SYNCHROTRON DESIGN ISSUES OF THE JAPANESE HADRON PROJECT

Y. Mori, Y. Ishi, M. Muto, H. Nakayama, C. Ohmori, S. Shibuya, T. Tanabe, and M. Tomizawa
INS, University of Tokyo, 3-2-1 Midori-chou, Tanashi-shi, Tokyo, 188 Japan
S. Machida and N. Tokuda
KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305 Japan

Abstract

The accelerator complex of the Japanese Hadron Project (JHP) consists of 200MeV proton linear accelerator, 3GeV fast cycling booster synchrotron, and 50GeV main synchrotron. One of challenging issues of those synchrotrons is the injection, acceleration and extraction (both slow and fast mode) of high beam current with minimum beam loss. The average beam current of the booster synchrotron is 200μA and that of the main ring is 10μA, which are realized by 25Hz repetition of an acceleration cycle with $5x10^{13}$ particles per pulse (ppp) and 0.3Hz of that with $2x10^{14}$ ppp, respectively. Heavy beam loading has to be overcome in the longitudinal plane and space charge effects and other collective beam instabilities are cured in the transverse planes. The machines are expected to be built in the KEK campus.

1 INTRODUCTION

The booster synchrotron of Japanese Hadron Project (JHP) will provide 3GeV 200μA beams (0.6MW) for a spallation neutron facility, a meson science facility, and an unstable nuclei facility. A part of the beams are further accelerated in the main synchrotron. It will deliver 50GeV 10μA beams for an intermediate energy nuclear and particle physics facility [1].

Because of the high beam current, even small beam loss on any stage should affect machine operation. Based on many design and operational experiences in other high intensity proton synchrotron facilities such as ISIS and AGS, we are designing machines emphasizing the necessity for minimizing beam loss. At the same time, machines are supposed to be built with the maximum usage of infrastructures so that some constraints arise such as machine circumference. In this paper, we will present some design issues of the booster and main rings.

2 OPTICS

First, we will list up requirements and specifications for the lattices design in order to satisfy high intensity operation with some given constraints. Then, we will explain some possible lattices for both main and booster synchrotrons.

2.1 Requirements and specifications

Most of requirements and specifications in both synchrotrons are similar.

- The booster is supposed to be built in the existing 12GeV synchrotron tunnel using its infrastructures. The circumference (340m) and superperiodicity (4) are predetermined.
- The main ring should fit in the area enclosed by TRISTAN tunnel. The circumference is about 4 times larger than the booster.
- We want to avoid transition energy crossing.
- To accommodate many rf cavities, an enough number of straight sections should be available.
- To accommodate a slow extraction system in the main ring, a straight section of at least 60m is necessary.
- Normal conducting magnets are used. The maximum field of the fast cycling booster is below 1T and that of the main ring is below 1.8T.
- To avoid space charge induced structure resonances, the phase advance per unit cell is not near by 90degrees [2].
- Normalized emittance at the booster injection is 140 π.mm.mrad. It gives incoherent space charge tune shift of -0.35.
- Normalized emittance at the main ring injection is 220 π.mm.mrad. It gives incoherent space charge tune shift of -0.11.

2.2 50GeV Main Ring

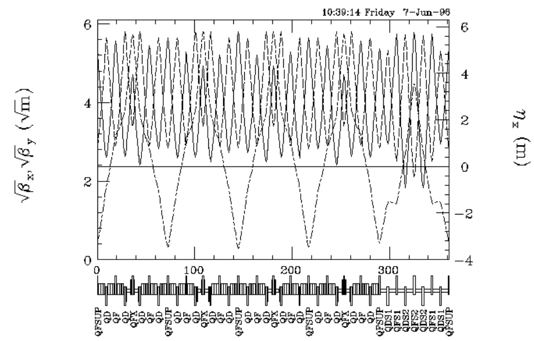

Figure 1: One quarter of main ring lattice functions. There is a missing bend cell per four unit cells. The arc consists of four such modules. The nominal tune is (18.6, 15.2) and gamma-t is 32I.

In order to avoid transition energy crossing, we adopt a so called imaginary gamma-t lattice. There are several schemes to make a momentum compaction factor negative and so the gamma-t is imaginary. For example, the Moscow KAON factory design took a missing bend scheme [3]. The scheme was inherited to the TRIUMF KAON lattices and the SSC low energy booster [4].

The current design of the main ring and booster lattices takes the similar scheme. The modulation of beta function is not so large so that it does not require huge magnet aperture for storing relatively large emittance beams. The missing bend sections can be used for the installation of rf cavities. The lattice functions (one quarter) of the main ring are shown in Fig. 1.

