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LATTICE DESIGN OF JHP CIRCULAR ACCELERATORS

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Abstract

The preliminary lattice design for the 3 GeV booster and the 50 GeV main ring in the JHP synchrotron complex has been done. The 3 GeV booster accelerates protons from 200 MeV to 3 GeV with the repetition rate 25 Hz, and injects them to the 50 GeV main ring. The 50 GeV synchrotron has no transition energy because of the imaginary-γ_t optics.

1 Introduction

The JHP accelerator complex mainly consists of the injector linac, the 3 GeV booster and the 50 GeV main ring [1]. The 3 GeV booster is a rapid cycle synchrotron with the separated function magnets. Each magnet is excited by an independent pulse power supply which is linked each other by multi network system [2]. Therefore we can use regular FODO lattice, and vary the horizontal tune and vertical tune independently.

The main ring has a novel lattice structure [3]. In this lattice, we can choose the value of the transition γ as we like. This value in the 50 GeV main ring is an imaginary number. In this report we represent the lattice design of the 3 GeV booster and the 50 GeV main ring. The optics code SAD (Strategic Accelerator Design) is utilized to optimize the parameters and to do the particle tracking.

2 3 GeV Booster

The 3 GeV ring is operated in a very high repetition rate 25 Hz which needs high rf acceleration voltage of 400 kV [4]. Thus the ring needs to have enough drift space for the rf cavities. In this ring, 24 straight sections each of which length is 6.57 m gives enough space for the rf cavities and the injection and extraction systems. Magnetic field of the bending magnets is rather weak (B=0.95 T) so that the rapid cycle operation is possible. The requirement that the ring is fitted into the KEK-PS tunnel makes the superperiodicity of the ring 4. The overview of the ring is shown in fig 1, and the betatron functions are shown in fig 2.

The nominal tune are selected as $(\nu_x, \nu_y) = (7.3, 4.3)$. The γ_t is 7.13 which is substantially larger than γ=4.20 at the top energy. Table 2 shows the lattice parameters of the 3 GeV ring.

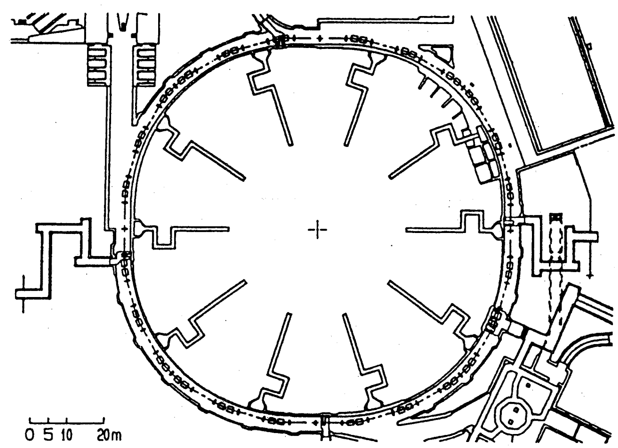

Figure 1: Layout of the 3 GeV booster

Table 1: Parameters of the 3 GeV Booster

circumference	339.36m
superperiodicity	4
structure	FODO
number of cells	24
maximum γ	4.20
γ_t	7.1
nominal tune	(7.3, 4.3)
natural chromaticity	-8.4, -6.3

3 50 GeV Main Ring

Protons are accelerated from 3 GeV to 50 GeV in the main ring. At the top energy, γ is 54.3. In a conventional way of designing a lattice by using regular FODO cell, γ_t approximately equals to the horizontal tune ν_x. It is difficult to avoid transition energy in the regular FODO lattice, because ν_x is about 20 - 30 in a machine of this scale.

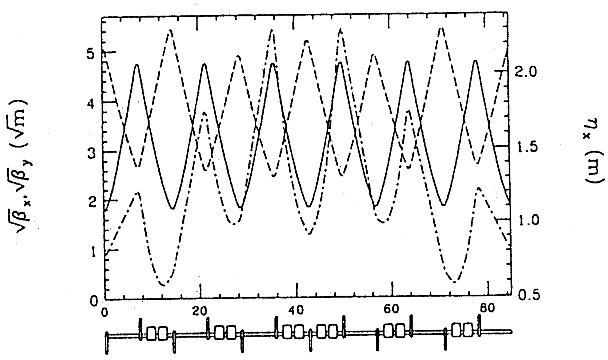

Figure 2: Beam optics functions of the JHP 3 GeV booster. β_x:solid line, β_y:dashed line, η_x:dash-dotted line.

