SIZE REDUCED DESIGN OF MEDICAL PROTON SYNCHROTRON

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Abstract

Several dedicated proton synchrotrons for the medical treatment have been designed in the world. Special emphasis shall be paid on the accelerator size alongside of the operability and maintenability, because they are installed at the hospital. In order to make the synchrotron small it is necessary to reduce the super periodicity. Former design is modified to investigate the feasibility from the viewpoint of the lattice design.

Introduction

To reduce the size of the synchrotron maintaining the required maximum proton energy, it will be required to develop the powerful beam handling devices to manipulate the beam at the limited space. In the former report the medical synchrotron was designed to deliver both the fast and slow extracted proton beam with the existing technologies to the patient treatment practice[1]. Although the number of the long straight sections is 6, all of them are occupied with many devices to monitor, to inject, to extract, to accelerate the beam, and to correct the orbit. Injection and extraction require the additional magnets to make the orbit bump. The kicker magnets for the fast extraction and the septa for the slow extraction occupy almost a long straight section individually. If these requirements are ignored except for the minimum installation requirements such as rf cavity, injection device and extraction device either for fast or slow extraction, big modifications of the lattice design will be possible retaining only three long straight sections. In the followings several lattice modifications are compared with the previous conservative design and the lattice of Loma Linda University Medical Center (LLUMC)[2].

Medical synchrotron design

According to an agreements of the PTCOG (Proton Therapy Co-Operative Group), the maximum proton energy is 250 MeV and the beam intensity is 3.5×10^{12} protons at an isocenter for 1 or 2 minutes which corresponds to about 4×10^{10}/sec. In the design of the medical synchrotron, these parameters are not only the present design goal but also it is important to provide stable proton beam with them. Proposed or approved synchrotrons for the medical use are listed in Table 1[1-5]. Parameters of PARMS follow the design of last year.

Table 1 Proposed and accepted proton synchrotron for medical use.

	HCL[3]	LLUMC[2]	ANL[4]	PARMS[1]
Max.Energy(MeV)	250	250	250	230
Repetition(Hz)	5	0.5	1	0.5-1
Intensity(nA)	20	10	3	10-20
Slow Beam Spill(s)	0.04	1	0.4	0.5
Av. Radius(m)	2.2	3.0	6.75	5.6
Bend.Radius(m)	2.0	1.6	4.3	1.55
Focusing	weak	edge	strong	strong+edge
Edge Angle(deg.)	-	18.8	-	30
Tune(H/V)	0.8/0.8	0.6/1.32	2.44/2.17	1.8/1.85
Harmonics	10	1	1	1
RF Freq.(MHz)	5-130	0.9-9.2	0.4-4.3	0.9-5.1
Injector	RFQ or DC acc.	RFQ	Pelletron	Tandem
Inj.Energy(MeV)	0.3	1.7	1.5	5
Inj.Turn No.	1	1	1	20

Modified lattice structure

So far the proton synchrotron design for PARMS is based on the strong focusing structure (DOFB structure with 6 superperiods) to adjust both horizontal and vertical tunes easily. The plane view is given in Fig.1 where several devices for the beam handling are also given. Its average diameter is as large as 11.2 m. It is about twice as large as that of LLUMC which is 6 m. If the length of the long straight section is reduced to 1.5 m from original 3 m according to the design of LLUMC, the average diameter becomes 8.4 m. The original drift length of the long straight section was determined from an edge angle of the bending magnet. Since the ring is composed of 6 bending magnets, each having a bending angle of 60 deg., the angle of 30 deg. affords an easy fabrication. Reduction in the drift length requires modification of the edge angle and also of the design of the beam handling devices so as to place in the shorter spaces.