The same lattice hardware configuration but a different excitation of magnets can make a dispersion free straight section. Fig. 2 is an example. The total phase advance in the arc is tuned as an integer and the dispersion function is closed inside the arc. The modulation of beta functions and the maximum value are larger, compared with Fig. 1. The dispersion free straight section may be necessary to install an internal target or a device for polarized beam acceleration.

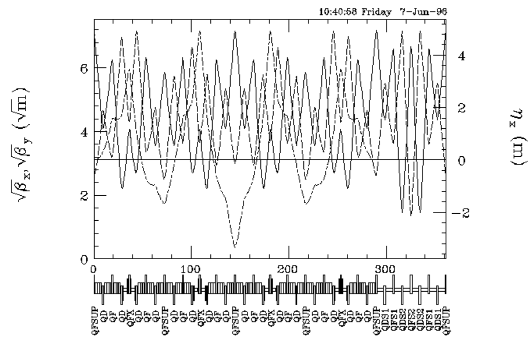

Figure 2: Main ring lattice functions. Quadrupole strength is tuned such that the straight section becomes dispersion free.

Fig. 3 shows lattice functions when the momentum compaction factor is varied. The horizontal and vertical tune can be almost unchanged and the maximum beta function is reasonable value in the range between -0.001 and -0.01, but the maximum dispersion function is somewhat large; more than 10m, when the amplitude of the momentum compaction factor becomes large, which may not be acceptable.

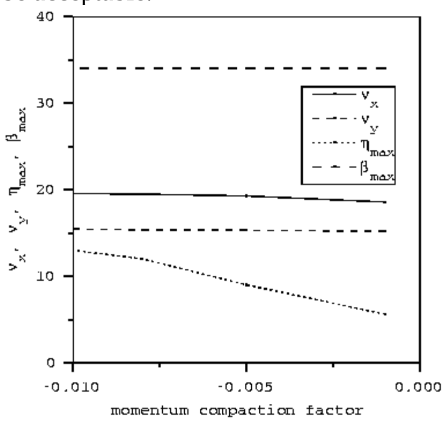

Figure 3: Lattice functions vs. momentum compaction factor.

2.3 3GeV Booster Ring

As a booster lattice, we also take the same scheme making gamma-t high, around 12, not imaginary. As shown in Fig. 4, there is a missing bend cell per two unit cells. The existence of many missing bend cells is advantageous in the booster, since the place for many rf cavities are essential to have sufficient total voltage; 420kV for 25Hz operation and twice if we increase the repetition up to 50Hz. As an alternative, normal FODO lattice is also designed.

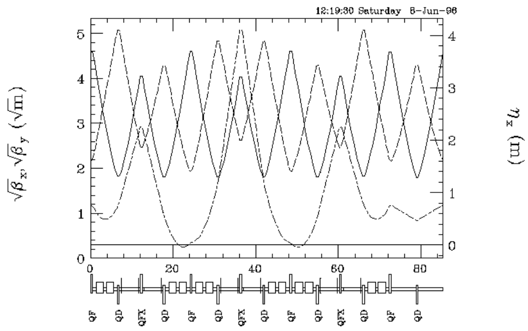

Figure 4: One quarter of booster lattice functions. The nominal tune is (7.8, 5.7) and gamma-t is 13.

3 DYNAMICS

A tracking study has been performed using 6-D thin lens code [5].

3.1 Dynamic Aperture of Main Ring

The dynamic aperture as a function of momentum amplitude and chromaticity is examined. A preliminary study of dynamic aperture with space charge effects is also searched. In all cases, a particle is tracked at the injection energy for 0.12s, corresponding to the time necessary for 16 bunches injection.

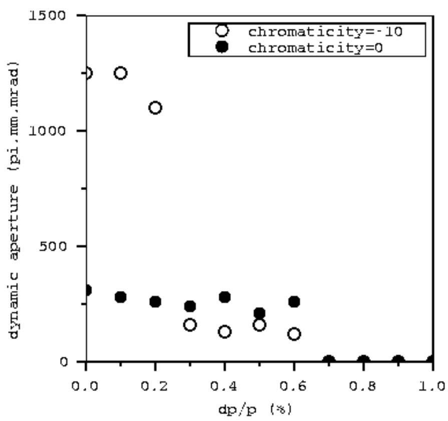

Figure 5: Dynamic aperture as a function of momentum amplitude.

Fig. 5 shows the momentum amplitude dependence taking chromaticity as a parameter. When the chromaticity is halfway corrected (natural chromaticity is around -20), the dynamic aperture of small momentum amplitude is larger than the case with full correction. Nevertheless, at the large momentum amplitude, full correction of chromaticity gives slightly bigger dynamic aperture. Above 0.7%, a particle is out of a bucket.

