large spiral step will cause beam loss at ES outer electrode.

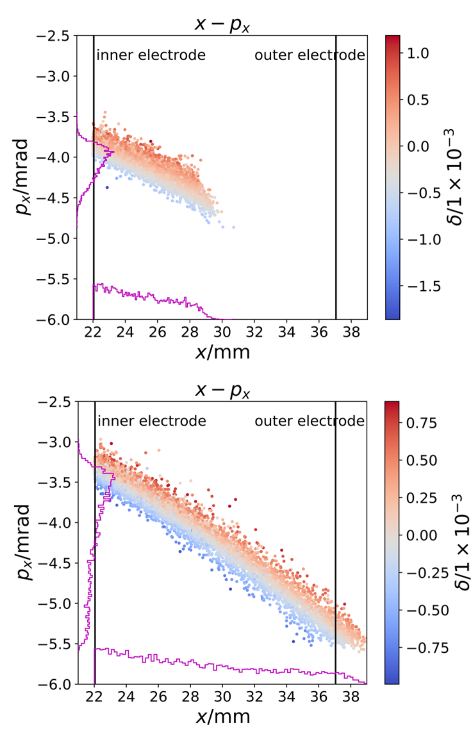

Figure 5: Phase space distribution at ES entrance, upper: for a large stable triangle area, lower: for a small stable triangle area.

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The trend in Fig. 3 can be explained with the reasons mentioned above. When the area is small, beam loss at the last three turns and ES outer electrode are dominant, since a large spiral step. When the area is small, the spiral step becomes small, beam loss at the inner electrode turns into a dominant reason. So the extraction efficiency increases initially and then decreases with the triangle area.

As we can see in Fig. 3, the ES position has a great influence on extraction efficiency. For a small area case, a smaller ES position induces a smaller spiral step, which is helpful to increase extraction efficiency. For a large area case, a larger ES position is preferred, which causes a larger spiral step.

Besides, the angle of ES is also important. The trajectory of the extracted beam in the ES channel for a small spiral step case is shown in Fig. 6. The black curves represent the particles that can pass the ES channel. The trajectory of these particles is a parabola. The blue curves represent the particles that were lost at the ES wire. Since the ES is parallel with the reference orbit，particles were not only lost at the entrance of ES, but also lost at the middle of ES. If the angle of ES is chosen at a suitable value, the loss at ES wire only occurs at the entrance of ES, the beam loss at ES wire will be minimized. The influence of the angle of ES will be tested and verified in further experiments.

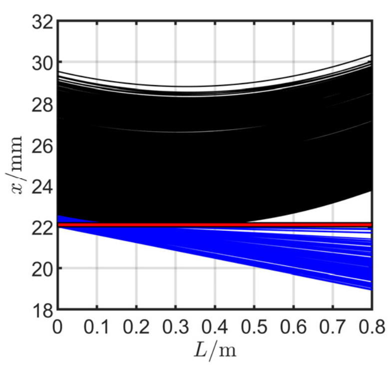

Figure 6: The trajectory of the extracted beam in the ES channel for a small spiral step case.

Although the trend in Fig. 3 can be explained, there still has some difference between simulation and experimental results. Some reasons that may cause beam loss are not considered in the simulation. Such as the closed orbit distortion, stable triangle area deviation, and the separatrices angle deviation because of magnet imperfections and misalignment. These factors will be also tested and verified in the future.

MULTIPLE ENERGY EXTRACTION

Multiple energy extraction can change the extracted beam energy in one cycle, which has been realized at HIMAC [3] and HIT [4] facility. In XiPAF synchrotron, an experiment of multiple energy extraction has been conducted. The experimental result is shown in Fig. 7. The proton beam injected in the ring was initially accelerated to higher energy, and then successively decelerated to lower energies. There have 3 flattops with different energies and each flattop can be used for extraction, corresponding to the beam energies of 65.28, 63.38, 60.47 MeV. 3 different energies proton beams were successfully extracted in 1.54 s as shown in the IC output signal. The time consumed for energy change is 140 ms and the beam extraction time was 100 ms for each energy step. The beam energy was measured by the beam revolution frequency in the ring. More details of the multiple energy extraction in XiPAF synchrotron will be reported in other papers as soon.

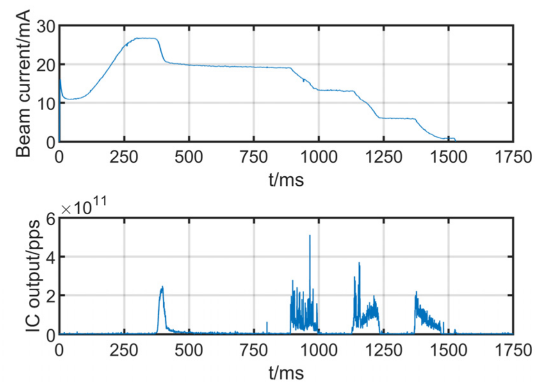

Figure 7: Multiple energy extraction results: beam current measured with DCCT and spill measured with IC.

CONCLUSION

The slow extraction commissioning for 60 MeV proton beam in XiPAF synchrotron has been completed. A large emittance reduces the total extraction efficiency. The maximal experiment extraction efficiency with the RF-KO method can up to 85%. Beam loss during the last three turns and at the ES electrodes are the main reasons responsible for low extraction efficiency. Some other factors such as the angle of ES, closed orbit distortion, stable triangle area deviation, and the separatrices angle deviation will be tested and verified in later experiments. Multiple energy extraction was successfully conducted in XiPAF synchrotron. 3 different energies proton beams were extracted in 1.54 s. More detail about the multiple energy extraction will be reported in other papers as soon.

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