An extremity of the original design will be an omission of the long straight sections remaining only 3 sections which are for injection, acceleration and extraction. Thus, the superperiodicity is reduced to 3. A lattice feasibility of the reduced symmetry

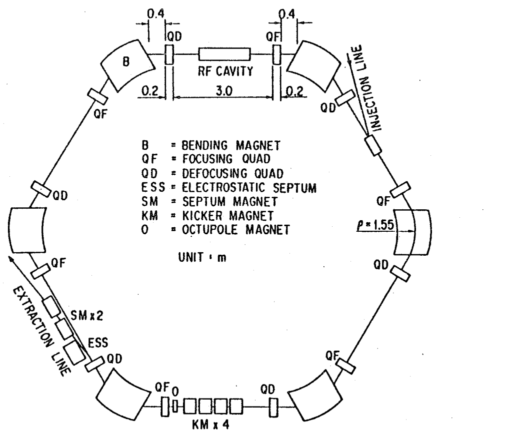

Fig.1 Original lattice design with 6 super periods.

should be discussed from the point of beam dynamics, but here more attention is paid to the lattice structures. Some modifications are given in Fig.2. If chosing the proper edge angle and drift length, the average machine radius is 2.7 to 3.6 m.

As the FOFBDB cell is one of the modifications of Fig.1, the rest is the drastic ones, that is, 2 bending magnets are joined to eliminate the short straight sections between bending magnets. To retain the tunabilities in both planes, the defocusing quadrupole magnets are places in upper two structures, while in FOBO (or OFOB) the vertical focusing is given only by the edge angle. In the latter case the vertical tune is disturbed little by the horizontal tune variation. Comparisons of betatron and dispersion functions are given in Fig.3.

The strong focusing of both planes is applied to the original DOFB structure, because the transition energy depends on the horizontal tune (Qx). If Qx is between 1.0 and 1.5, the transition appears during acceleration. The situation is same in another modified designs. Therefore Qx is kept less than 1.0 so that the transition is well below the injection energy, while the vertical tune (Qy) is kept larger than 1.0 to avoid the weak focusing in both planes. Dispersion function (η) becomes large compared to the original design and big vertical phase advances are observed in the modified DOFB and OFOB lattice. In FOFBDB cell the dispersion can be kept less than 6.5 m. But both Qx and Qy are affected by the combination of the edge angle and drift length as shown in Fig.4. If the tuning for the slow extraction is considered, the available drift length is around 1 m.

In the modified DOFB cell the maximum dispersion appears in the bending magnet. It depends large on the edge angle and quadrupole strength as given in Fig.5 and Fig.6, respectively. When applying the slow extraction, the dispersion varies large during extraction and it will become difficult to obtain an uniform spill.

The OFOB structure is the farther modification of above DOFB lattice whose Qy shows the small

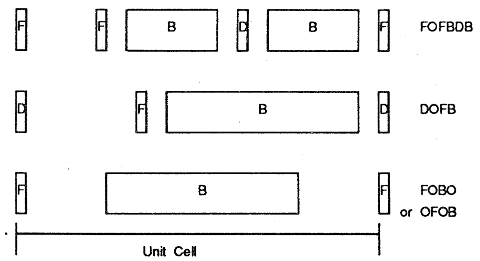

Fig.2 Three lattice structures, unit cell length is not same.

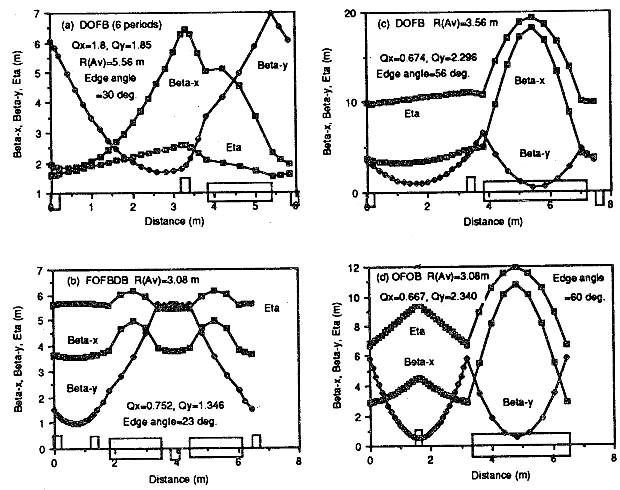

Fig.3 Betatron and dispersion functions for each cell, (a) original DOFB with 6 superperiods, (b) (c) and (d) modified cell FOFBDB, DOFB and OFOB with 3 superperiods, respectively.

