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Lattice Design of the Synchrotrons for the KEK/JAERI Joint Project

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Abstract

The baseline design of synchrotrons is fixed for the KEK/JAERI joint project. It is based on the design of the JHF synchrotrons, which were expected to be constructed at KEK Tsukuba site. The main differences from the JHF design are 1) smaller circumference of the 3GeV ring, 2) higher average beam current, 3) higher injection energy of the 3GeV ring, and 4) two-fold symmetry lattice for the 50GeV ring.

1 Introduction

The joint project between KEK and JAERI plans to construct two high intensity synchrotrons at JAERI Tokai site, one is the 3GeV ring with the average current of 333μA and the other is a 50GeV with 15μ A [1]. Both synchrotrons are similar to the ones originally designed for the Japan Hadron Facility (JHF) project.

However, there are some major changes from the original JHF design. First, the circumference and shape of the 3GeV ring is free from a constraint of the existing tunnel, unlike the JHF 3GeV ring which was supposed to fit into the KEK Proton Synchrotron tunnel. Therefore we reduced the circumference; originally it was 340m, now around 300m. The shape has three-fold symmetry with three straight sections for injection and collimation, rf, and extraction, respectively. Secondly, a goal of the output beam power of the 3GeV ring is increased up to 1MW. Accordingly, the average current is now 333μA instead of 200μA. Thirdly, in order to realize higher average current with larger number of particles per pulse, the injection energy of the 3GeV ring is now 400MeV.

As for the 50GeV ring, about 100m long straight section is inserted to ease a slow extraction system.That makes the change of symmetry of the ring from four-fold to two-fold. We will describe the lattice design of two synchrotrons.

2 Emittance and Acceptance

For a high current hadron machine, the most crucial issue is the radio-activation of machine components due to beam loss. There are several sources that cause beam loss. Among them, the space charge force is considered as a major one.

In order to reduce the space charge force among particles in a beam, we would take relatively large emittance, and therefore large beam size since the tune shift with space charge effects is inversely proportional to the emittance. On the other hand, large beam size imposes large aperture of magnets and there is a certain limit. In fact, there is another factor to be considered. Since the beam loss is unavoidable in any case, the best thing we can do is to localize it. Both 3GeV and 50GeV ring assume a beam collimation system, which makes a bottleneck in the rings, but still should have enough aperture compared with the emittance.

As a compromise among those requirements, the emittance of the beam and machine acceptance are chosen as in Table 1. In terms of a vacuum duct size, a typical size at the 3GeV ring is 240ϕ mm and one at the 50GeV is 120ϕ mm.

3 Lattice of the 3GeV Ring

The 3GeV ring is a rapid cycling machine with resonant power supply. In order to avoid saturation of magnets, the maximum field strength of the bending magnets is limited to around 1T, which makes the circumference of the ring relatively longer compared with a slow cycling machine with similar extraction energy.

Table 1: Emittance and acceptance (π mm-mrad).

3GeV ring	
injection emittance after painting	144
collimator acceptance	216
magnet acceptance	>216
emittance at extraction	54
acceptance of extraction system	216
50GeV ring	
injection emittance	36 to 54
collimator acceptance	54 to 81
magnet acceptance	>81
emittance at extraction	4.1 to 6.1
acceptance of extraction system	6.1

The quadrupole magnets have an independent power source but should be synchronized with the bending field. We use the idea of multi-network power supply [2] to make sure a tracking between quadrupole and bending magnets. However, the smaller number of quadrupole families is still preferable.

If the normal FODO cell structure is adopted, transition energy is easily located in the middle of energy range of the operation. In order to avoid the transition crossing, we employ the modulation of bending curvature and the transition energy is pushed up, but yet a real number. The minimum unit of the lattice is, we call it "module", three FODO cells which have no bending magnets in two half cells at the middle. The focusing quadrupole at the center is split into two to insert a sextupole for chromaticity correction. Two of such module make up one arc section.

The straight section consists of three FODO cells. At the early stage of the design, we also considered doublet and triplet cells instead of FODO. However, it turns out that it is impossible to install an injection system in quadrupole free space. Once we decided to have a quadrupole in between the system, the FODO cell is better for the injection system. The same thing is true for the extraction system.

Still, the injection and extraction system are the difficult parts to design. Because of the Lorentz stripping, the maximum H$^-$ bump field is limited. At the same time, the beam has to be kicked with a large angle to clear wide (1.5m) quadrupole magnets.

We have designed a lattice with three-fold symmetry and the circumference of about 300m. The main parameters of the lattice is shown in Table 2 and lattice functions of a superperiod are shown in Fig. 1. Details of extraction system is also shown in Fig. 2.

The dynamic aperture is calculated by single particle tracking. One of the drawbacks of that kind of high transition lattice is the stronger sextupole field required to correct chromaticity. The dispersion function becomes large only near the focusing quadrupole at the center and that is the place where horizontal and vertical beta functions differ not much. We split the focusing quadrupole into two and install a focusing sextupole in between. By splitting the focusing quadrupole, the dynamic aperture of well above 216 π mm-mrad is obtained even for off-momentum (+-1%) particles. However, the one with no split quadrupole and a sextupole located by the side of it has transverse acceptance of less than 216 π mm-mrad for the off-momentum particles.

The COD is calculated by statistical estimate. With some error fields and miss-alignment are assumed, the expected CODs are almost 8mm. We certainly need correction dipoles. With them, the corrected COD is expected to within 3mm.

