Lattice Design of a Medical Synchrotron

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1. Introduction

The proton therapy is a fast-growing method for a cancer treatment because it can concentrate proton beams into cancer cells and minimize damage on normal cells by using a Bragg peak. The design study on the synchrotron for the proton therapy is in progress as an R&D for using PEFP (proton engineering frontier project) accelerator technology. The injection energy is 3 MeV which is provided by an RFQ (radio frequency quadrupole). The maximum extraction energy is 250 MeV for treatment of deepest tumors in human body. It includes a slow extraction method through the third-order resonance and a single turn extraction option. This brief report summarized the lattice design of the synchrotron.

2. Medical Synchrotron

The facility for the proton therapy consists of a 250-MeV proton synchrotron, five treatment rooms including three rooms for gantries, one for fixed beam and one for experiment. The layout is given in Figure 1.

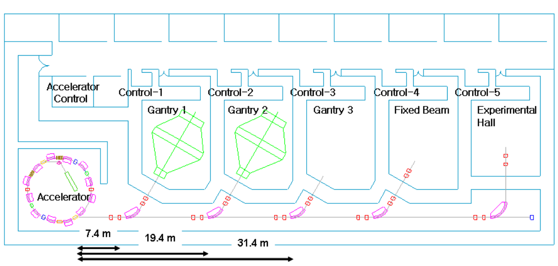

Fig. 1. Layout of a proton therapy facility including a synchrotron and five treatment rooms.

2.1 Proton Synchrotron

The medical proton accelerator consists of a 3-MeV RFQ and a 250-MeV synchrotron. The maximum extraction energy of 250 MeV can cover the deepest tumors in a human body. The lattice consists of six FODO cells with 12 combined function sector magnets as shown in Figure 2. It includes an injection septum magnet, an extraction septum magnet and a kicker, two RF cavities for acceleration, two quadrupole magnet pairs for tune adjustment, and two sextupole magnet pairs for slow extraction. The linear accelerator will be installed in the ring.

Tunes

We choose 1.75 and 1.25 for the tune values in the horizontal and vertical directions. The fractional tune of a quarter makes possible to paint proton beams four times in the transverse phase space. The horizontal tune is approximately equal to the transition gamma in a FODO lattice. That is why we choose horizontal tune as 1.75 instead of 1.25 which increases the transition energy to 603 MeV from 243 MeV. Hence we can avoid the transition crossing even in the maximum extraction energy.

Magnet specification

The quadrupole component in a combined function magnet can be obtained by giving a transverse slop to the pole face of the bending magnets. In this study, we choose the bending radius of 2.101 m. Then we varied the length difference between the focusing and defocusing magnets in order to adjust horizontal and vertical tunes. The result is given in Figure 3.

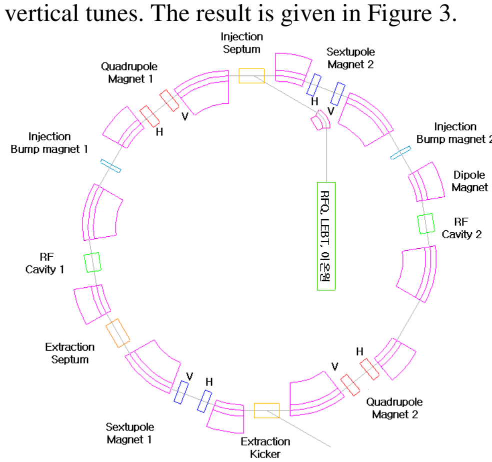

Fig. 2. Layout of a proton therapy facility including an accelerator and five treatment rooms.

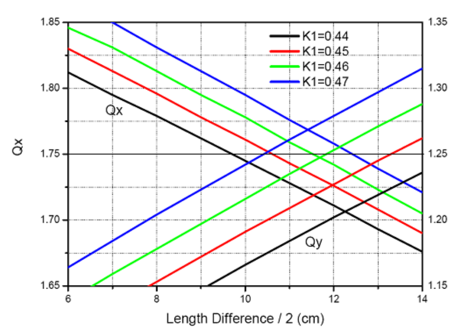

Fig. 3. Horizontal tune Qx and vertical tune Qy depending on the length difference between horizontally focusing and defocusing magnets.

