CPC(HEP & NP), 2009, **33**(Suppl.Ⅱ): 30—32 Chinese Physics C Vol. 33, Suppl.Ⅱ, Jun., 2009

Design of slow extraction system for therapy synchrotron*

ZHANG Jin-Quan(张金泉)1) SONG Ming-Tao(宋明涛) WEI Bao-Wen(魏宝文)

(Institute of Modern Physics, CAS, Lanzhou 730000, China)

Abstract Based on the optimized design of the lattice for therapy synchrotron and considering the requirement of radiation therapy, the third order resonant extraction is adopted. Using the momentum-amplitude selection method, the extraction system is designed and optimized. An extraction efficiency of more than 97% and a momentum spread less than 0.11% are obtained.

Key words slow extraction, third order resonance, synchrotron

PACS 29.27.Ac, 29.20.dk, 87.56.bd

1 Introduction

The technology of the third order resonant extraction was formed and developed in the experiment for nuclear physics and particle physics. In recent years, according to the medical requirements of tumour therapy, slow extraction has also been used extensively in proton and heavy ion therapy synchrotrons owing to their merit of extending the extraction time more than one second, for example, the medical synchrotrons operated in Germany and Japan, and those in design or construction phase. The application of a third-integer resonant extraction extends the beam spill time sufficiently to scan the beam over the irradiation field, to perform on-line dosimetry at patients and to switch the beam on and off according to the dose requirement.

To meet the requirements of compactness, low cost and high reliability, the lattice of the therapy synchrotron[1] is iteratively optimized. Taking a stripping injection scheme, the synchrotron now boasts of a cyclotron injector. The main parameters of the lattion are listed in Table 1. Based on this lattice and the injection system, the slow extraction system is designed. The duration of beam extraction can be extended up to 10 s.

Table 1. Main parameters of the lattice.

particles	p and C
extraction energy	P: 60—250
P/MeV, C/(MeV/u)	C: 120—430
circumference/m	63.5
super periodicity	2
injection energy/(MeV/u)	7
tune Q_x/Q_y	1.67/1.72
max. β_x/β_y/m	10.6/20.1
natural chromaticity	H/−0.974
	V/−2.989
max. dispersion D_x/m	5.90

2 Design of the slow extraction

Generally speaking, the particle trajectories in the linear approximation are circular in the normalized phase space. During the extraction process, the horizontal work point is shifted to approach the third order resonance line. When the third order resonance is excited by the resonance sextuple, the phase space is split in to stable and unstable regions by the separatrices. The particles are driven into the resonance region continuously and extracted by the electrostatic septum and the magnetic septum[2, 3]. In the slow extraction system, some conditions are required:

Received 6 January 2009

* Supported by Key Equipment R & D Fund of CAS (0713040YZ0)

1) E-mail: jinquan_zhang@impcas.ac.cn

1) The clinic synchrotron works usually below the transition energy. For the purpose of the stability of the transverse motion, the chromaticity of the machine must be negative.

2) The extracted beam satisfies the Hardt condition, all separatrices of different momentum should be superimposed at the electrostatic septum.

3) The phase advance from the resonance sextupole to the extraction electrostatic septum and the phase advance from the electrostatic septum to the magnetic extraction septum must meet certain requirements.

4) It is better for the resonance sextupole and chromaticity sextupoles to act orthogonally.

5) There should be sufficient room between the extracted beam and the circulating beam at the extraction magnetic septum.

Considering these pre-conditions, the slow extraction system is designed with the least elements. It consists of one resonance sextuple, four chromaticity sextupoles, one electrostatic septum and one magnetic septum (Fig. 1).

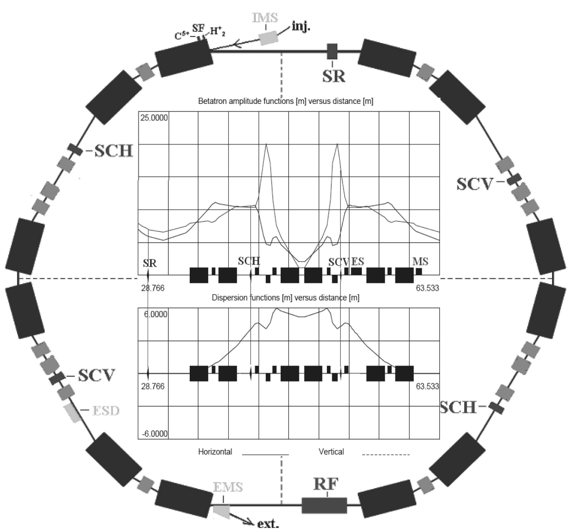

Fig. 1. Layout of the extraction elements. ESD: electrostatic septum deflector. MS: extraction magnetic septum. SR: resonance sextupole. SCH: horizontal chromaticity sextupole. SCV: vertical chromaticity sextupole.