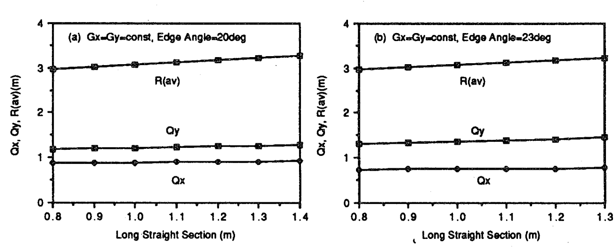

Fig.4 Tune variations by the combination of the edge angle and drift length.

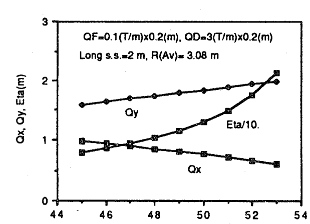

Fig.5 Edge angle dependence of tunes and the maximum dispersion.

dependence on Qx (or strength of the focusing quadrupole). If chosing suitable Qy for the extraction, Qx can be adjusted to the resonance without regarding to Qy. In Fig.7 and Fig.8 the tune and dispersion dependence on the focusing strength and edge angle are given respectively.

Preliminary simulation of the slow extraction

To deliver the beam to the treatment room, two extraction modes, fast and slow extraction, are desirable. Present design is limited to either mode to make the ring as small as possible. The third case of OFOB described above gives the promising results and its extension to 4 superperiods will be studied next to accommodate both modes.

From the tunability of Qx it is desirable to use the third integral resonance of 2/3 for the slow extraction. The beam separatrix observed under the influence of the sextupole field at an entrance of the electrostatic septum is given in Fig.9 where the right side of extraction orbit in the phase space is used.

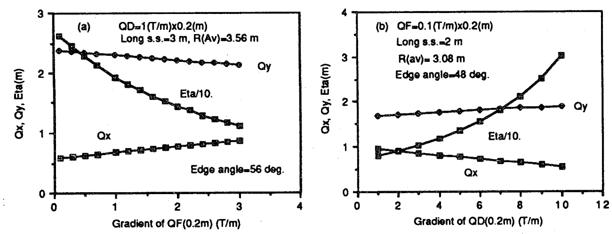

Fig.6 Quadrupole strength dependence of tunes and the maximum dispersion. When varying (a) focusing (b) defocusing quadrupole strength.

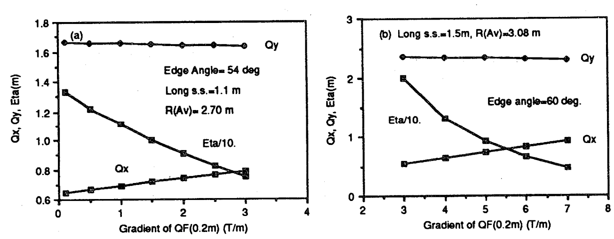

Fig.7 Focusing strength dependence of the tunes and the maximum dispersion for the edge angle of (a) 54 and (b) 60 deg.

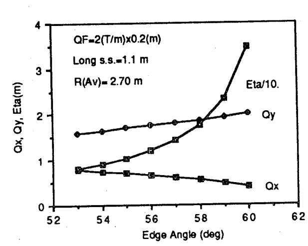

Fig.8 Edge angle dependence of tunes and the maximum dispersion.

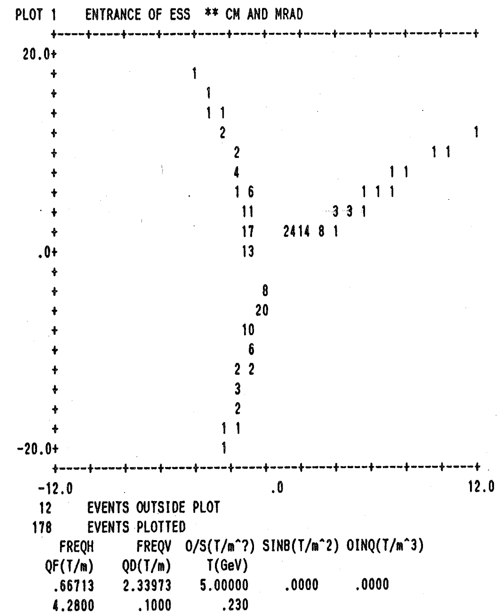

Fig.9 Separatrix of the slow extraction at the resonance of Qx=2/3.

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