SLOW EXTRACTION DESIGN OF HIMM

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Abstract

A heavy ion medical machine (HIMM) is proposed for cancer therapy in Lanzhou, China. The slow extraction design of the synchrotron is introduced in this paper. Eight sextupoles are used; four of them are for correcting the chromaticity and the rest for driving the 3rd-order resonance. In order to save the aperture of vacuum chamber, a 3-magnet bump is adopted during the extraction process. The phase space map in the entrance of the electrostatic septum and the last 3 turns' particle trajectory before particle extraction are given.

INTRODUCTION

HIMM is the first carbon ion cancer therapy facility in China. The facility has been designed based on the experience of the construction and operation of the HIRFL-CSR [1, 2]. Fig. 1 shows the layout of the HIMM. An ECR ion source is put under the cyclotron, which produces the C^{5+} beam. The beam will be injected into the cyclotron from the axis direction, and be accelerated from 29 keV/u to 7 MeV/u, then injected into the synchrotron by the charge exchange injection method. The facility contains four treatment rooms with four irradiation ports (horizontal; horizontal + vertical; vertical; 45 degree to the horizontal).

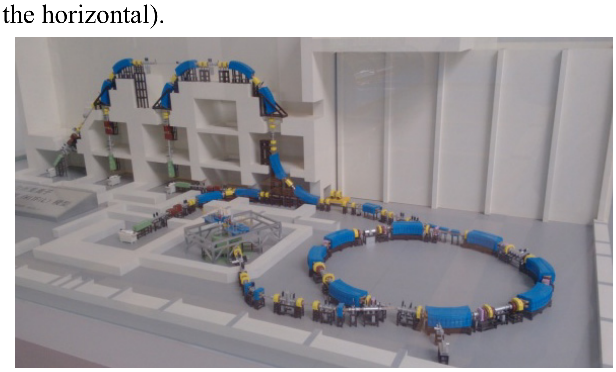

Figure 1: Layout of the HIMM.

DESIGN OF THE SLOW EXTRACTION

Figure 2 shows the Twiss parameters of the synchrotron, the last dipole in the figure is the extraction magnet septum, and the last third dipole is the electrostatic septum (ES). 1/3 resonance with RF-KO method is adopted for slow extraction. The ES is put in the descending part of the dispersion to fulfill the Hardt condition [3]. The phase advance between the two septa is 75 degrees. There are 8 sextupoles in the synchrotron, and they are placed symmetrically in the ring. Since the horizontal work point has been chosen as 1.68 just near the even number, and the super-period is 2, the chromaticity and the resonance driving function can be achieved separately. Table 1 lists the main parameters of the synchrotron.

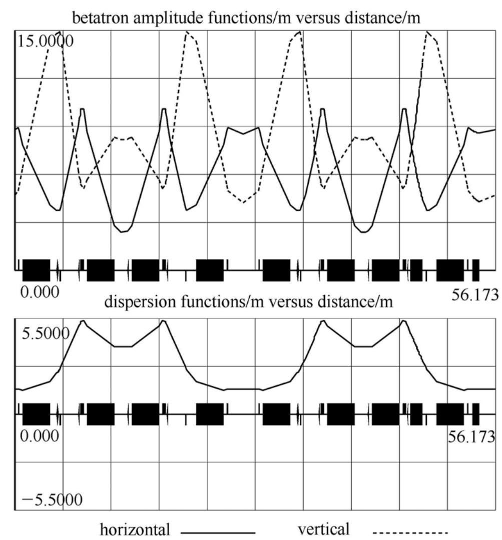

Figure 2: Twiss parameters of the synchrotron.

Table 1: Parameters of the synchrotron

circumference (m)	56.2
magnet rigidity (T_m)	0.76-6.62
Qx/Qy	1.68/1.27
super period	2

SIMULATION RESULTS

The simulation of slow extraction is carried out using MADX [4]; the separatrices of the beam with different momentum are shown in fig. 4. The green, red, and blue colours represent the beam with a momentum deviation of -0.1%, 0%, 0.1%, respectively. The black line in the horizontal position of 0.055m represents the electrostatic septum without extraction orbit bump. The original particle distributions are Gaussian distribution with one sigma emittance equal 7.5πmm-mrad and 1.5πmm-mrad in the horizontal and vertical direction respectively. The total number of particles been tracked in Fig. 4 is 15000. The turn number been tracked is 3000. The maximum transverse RF kicker angle in the track process is 0.03mrad. The Hardt condition is fulfilled very well from the Fig. 4. Since the original particle emittance is near or larger than the stable emittance, there are some particles outside the stable area. The chromaticity of the synchrotron in the extraction process is -2.5, that means

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the particles with momentum deviation of -0.1% and 0.1% will have the 1.4 times and 0.7 times stable emittance from the ideal one.