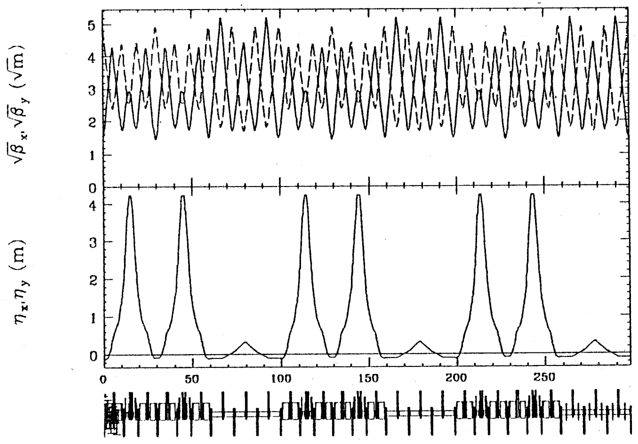

Fig. 1 Lattice functions of 3GeV ring.

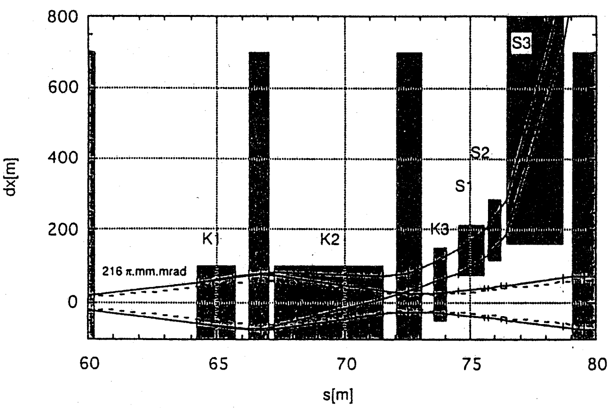

Fig. 2 Circulating and extracted orbit in a straight section.

4 Lattice of the 50GeV Ring

The 50GeV ring has the same cell structure for the arc, namely three FODO cells as a module and the transition energy is pushed up to an imaginary number. Six of such modules make up 300m long arc section with 90 degree total bending angle. Since the momentum spread of the beam is assumed to be +-1%, the largest beam size occurs at the focusing quadrupole at the center of the module.

Two 100m straight sections are used for fast and slow extractions of the 50GeV beams. The other two shorter straight sections are used for injection, collimation, and abort channel for one and rf for the other. The longer straight section has the optics which is simply doubled one of the shorter straight. That reduces the number of quadrupole families. The dispersion function in the straight section is less than 1m. We prefer zero dispersion for the slow extraction system, but that amount of dispersion is allowed.

Natural chromaticity of 50GeV ring is about -30, that means the tune shift of off-momentum particles reaches +-0.3. We definitely need chromaticity correction sextupole. However, we have the same problem of the 3GeV ring, that is the relatively stronger sextupole strength because of the dispersion function and beta functions at the location of sextupoles.

One way we adopted against the relatively stronger chromaticity correction sextupoles is to keep higher periodicity. By taking the phase advance of 2π or 4π for horizontal and π or 2π for vertical in the straight section, as far as the sextupole driving terms are concerned, the straight section becomes transparent. The 24-fold symmetry of the arc is preserved. For on-momentum particles, dynamic aperture of more than 200 π mm-mrad is obtained. Table 3 shows the main parameters of the 50GeV ring.

References

[1] "The Joint Project for High-Intensity Proton Accelerators", KEK Report 99-4, JAERI-Tech 99-056, 1999.
[2] "JHF Accelerator Design Study Report", KEK Report 97-16, 1998.

Table 2: Main parameters of the 3GeV ring

injection energy	400 MeV
beam intensity	8 x 10^{13} ppp
repetition	25 Hz
nominal tune	7.8/5.3
quadrupole families	7
natural chromaticity	-10/-9
momentum compaction factor	0.00989
harmonics	2
radio frequency	1.43-1.96 MHz
rf voltage	420 kV

Table 3: Main parameters of the 50GeV ring

beam intensity	3.2 x 10^{14} ppp
repetition	0.3 Hz
nominal tune	23.85/16.40
quadrupole families	8
momentum compaction factor	-0.001
harmonics	10
radio frequency	1.96-2.02 MHz
rf voltage	280 kV

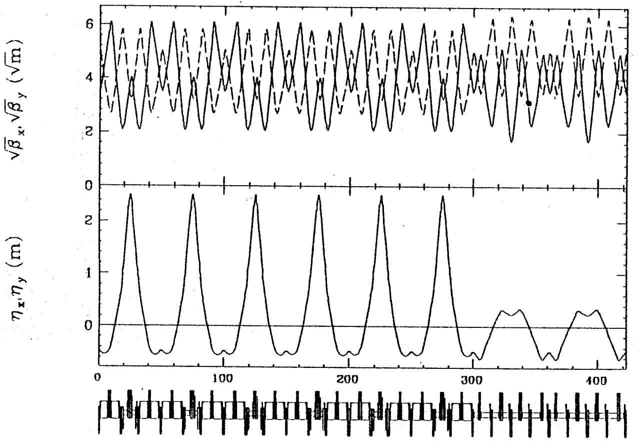

Fig. 3 Lattice functions of 50GeV ring (one arc + long straight).