Therefore, a imaginary-γ_t lattice is employed to eliminate the transition energy. The momentum compaction factor is given by

$$\alpha = \frac{1}{\gamma_t^2} = \frac{1}{C}\oint \frac{\eta(s)}{\rho(s)} ds, \tag{1}$$

where $\eta(s)$ is the dispersion function, $\rho(s)$ is the radius at the orbit position of s in the ring and C is the circumference of the ring. A high γ_t *i.e.* a low α can be obtained when the dispersion at the bending magnet are small.

In order to get this optics, we use a unit cell as shown in Fig 3. This unit cell consists of three DOFO normal cells;

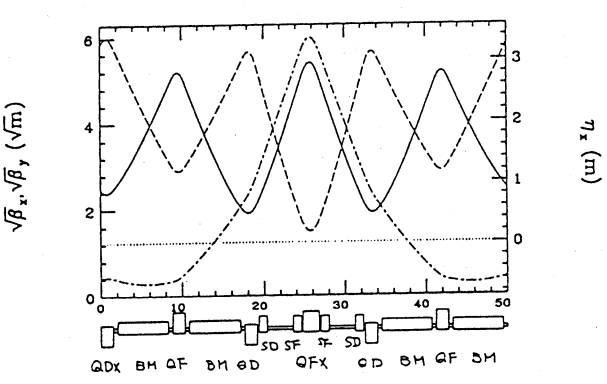

Figure 3: Beam optics functions of the imaginary-γ_t lattice for the 50 GeV main ring.

the central cell has no bending magnets. In this configuration, the dispersion at the bending magnets are small. If the integration of η/ρ is negative, γ_t becomes imaginary. Hence the beam never encounters transition in this ring. The benefit of using this lattice is that one can obtain imaginary-γ_t keeping the optics stable. In the arc of the main ring there are two types of focusing quadrupole magnets QF and QFX, and two types of defocusing quadrupole magnets QD and QDX. The γ_t is optimized so that its absolute value is less than 100 by using these quadrupole magnets.

The circumference of this ring is 1442m which corresponds to the harmonic number h=34. Since we need at least four straight sections, we take superperiodicity of 4. The 90° arc consists of six unit cells mentioned above. A bending angle of each bending magnets is 3.75°. There are four straight sections for the injection and the extraction systems, rf cavities and devices to prepare the polarized beam. We are also investigating the possibility of employing superferric magnets, but here we report the feasibility of the ring using normal conducting magnets. In this scheme, there are strong constraints in designing the lattice: magnetic field of the bending magnets should be less than 1.8 T, and field gradient of the quadrupole magnets should be less than 25 T/m. Therefore length of the bending magnets is 6.2m; relatively strong quadrupole magnets which are in the insertions and the missing bend cells have the length of 2m; the length of the remaining quadrupoles are 1.5m. Length of the arc and the straight sections are 300m and 60.5m respectively. There are four normal cells in each straight section. Each cell has 5.56m drift space in which one can locate the extraction septa and kickers.

Two operating modes are considered with the same the lattice: a dispersion free mode and a high intensity mode. In the dispersion free mode, the dispersion in the straight sections are zero for the polarized beam experiments. But for the high intensity mode, we require minimum β^{max} instead of dispersion free straight sections in order to reduce beam loss.

Since the natural chromaticities are high, the tune spread due to the momentum spread is not negligible; chromaticity correction is essential. The correction is performed by two family sextupole magnets SF and SD. SF's are placed on both side of QFX's, and SD's are placed closed to the QD's in the missing bend straight sections. The necessary field strength of these sextupole magnets to correct the chromaticity as zero are not so high (SF:29T/m^2, SD:59T/m^2) because of the high dispersion in the missing bend sections. With these non-linear elements, we obtain enough dynamic aperture [5]. Table 3 shows the lattice parameters of the 50 GeV main ring in both operation modes.