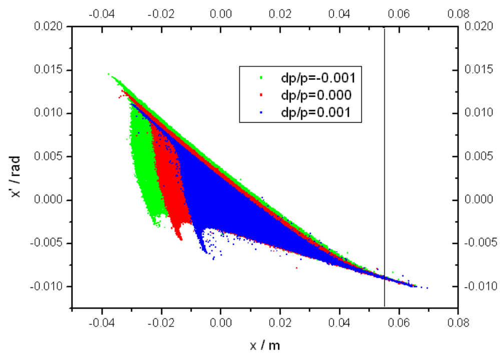

Figure 4: Separatrices of the extracted beam.

The extracted beams in the phase space at the entrance of the ES are shown in Fig. 5. Similar to Fig. 4, the green, red, and blue colours represent the beam with a momentum deviation of -0.1%, 0%, 0.1% respectively. There are some particles which do not fulfil Hardt condition; these particles are the little part of the all particles. It is a little effect to the extraction efficiency. The spiral step is about 12 mm as shown in the figure.

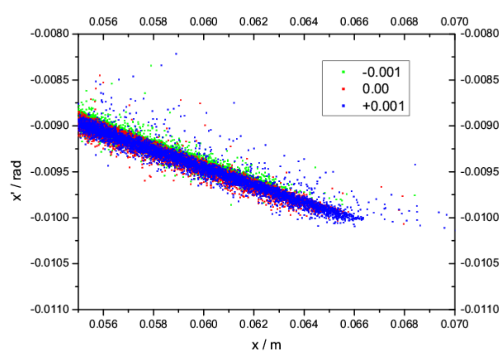

Figure 5: Extracted beam at the entrance of the electrostatic septum.

Figure 6 shows the spill distribution at the entrance of the ES. The histograms show the extracted particles density distribution in the horizontal direction and the vertical direction respectively. The particle density distribution in horizontal direction is decreased since the method of extraction is RF-KO and the original distribution is a Gaussian distribution. The vertical particle density distribution is a Gaussian distribution since the particle distribution in the synchrotron is a Gaussian distribution and the particles do not have any other affection in the vertical direction. The particles with different momentum will have different tunes, then the different stable emittance, then different spiral steps, as shown in Fig. 6 (a). The spill distribution in real space is described in Fig. 6 (b)

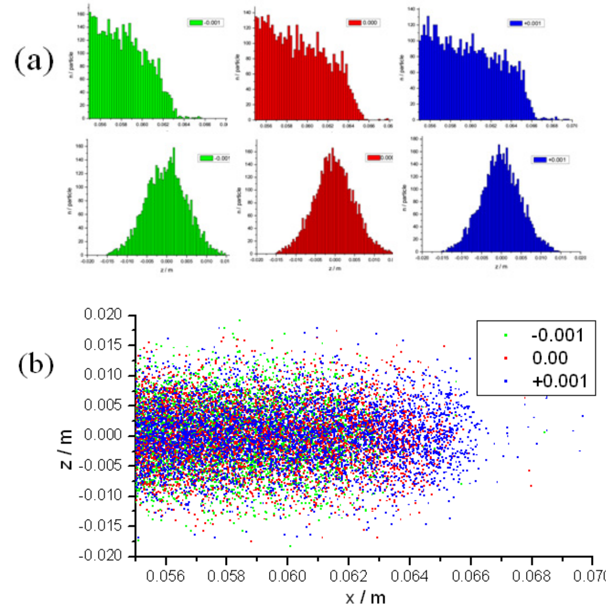

Figure 6: Extracted particle distribution at the entrance of the ES. From the top: horizontal direction, vertical direction, real space with a coordinate x-z.

Figure 7 shows the trajectory of the last three turns before extraction and the extracted segment between the electrostatic and magnetic septa. The angle of the electrostatic septum is -10 mrad; just parallel with the extraction spill. The kick angle of the ES is 8.75 mrad corresponding to an electric field intensity 85kV/cm in 400MeV/u C6+. The ES has a bending radius of 200m to reduce the voltage of the ES. The extraction orbit has been bumped by a 3-magnet bump, which raised a height of 10-15 mm at the entrance of ES during extraction. The margin area of the extraction orbit is 10mm in the synchrotron.

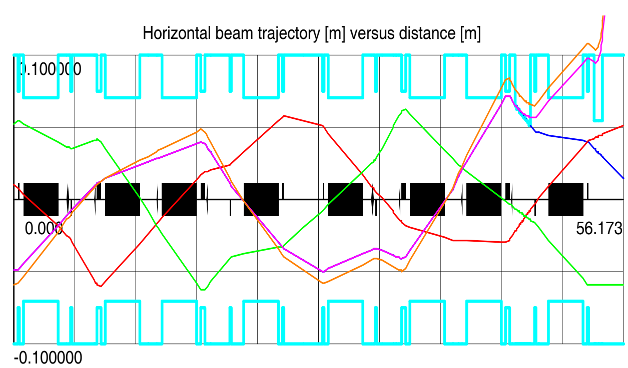

Figure 7: The trajectory of the last three turns before extraction and the extracted segment between ES and MS.

CONCLUSION

The 3rd resonance slow extraction of the HIMM has been described. The extraction simulation is done with the accelerator codes MAD-X. To save enough vacuum chamber space for beam injection, the 3-bump orbit has been adopted in the extraction process.

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