THE DEVELOPMENT OF INJECTION AND EXTRACTION SOFTWARE IN THE RAPID CYCLING SYNCHROTRON

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Abstract

The Rapid Cycling Synchrotron is widely used in medicine, materials and biology. The software, which studies injection and extraction of the synchrotron and is widely applied in almost all those synchrotrons, is useful to design of the new synchrotron. In this paper, the development of the software is introduced and an example is presented.

INTRODUCTION

The Rapid Cycling Synchrotron is widely used in medicine, materials and biology. High-energy, ionising radiation has proved to be effective in the treatment of cancerous tumours by causing double-strand breaks in the cell DNA. In particular, hadrons have the advantageous property of penetrating the body easily and then depositing their energy at a depth determined by their initial energy [1]. The characteristic of some materials will be changed as it is irradiated by high energy proton beam. It is specially used in aerospace, the spacecraft and all the detectors in universe may be broken with the action of cosmic high ray. The ion synchrotron helps researchers predict uncharted phenomenon of the spacecraft in outer space and adopted novel method to improve the lifetime of the spacecraft. The synchrotron also offers the micro-beam which is used in biology [2]. The biologist uses the micro-beam to study the single cell of the biology. It promotes the development of the biology and medicine.

The rapid cycling synchrotron is widely studied and constructed in all over the world now, it is different for every synchrotron and the software of injection and extraction study is also different, thus a lot of repetitive work is done again and again. A rapid cycling synchrotron is firstly designed and the software of injection and extraction design is development based on matlab/AT [3]. Then, according to the software, the widely software which can simulate injection and extraction for all the synchrotron is plan to develop. The software will help researchers to design and construct new synchrotron.

THE RAPID CYCLING SYNCHROTRON

The typical rapid cycling synchrotron is designed to accumulated proton beam and accelerates it from 7 MeV to 300 MeV with the repetition rate of 0.5 Hz. The layout of the synchrotron is shown in Fig. 1. The beam injects the synchrotron by two bumps, injection magnets septum (IMS) and injection electrostatic inflector (IEI). The beam is slow extracted by sextupoles, RF knockout (RFK), extraction magnets septum (EMS) and extraction electrostatic septum (EES) for micro beam, material and biology study. The lattice of the rapid cycling synchrotron adopts a FODO cell based 2-fold structure. The main parameter of the synchrotron is given in Table 1.

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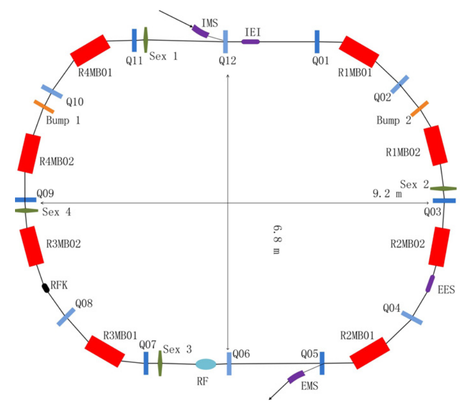

Figure 1: The schematic view of the synchrotron

Table 1: The Main Parameters of the Synchrotron

Parameters	Units	Values
Circumference	m	35
Inj. Energy	MeV	7
Ext. Energy	MeV	300
Tunes(H/V)		1.72/1.28
Repetition rate	Hz	0.5
Emittance	π mm-mrad	150/50
Particle Number		$2*10^{11}$

INJECTION

The proton beam, which is pre-accelerated by linear accelerator, is injected into synchrotron by multi-turns injection method. Injection energy of 7 MeV is decided in consideration of space charge limitation for proton.

The linear beam passes through the IMS and the IEI and arrives injection point, thus injection beam joins circular beam and ramps with circular beam together. The orbit of the linear beam is easily given in injection region. The lowest aperture of the synchrotron is generally the EES, and the circular beam may lose at EES and EMS, so it has to judge the loss beam in extraction region before every ramping turn. Furthermore, the circular beam ramps one turn and arrives in injection region, it may enter and hit the IMS and IEI, thus the beam loses, so the beam also

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should be judged at them. The closed orbit is bumped by two bump magnets, and the intensity of the bump steps down. Injection beam is painted around 200 π.mm.mrad in horizontal phase space by sweep of magnetic field of the two bump magnets.

According to the physical consideration, the injection software based on AT is developed, and injection process is simulated. The linear beam is injected in synchrotron with 50-turn injection and 100 particles per turn in the simulation. Fig. 2 gives the change of the closed orbit, the circular beam and linear beam at injection point and injection efficiency. The height of the closed orbit in the injection region decreases from 36 mm to 24 mm. The efficiency of the injection is over 98% with 50-turn injection. Injection beam is adiabatically captured into buckets for acceleration.

