LATTICE DESIGN OF JHF SYNCHROTRONS

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Abstract

Several kinds of lattice structures have been designed and examined for the JHF synchrotorons. The high(or imaginary) γ_t lattice has been used as the 50 GeV main ring to avoid beam loss at the transition crossing. We have studied the feasibility to apply this scheme to the 3 GeV booster as a flexible momentum compaction lattice. These rings have wide tunablilities and flexibilities of the linear optics. The possibility of increasing the extraction energy of the booster to 6 GeV has been investigated.

1 INTRODUCTION

The Japan Hadron Facility(JHF) consists of the 50 GeV main ring, the 3 GeV booster and the 200 MeV linac. Because the beam intensity of the main ring is extremely high (2×10^{14}ppp), a low beam loss is required. In order to avoid beam loss at the transition crossing, we have employed the imaginary γ_t lattice which does not have a transition energy.

The 3 GeV booster is a rapid cycle synchrotron of which repetition rate is 25 Hz. It will be constructed in the existing KEK-PS main ring tunnel, which gives geometrical constraints. The detailed description of the "reference design" of the 3 GeV booster which contests of 28 normal FODO cells is found in [1]. Here we present the "alternative design" whose basic concept is the same as that of the main ring lattice, which has a flexible momentum compaction factor.

As one of the upgrade plans, the possibility of 6 GeV booster is also described. This is for the case if the booster should be able to accelerate the beam up to for instance 6 GeV in order to increase the beam power.

All of these machines should be able to handle very high beam intensity. In order to avoid a space charge induced resonance, a local phase advance should be away from 90 degree[2]. The optics code SAD is utilized to optimize the parameters and to do the particle tracking[3].

2 JHF 50 GEV MAIN RING

The momentum compaction factor α is described as

$$\alpha \quad = \quad \frac{1}{\gamma_t^2} = \frac{1}{C}\oint_C \frac{\eta(s)}{\rho(s)} ds \qquad (1)$$

$$= \quad \frac{\nu_x^3}{R}\sum_{n=-\infty}^{+\infty}\frac{|a_n|^2}{\nu_x^2 - n^2}, \qquad (2)$$

where γ_t is the transition gamma, $\eta(s)$ is the dispersion function, $\rho(s)$ is the local radius of curvature at the position s, C is the circumference of the ring, R is the average radius of the ring and ν_x is the horizontal tune. The factor a_n is given by

$$a_n = \frac{1}{2\pi}\int_0^{2\pi}\frac{\beta_x(\phi)^{3/2}}{\rho(\phi)}\exp(-in\phi)d\phi, \qquad (3)$$

where $\phi = \frac{1}{\nu_x}\int\frac{1}{\beta_x(s)}ds$. In an ordinary FODO lattice, the $n = 0$ term (DC component) is dominant. Suppose the arc sections consist of k periodic structures (referred as "modules"). If the horizontal tune is chosen so that the denominator in the equation 2 is negative and its absolute value is quite small and a_k has the finite value somehow, the $n = k$ term cancels the DC component. To make a_k finite, β or ρ should be modulated properly [4]. We prefer ρ modulation to β modulation because the β modulation causes large beam size. Therefore, one obtain small α (high γ_t) or negative α(imaginary γ_t) lattice.

We construct the module using 3 FODO cells which have one missing bend cell in order to make ρ modulation as shown in Figure 1. The module has four families

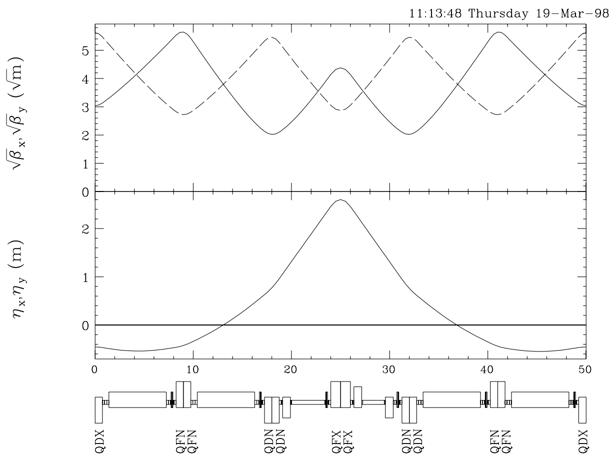

Figure 1: Beam optics functions of the module in arc section of the JHF 50 GeV main ring. $\beta_x^{1/2}$:solid line, $\beta_y^{1/2}$:dashed line.

of quadrupoles(two focusing and two defocusing) as tuning knobs. The main ring has the four-fold symmetry. The