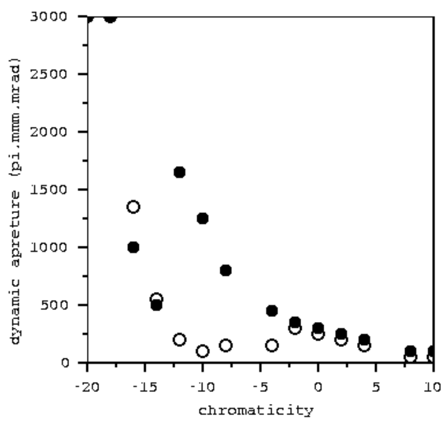

Figure 6: Chromaticity dependence of dynamic aperture in the main ring.

Fig. 6 shows the dynamic aperture as a function of chromaticity with two momentum amplitude particles. The filled circle has the momentum of 0% and the empty circle does 0.5%. When the chromaticity is -20 and -18, the dynamic aperture is almost infinite although there are dots at 3000, which just means 'no limit'. There is a chromaticity region around -15 to -5 where the dynamic aperture looks largest for a zero momentum amplitude particle, which is already seen in Fig. 5. However, That is not the case for the large momentum one. From the instability point of view, it is not necessary to correct the chromaticity in both booster and main ring. The optimized chromaticity for operation is not determined.

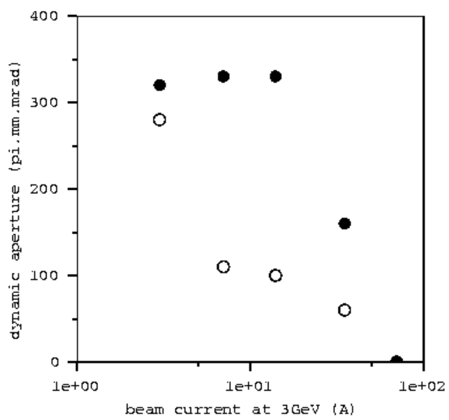

Figure 7: Dynamic aperture with space charge effects.

In terms of the incoherent tune shift, space charge effects are not so large, -0.35 for the booster and -0.11 for the main ring. Nevertheless, the dynamic aperture may be deteriorated by the space charge nonlinear force. Taking the space charge force as an external kick, meaning that electrostatic potential created by a Gaussian charge distribution almost continuously distributed around the ring, the dynamic aperture was surveyed as shown in Fig. 7. The filled circle has the momentum amplitude of 0% and the empty circle does 0.5%. Up to the nominal intensity, that is 7A, the dynamic aperture is larger than the emittance, that is 54 π.mm.mrad (unnormalized). However, some reduction of dynamic aperture due to space charge above 4A is observed, especially when the momentum amplitude is large.

3.2 Synchrobetatron Coupling in Booster

In the booster ring, the synchrotron tune is relatively high (0.015 at injection) because of the fast cycling nature and high required rf voltage. The emittance growth due to synchrobetatron coupling is simulated taking horizontal tune as a parameter [6]. Above 7.85, some growth is observed. Around the nominal tune, that is 7.80, no significant growth is seen.

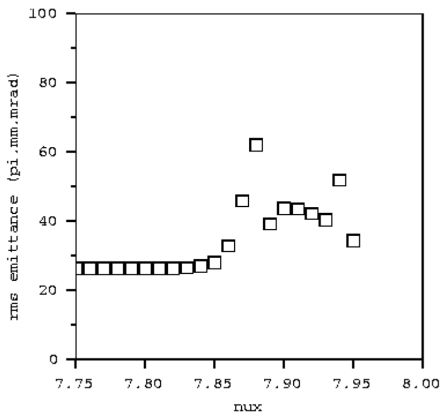

Figure 8: Synchrobetatron coupling in the booster.

REFERENCES

[1] Y. Mori and JHP synchrotron design group, "Outline of JHP Synchrotron Design", Proceedings of the 10th Symposium on Accelerator Science and Technology, pp.454-456, Tokai, 1995.

[2] S. Machida, "Space Charge Induced Resonances in a synchrotrons", to be published in Nuclear Instruments and Methods.

[3] N. I. Golubeva, A. I. Iliev, Yu. V. Senichev, "The New Lattices for the Booster of Moscow KAON factory", International Seminar on Intermediate Energy Physics, Moscow, 1989, pp.290-297.

[4] U. Wienands, et al, "The High Gamma-t Lattice of the SSC Low Energy Booster", International Journal of Modern Physics A, 2B (1993), pp.1070-1072.

[5] S. Machida, "The Simpsons code; 6-D Tracking with Acceleration", AIP conference Proceedings 297, p.459, 1993.

[6] S. Machida, "Synchrobetatron coupling resonances in a fast cycling synchrotron, to be published in Nuclear Instruments and Methods.