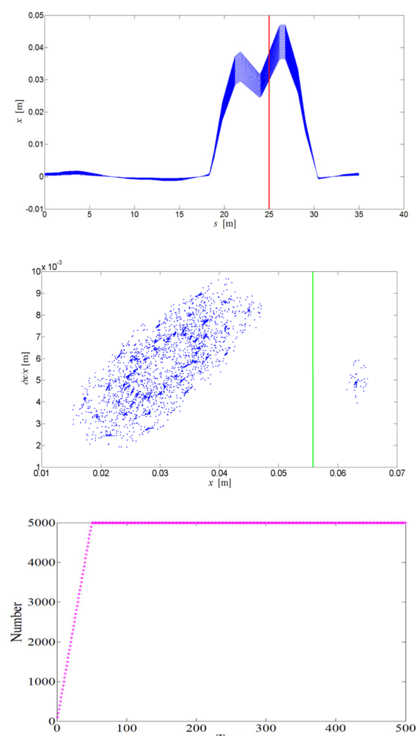

Figure 2: The closed orbit in injection (top), injection beam and circular beam in injection point (middle) and injection efficiency (bottom).

EXTRACTION

The layout of extraction is shown in Fig. 1, the components of extraction include four sextupoles, the RFK, EMS and EES. The resonance sextupole (Sex 1) is placed in a dispersion-free region before the arc, and the other resonance sextupole (Sex 3) is symmetrical with Sex 1. Sex 2 and Sex 4 correct chromaticity for the Hardt condition.The accelerated beam is extracted by slow extraction scheme using a third order resonance $\nu_x = 5/3$ by the transverse RFK [4][5]. The phase advance to the EES is well above the permissible minimum of 230 degree and close to the ideal of 225 degree, the phase advance to the EMS is a comfortable 81.5 degree, which gives 98% of kick that would be available if the phase advance were 90 degree. The dispersion function are configured with $D_x>0$ and $D'_x<0$ at EES for the Hardt condition. Stabilities of extraction beam parameters, for example beam position, beam size, momentum deviation and extraction efficiency, are very important issue for particle beam therapy, material and biology study. In the RFK method, the separatrix is kept constant whole extraction, so the control of extraction is very easy, and it makes extraction beam position and extraction efficiency more stable.

The software of extraction checks the reasonable of the lattice design, and simulates the beam loss and beam stability. The accelerated beam is completely extracted at several million turns, even several ten million turn. The study of extraction also includes several kilo turns, even more. The tune of the synchrotron firstly adjusts to 1.67. The code can analyze the beam loss at IMS, IEI and EMS, then, the accelerated beam passes through the synchrotron with reasonable intensity of the sextupole and RFK. The particles are judged when they arrive at EES. Some particles hit the EES and lose, some particles enter in EES and EMS and are extracted, even some lose in pipe, but many particles per turn pass through the extraction region and ramp again. In order to stability and uniformity of the extraction efficiency, the intensity of the resonance sextupole and RFK should be considered carefully. To decrease beam loss in extraction, the component of EES and EMS should be designed reasonably, including its location, gap, length and intensity. The aperture of the magnets in the extraction region should be given through the software. Furthermore, the orbit of the extraction beam is also given. In fact, only the first and third quadrants are usable to extraction beam, the software compares advantage of two quadrants. The spiral step and spiral kick are also confirmed in the simulation.

To check the software, the extraction of the designed synchrotron is simulated. 20 kilo particles ramp 0.2 million turns. Fig. 3 gives the distribution of the extraction beam at the EES, and the loss rate is about 7%. The extraction beam is referred to as the rayleigh distribution when only the resonance sextupole, but it change uniformity as the effect of the sextuple and the RFK shown in Fig. 4. The parameters of the EES and EMS are shown in Table 2. The efficiency of the extraction is over 90% in the simulation.

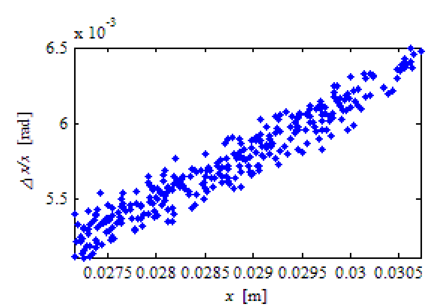

Figure 3: The extraction beam at the EES.

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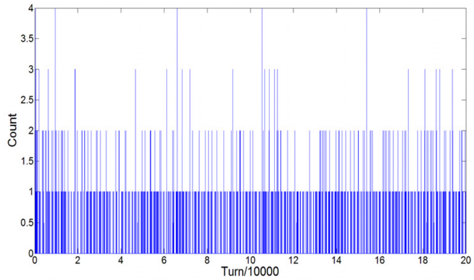

Figure 4: The extracted efficiency with the sextupole and the RFK.

Table 2: The Main Parameters of EES and EMS

Parameters	Units	Values
Length(EES)	m	0.5
Gap(EES)	mm	10
Kick(EES)	mrad	5
Electric filed(EES)	kV/mm	0.3
Length(EMS)	m	0.8
Gap(EMS)	mm	20
Thickness(EMS)	mm	15
Kick(EMS)	rad	0.1
Magnet filed(EMS)	T	0.675

SUMMARY

The simulated software of the injection and extraction design for rapid cycling synchrotron based on matlab/AT is developed, which treats with injection and extraction design particularly, and is the wide software for this entire type synchrotron. The program is check by the designed synchrotron, and it shows it is usable. The software will be improved so as to a wholesome software.

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