The sextupole for resonance excitation is set in a dispersion free section of the ring, making no contribution to chromaticity. The other two sextupole families are arranged oppositely in four dispersive sections for chromaticity correction, contributing nothing to the resonance excitation owing to the two-fold symmetry of the ring lattice. To fulfill the Hardt condition, the electrostatic septum deflector (ESD) is located in a section, where the dispersion is decreasing. The extraction magnetic septum (MS) is located in the other dispersion free section. Table 2 shows the horizontal twiss parameters and phase advance at each extraction element. The parameters of the extraction elements are listed in Table 3.

Table 2. Horizontal twiss parameters and phase advance of the extraction elements.

	SR	SCH	SCV	ESD	MS
β_x/m	6.04	10.40	6.03	10.37	6.66
α_x	0.38	−0.10	−2.41	0.10	0.51
D_x/m	0.0	3.97	4.27	3.78	0.0
DP_x	0.0	0.97	0.59	−0.97	0.0
μ/rad	0.0	1.2	3.86	9.28	10.0

Table 3. Parameters of the extraction elements.

	effective length	field intensity
SR	0.3 m	63.7 T/m^{-2}
SCH	0.2 m	19.7 T/m^{-2}
SCV	0.2 m	−3.58 T/m^{-2}
ESD	0.8 m	76 kV/cm
MS	0.65 m	0.51 T (max.)

Based on the layout of the extraction system and the emittance of the injected beam after rf trapping, the simulation and optimization are carried out. Fig. 2 shows the separatrices of extraction at the electrostatic septum. The extraction efficiency of 97% is foreseen. Fig. 3 describes the last 3 turns of extracted carbon beam. There are two orbits shown, one for the zero-amplitude particles exactly on resonance and the other one is for the particles with maximum amplitude at the extraction energy $E = 120$ MeV/u. The momentum spread of the extracted beam is $\Delta p/p = 0.11\%$.

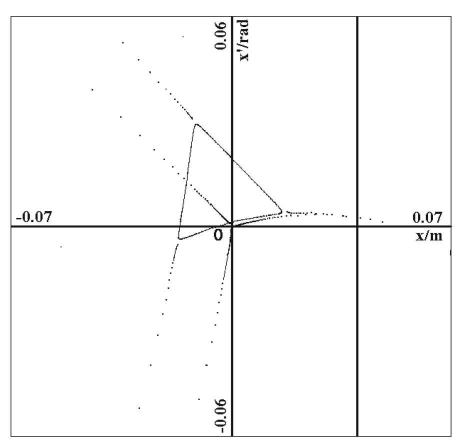

Fig. 2. Phase space and separatrices ($\Delta p/p = 0$, $\Delta p/p = -0.11\%$).

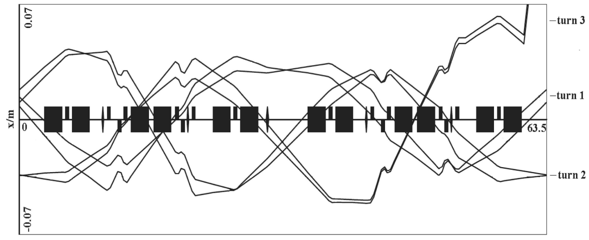

Fig. 3. Last 3 turns of the separatrices for extracted carbon beam (E = 120 MeV/u).

3 Summary

The lattice of the synchrotron is designed and optimized for the tumour therapy facility. Based on the optimization lattice and the requirements of the third order resonant extraction, an extraction system is designed followed by ion orbit simulation. The method of momentum-amplitude is adopted in the extraction system. The extraction efficiency of 97% and the momentum spread less than 0.11% for carbon are foreseen. Compared with the extraction system of the former lattice[1], optimization is made for the whole extraction system. The only cost to be paid is that the maximum voltage of electrostatic septum is raised from about 60 kV/cm to 76 kV/cm, which is trivial for state-of-the-art technology.

References

1 ZHANG Jin-Quan et al. HEP & NP, 2007, **31**(12): 1122 (in Chinese)

2 Hiramoto K, Nishi M. NIM A, 1992, **322**: 154—160

3 DING Xiao-Ping et al. HEP & NP, 2001, **25**(2): 167—173 (in Chinese)