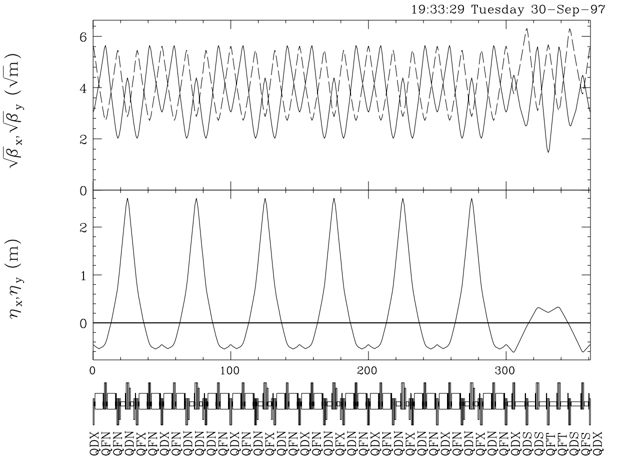

Figure 2: Beam optics functions of one superperiod of the JHF 50 GeV main ring.

90-degree arc consists of 6 modules. The long straight section has 4 FODO cells of which horizontal and vertical phase advances are 2π and π respectively. Thus, the beam optics in the arc is not disturbed by the insertion. The lattice parameters of the main ring are shown in Table 1. The maximum values of both horizontal and vertical beta

Circumference	1445m
superperiodicity	4
(ν_x, ν_y)	(21.8,15.4)
(ξ_x, ξ_y)	(-27, -21)
Momentum compaction factor	-0.001
γ_t	$32i$
Max. field of B magnets	1.9T
Max field grad. of Q magnets	20T/m

Table 1: Lattice parameters of the 50 GeV main ring

functions when the momentum compaction factor is varied are shown in Figure 3. The momentum compaction factor is adjustable from -0.0023 to 0.001 without significant increase of the beta functions. Also we examined the maximum dispersion when α is varied as shown in Figure 4.

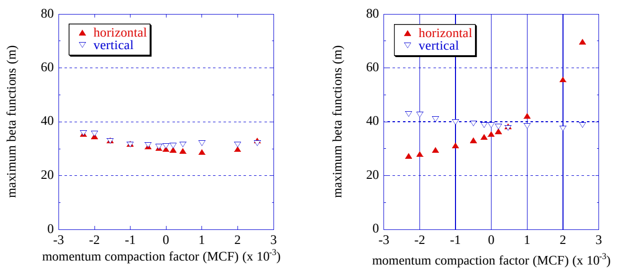

Figure 3: Maximum beta in the arc(left) and straight section(right) vs momentum compaction factor.

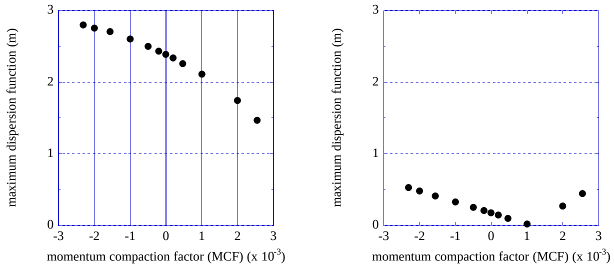

Figure 4: Maximum dispersion in the arc(left) and straight section(right) vs momentum compaction factor.

Therefore, the maximum beam size does not change very much if we vary the momentum compaction factor.

3 JHF 3 GEV BOOSTER

The lattice design of the 3 GeV booster has been carried out under strict geometrical constraints that the ring should be fitted into the KEK-PS main ring tunnel. The transition energy is higher than the extraction energy of 3 GeV even in the reference design which consists of ordinary 28 FODO cells. However, in terms of longitudinal phase space matching between the booster and the main ring the flexibility of the phase slippage factor $\eta = \alpha - \frac{1}{\gamma^2}$ is helpful. Thus, the feasibility of flexible momentum compaction (FMC) lattice is investigated. The idea which is used for the main ring can realize the FMC lattice. One module is made of 2 normal FODO cells at this time. One superperiod shown in Figure 5 consists of three modules as an arc and one FODO cell as a straight section. The superperiodicity of the ring is 4. The main parameters of the 3 GeV booster are shown in Table 2. Using three knobs which are two focusing and one defocusing quadrupole magnets, the momentum compaction factor can be adjusted from almost zero to 0.009. But the nominal value is chosen to 0.006 in order to eliminate the second order effects, which come from the $(\Delta p/p)^2$. Also flexibility of the tune is examined.

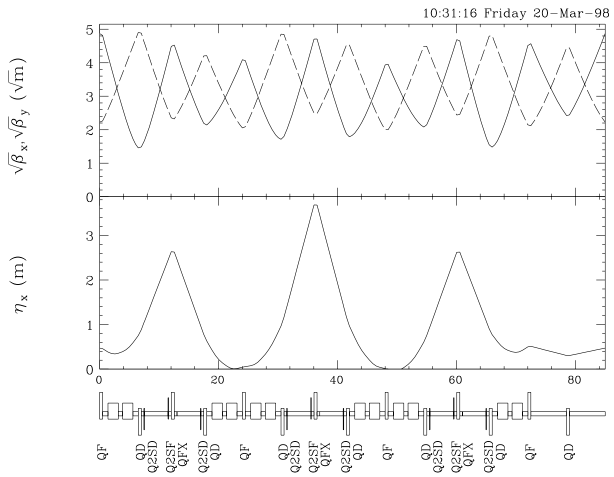

Figure 5: FMC lattice for the 3 GeV booster.