We found that if the half of length difference is 0.117 m and the quadrupole component, K_1 which is given by $(\partial B_y / \partial x)/(B\rho)$, is 0.46 /m^2, tune values are very close to the design values. In this case the bending angles of focusing and defocusing bending magnets are 26.8° and 33.2°, respectively. The quadrupole component corresponds to the height difference of 11% in the inner and outer pole gap.

Lattice Design

We studied the lattice functions by using MAD8 code [1]. In the first step, we calculated the lattice functions without tune adjustment. The result is given in Figure 4. The tunes values are 1.749 and 1.250 in the horizontal and vertical directions, respectively. As indicated in Figure 3, they are very close to the designed tune values. The maximum values of the beta function are 5.7 m and 6.7 m, respectively. The maximum value of the dispersion function is about 2.1 m. In order to test the tune adjustment, we used two quadrupole pairs to make them the exact design values, 1.750 and 1.250. The result is given in Figure 5. We found that the adjustment works very well with very small disturbance to the lattice functions.

The main parameters of the medical synchrotron are determined by the lattice study and summarized in Table 1.

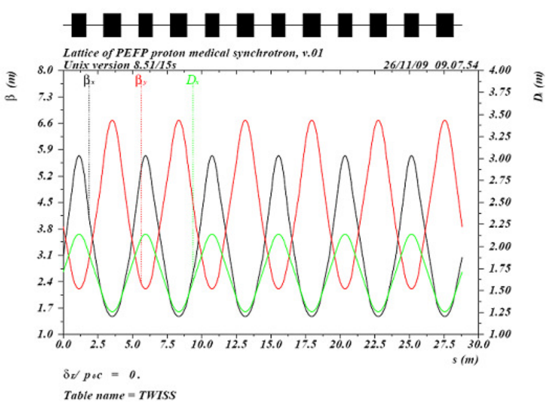

Fig. 4. Lattice functions before tune adjustment: Maximum values of beta function in the horizontal and vertical directions and dispersion function are 5.7 m, 6.7 m, and 2.1 m, respectively.

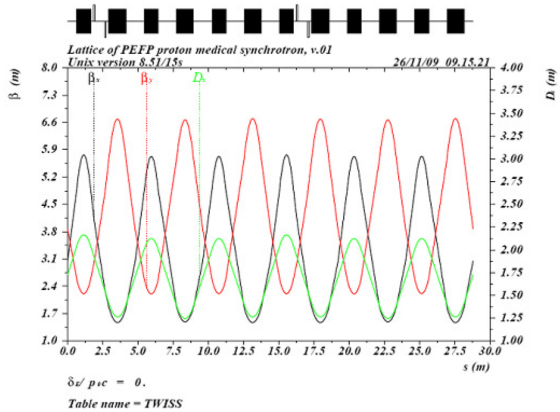

Fig. 5. Lattice function after tune adjustment: Lattice functions are very similar to the case before adjustment.

Table 1: Parameters of the medical synchrotron.

Parameters	Values
Particles	Proton
Injection Energy	3 MeV
Extraction Energy	70 ~ 250 MeV
Circumference	28.8 m
Lattice	FODO (12 combined function)
Admittance	10 π mm-mrad
Tune	1.75 (horizontal) / 1.25 (vertical)
Extraction	Slow : sextupole resonance Fast: single turn
RF frequency	0.83 ~ 6.89 MHz
Repetition Rates	0.5 ~ 60 Hz

3. Conclusions

We studied the lattice design for a proton medical synchrotron. The lattice consists of the six FODO cells with 12 combined function dipole magnets. We obtained the reasonable values of the lattice functions by using MAD8. From the lattice study, we determined the main parameters of the synchrotron. In near future we will study the beam dynamics issues including injection, acceleration, and extraction.

This work was supported by Ministry of Education, Science and Technology of the Korean Government.

REFERENCES

[1] Hans Grote and F. Christoph Iselin, "The MAD Program: Version 8.19 User's Reference Manual", CERN/SL/90-13 (AP) (Rev. 5), 1996.