Abstract

XiPAF (Xi’an 200 MeV Proton Application Facility) is a project to fulfill the need of the experimental simulation of the space radiation environment. It comprises a 7 MeV H-linac, a 60–230 MeV proton synchrotron and experimental stations. The installation of the synchrotron, beam line and one experimental station were completed at the end of December 2019, and commissioning has just begun. Circulating beam around the synchrotron was observed on the first day of operation, and now 10–200 MeV proton beam directly extracted from the synchrotron had been transported to the experimental station for user experiments. The results of the commissioning and data analysis are presented in this paper.
for horizontal and six for vertical), one DCCT, one FCT, and two scintillating screens one is on the injection section and near the stripping foil, and the other locates the straight segment adjacent to the injection section.

Figure 2: Beam diagnostics layout of XiPAF synchrotron.

The injection system of XiPAF synchrotron consists of a septum magnet, a carbon foil, two bumper magnets, and three Chicane dipoles [5]. Two scintillating screens are used to observe the circulating beam on the first turn. As the injected beam is accumulated in the ring, the beam signal can be measured on DCCT and FCT (Fast Current Transformer). Due to the slow response of DCCT, it is unable to accurately measure the evolution of beam intensity during the injection phase. So, the variation of beam intensity with time can be obtained by integrating the FCT signal [6].

The beam intensity curve during the injection phase is shown in Fig. 3, the blue line is the beam signal measured by FCT, the red one represents the beam intensity by integrating the FCT signal. In this case, the injected beam is 1.1 mA measured by ACCT at exit of MEBT. After 60 μs injection, the beam intensity accumulated in the ring is 47 mA, corresponding to $2.5 \times 10^{11}$ ppp.

Figure 3: Beam intensity curve during the injection.

After the injection, in order to achieve the adiabatic capture, the RF voltage increases linearly from 0 to 600 V over 10 ms. When the beam is captured, its central energy oscillates with the synchronous energy as the center, and its transverse motion oscillates with the closed orbit. For a selected closed orbit, the synchronous energy under this closed orbit can be changed by adjusting RF frequency and the field strength of dipoles synchronously to keep the closed orbit as a constant. If the synchronous energy matches with the injected beam energy, the maximum capture efficiency can be obtained. The result of capture efficiency is 65% calculated by the data measured by FCT.

Figure 4: The diagram of the magnets and RF cycle.

The mismatch of the beam energy, the magnetic field of dipoles and RF frequency and phase, will cause the beam to oscillate laterally and beam loss. The matching between the field of dipoles and RF frequency can be achieved by modifying the frequency curve based on the closed orbit curve measured by BPMs during acceleration.

The dual-harmonic acceleration was used in XiPAF synchrotron, the ratio (denoted by the symbol $r$) of RF voltage of the second harmonic to the first harmonic determines the shape and size of the Bucket. The beam intensity curves under three acceleration conditions ($r = 0$, $r = 0.5$, $r = -0.5$) were measured using DCCT, as shown in Fig. 5(a). The dual-harmonic acceleration ($r = -0.5$) can significantly improve the acceleration efficiency and beam intensity. After acceleration to 60 MeV, the beam intensity is 53 mA, as shown in Fig. 5(b), corresponding to $1 \times 10^{11}$ ppp.

Figure 5: The results of dual-harmonic acceleration, (a) is beam intensity for three $r$ values, (b) is the beam intensity after optimization.

SLOW EXTRACTION TEST

Before the extraction, the optics measurement and correction have been carried out at 7.1 MeV and 60 MeV, the measurement has a good agreement with the corrected optical model, refer to [7] for details.

The extraction system of XiPAF synchrotron is described in Ref. [8]. An ionization chamber (IC) on the HEBT is employed to measure the extracted beam. Limited by the thickness of shielding walls of the temporary plant, the beam extraction commission in this stage is focused on 60 MeV and 10 MeV. The beam extraction of 200 MeV was briefly tested, without the optimization the extracted beam intensity on IC is about $2 \times 10^{10}$ ppp.

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60 MeV Slow Extraction

For 60 MeV beam extraction, two key points of beam commission are extraction efficiency and the spill ripple. For XiPAF synchrotron, the main sources of beam loss during the extraction are as following:

- The beam envelope exceeds the vacuum pipe size near the first extraction septum magnet MS1 (the pipe size near MS1 side is smaller than the requirement, can be alleviated by a local bumper orbit [6]) during the process of RF-KO excitation before extraction.
- Beam loss on the anode wires of the electrostatic septum (ES) because of the improper position and angle of particles at the entrance of ES.

Figure 6 shows the variation of extraction efficiency with the area of the triangle when the ES anode wire array is located at 19 and 22 mm. The black line is the simulation results, and the red line is the measurement results. In the experiment, the maximum extraction efficiency by RF-KO is 85%, refer to [9] for detailed analysis.

Figure 6: Extraction efficiency of simulation and experiment.

The spill ripple magnitude is written as \( R = \frac{\sigma}{\mu} \), using the definition in Ref. [10]. In our experiments, the dual FM method was adopted, and the feedback system was used to modify the amplitude of the RF-KO over the extraction duration. Finally, a smooth spill structure was obtained (shown in Fig. 7), and R value is 0.179.

Figure 7: Spill structure with dual FM method and the feedback.

10 MeV Slow Extraction

XiPAF is built for Single-Event Effect (SEE) test, which requires slow extraction beam from 10 ~ 200 MeV. Traditionally, the low energy beam (10 ~ 60 MeV) is achieved by the degrader, which may cause beam loss and energy spread increase. Compared with using degrader, the direct low energy extraction can obtain higher beam intensity within the energy spread requirements [11].

In this commission phase, 10 MeV beam extraction from the synchrotron was carried out, and the results are given here briefly, and more details will be reported soon elsewhere. The space charge effect is a priority in the slow extraction of 10 MeV beam. When the extraction working point is above the \( \nu_x = 5/3 \) resonance line, limited by the Laslett tune shift, after acceleration to 10 MeV, the beam intensity is 6.4 mA, the maximum extraction intensity is \( 1.1 \times 10^{10} \) ppp.

In order to improve the beam intensity of 10 MeV direct extraction, the working point was selected to the value of below \( \nu_x = 5/3 \) resonance line. After parameters optimization, including working point (\( \nu_x = 1.663 \)), RF voltage during the extraction (60 V), the central frequency of RF-KO, etc. the beam intensity of 10 MeV direct extraction measured by IC is \( 4.7 \times 10^{10} \) ppp, as show in Fig.8.

Figure 8: Beam intensity and extraction efficiency for 10MeV slow extraction.

CONCLUSION

The beam commissioning of XiPAF synchrotron in the temporary plant is finished, 10 ~ 200 MeV proton beam has been extracted directly from the ring. The extraction beam intensity for 10 ~ 60 MeV is about \( 5 \times 10^{10} \) ppp.

So far, some user experiments from five organizations have been carried out on XiPAF, including single particle effect and displacement damage effect experiments of more than 50 core electronic devices. In the temporary plant, the extraction efficiency optimization and spill ripple research will be continued, and the multi-energy extraction will be further developed. Now the formal plant of XiPAF is under construction. Once it is completed, all the equipment will be moved to new plant, where it will be installed and commissioned according to the design scheme.

REFERENCES