3.1 Dispersion Free Mode

To provide the dispersion free straight sections, we set the horizontal phase advance in the arc to integer; $\psi_{arc} = 5\times 2\pi$. Vertical tune is changed by using the all quadrupole magnets in the ring. On the other hand, horizontal tune is adjusted by varying the quadrupole magnets only in the straight sections. Therefore, it is feared that the maximum value of the betatron functions become large when the horizontal tune is changed widely. A tunability of this operation mode is tested on several operating points at which the tunes in the arc are $(\nu_x, \nu_y) =$

Table 2: Parameters of the 50 GeV main ring

	dispersion free mode	high intensity mode
circumference	1442m	
superperiodicity	4	
structure	3-cell DOFO	
number of cells	88	
maximum γ	54.3	
γ_t	$27i$	$51i$
nominal tune	(24.25, 20.70)	(22.73, 22.66)
natural chromaticity	-32, -34	-30, -31

$(5.0, 4.8), (5.0, 4.6), (5.0, 4.4), (5.0, 4.2)$.

Fig 4 shows the betatron functions at the operating point $(\nu_x, \nu_y) = (24.25, 20.70)$.

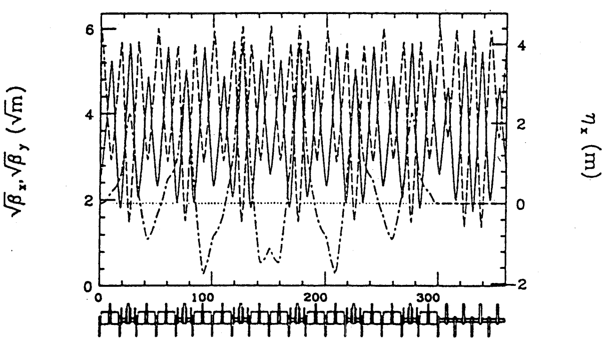

Figure 4: Beam optics functions of the 50 GeV main ring in the dispersion free mode.

With this optics, $\gamma_t = 27i$, $\beta_x^{max} = 32$m and $\beta_y^{max} = 37$m. Even if we change the ν_x and ν_y 23.25 - 24.75 and 20.70 - 23.06 respectively, β's do not exceed 40m. Also the dynamic aperture at each operating point is calculated respectively after the chromaticity correction is performed, and is found to be larger than the acceptance. Thus substantial tunability is obtained with this operation mode.

3.2 High Intensity Mode

To keep the beam loss small in the high intensity mode, the beam size is desired to be small. Then we need to make β as small as possible *i.e.* to make β^{max} flat all over the ring. To do this, we sacrifice the benefit of the dispersion free straight sections; but we still require the imaginary-γ_t. Fig 5 shows the optics of this mode. One can find that no β modulations.

The dispersion function in the straight sections take non zero values; but these values are not so high that the injection and the extraction can be done in these sections. A

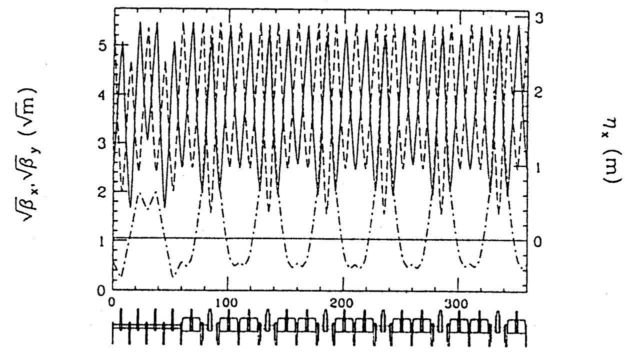

Figure 5: Beam optics functions of the 50 GeV main ring in the high intensity mode.

tunability of this mode is tested as well as the dispersion free mode. We vary the tune ν_x =22 - 24, ν_y =21 - 24, and find that β's are less than 32m. Dynamic aperture is examined in several operating points and found to be larger than the acceptance.

4 Summary

The 3 GeV booster has been designed with regular FODO cell structure. It will be constructed in the KEK-PS tunnel. The 50 GeV main ring has been also designed with the imaginary-γ_t lattice. We investigated feasibility of 50 GeV main ring with imaginary-γ_t optics, and found that it has enough tunability and dynamic aperture.

References

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