Circumference	341.2m
superperiodicity	4
(ν_x, ν_y)	(7.8,5.7)
(ξ_x, ξ_y)	(-10.3, -8.2)
Momentum compaction factor	0.006
γ_t	12.9
Max. field of B magnets	0.95T
Max. field grad. of Q magnets	9T/m

Table 2: Lattice parameters of the 3 GeV booster(FMC lattice).

We can vary the tunes by about 2 in both horizontal and vertical directions keeping the stable linear optics.

Due to the geometrical reason, the injection point should be located in one of the missing bend straight sections of which length is 5.05m. In order to reduce the space charge effects the phase space painting is done during the beam injection. Eight bump magnets used for horizontal phase space painting can be installed in one missing bend straight section.

The fast beam extraction has been examined as well. Two consecutive 6 m long straight sections are available for kicker magnets and septum magnets.

If the booster extraction energy goes up to 6 GeV with the same beam intensity and the same repetition rate the beam power becomes higher by factor of 2. The required rf voltage becomes twice as much as that for the 3 GeV ring. But the recent development of the rf cavities which provide the field gradient of 50kV/m[5] realizes this upgrading path. We need totally 15m space for them. One can imagine that the injection energy also increases to 400 MeV. The upgraded lattice has been designed considering followings.

- The transition gamma should be sufficiently higher than 7.4.
- The length of the straight sections are long enough for the 400 MeV injection and the 6 GeV extraction.
- The field strength and gradient of the magnets should be reasonably low.
- The ring should be fitted to the tunnel.

We have modified the FMC lattice of the 3 GeV booster. The missing bend straight sections are filled with the bending magnets except for the center module of the arc. Figure 6 shows the modified FMC lattice for 6 GeV booster. The second half cell from the both ends are half filed to get better fitting to the tunnel. The length of QMs is extended from 0.5m to 1m. That is why the field gradient is rather small. Number of knobs is still four. The sufficiently high transition gamma of 12.9($\alpha = 0.006$) is obtained. The horizontal and vertical tunes can be varied 6.7 - 7.5 and 5.2 - 6.4 respectively. The field strength of BMs are 1.3 T and the field gradient of QMs are less than 8 T/m. The length of the drift space in the straight section is 7.5m. We can

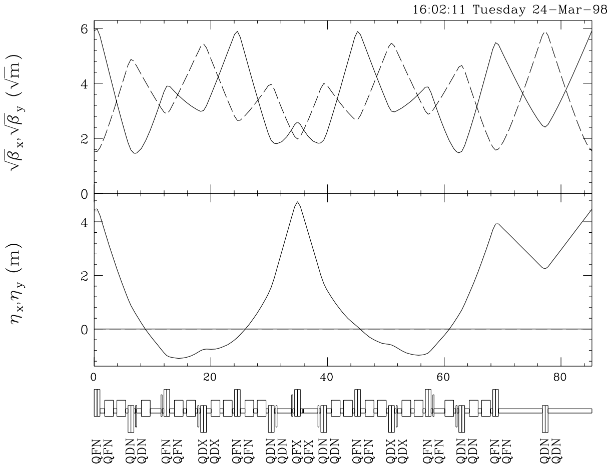

Figure 6: FMC lattice for the 6 GeV booster.

use two consecutive drift space for the injection and the extraction of the beam. The tunnel fitting of 6 GeV lattice becomes better because the BMs are distributed uniformly compared with the 3 GeV FMC ring. The lattice parameters of the 6 GeV booster are shown in Table 3.

Circumference	341.2m
superperiodicity	4
(ν_x, ν_y)	(6.8,5.8)
(ξ_x, ξ_y)	(-9.8, -5.4)
Momentum compaction factor	0.006
γ_t	12.9
Max. field of Bmagnets	1.3T
Max. field grad. ofQmagnets	8T/m

Table 3: Lattice parameters of the 6 GeV booster.

4 CONCLUSIONS

The 50 GeV main ring has been designed using FMC lattice. It has the imaginary transition gamma of $32i$. The momentum compaction factor can be adjusted flexibly. Using similar lattice structure, the 3 GeV booster has been also designed so that the phase slippage factor can be varied. We can vary the momentum compaction factor from ~ 0 to 0.009. The 6 GeV booster as an upgrade option has been designed. It has the sufficiently high transition gamma of 12.9.

5 REFERENCES

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