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OUTLINE OF JHP SYNCHROTRON DESIGN

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Abstract

An outline of the JHP synchrotron design is described.

1. Introduction

The Japanese Hadron Project (JHP) was revised very recently.[1] The revised JHP consists of the following three accelerators;

(1) injector: 200 MeV proton linear accelerator
(2) booster: 3 GeV proton synchrotron
(3) main ring: 50 GeV proton synchrotron

The accelerators will be constructed at the north site of the KEK and the whole plan view of the accelerator complex is shown in Fig.1.

The first stage of beam acceleration of the JHP is provided by the linac. The linac accelerates H⁻ ions up to 200MeV. The expected peak beam current in the Injector linac is at least 20mA and the pulse duration and the repetition rate of the beam is more than 400 μsec and 25Hz(50Hz in future), respectively.

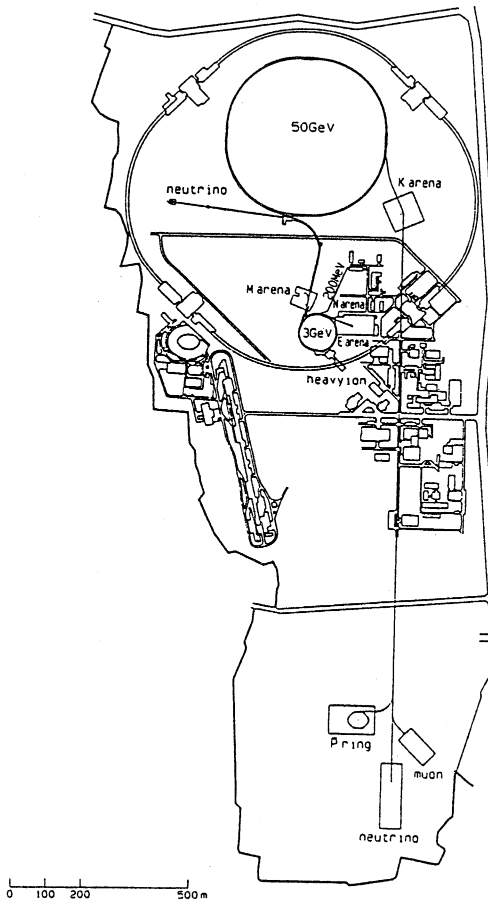

Fig.1 Whole plan view of the JHP accelerator complex.

The H⁻ beam is injected into the booster by charge-exchange multi-turn injection and accelerated up to 3 GeV. The 3 GeV booster will be constructed in the exiting tunnel for the present KEK-PS main ring. All of the components of the KEK-PS main ring such as dipole magnets, quadrupole magnets, vacuum chambers and others will be removed. The booster is a rapid cycling proton synchrotron and its repetition rate is 25Hz. The expected beam intensity in the booster is 5×10^{13} ppp (protons per pulse), therefore, the average beam current becomes 200 μA. The total power of the extracted beam from the booster reaches 0.6MW. The accelerated 3 GeV protons are supplied into three experimental facilities; a pulsed spallation neutron source facility(N-arena), a meson facility(M-arena) and an unstable nuclei facility(E-arena), and into the 50 GeV main ring.

Protons from the booster are injected into the main ring and accelerated up to 50 GeV. The expected beam intensity in the main ring is 4×10^{14}ppp and the repetition rate is about 1/6Hz, respectively. Thus, the average accelerated beam current reaches 10 μA in the 50 GeV main ring. The 50 GeV protons are extracted by a slow and fast extraction schemes for two experimental areas, respectively; one is for the experiments using secondary beams(K,p,$\bar{p}$) and primary beams by slow extraction, and the other for the neutrino oscillation experiment by fast extraction.

In addition to acceleration of high intensity protons, heavy ion and polarized proton beams are also requested. Using the 500 MeV booster of the KEK-PS as an injector of the 3 GeV booster, it becomes feasible to accelerate these particles.

2. Outline of the ring design

The 3 GeV booster is a rapid cycling proton synchrotron where the repetition rate of the acceleration is 25Hz. (This repetition rate will be amended up to 50 Hz in future by adding more rf acceleration system.) In order to accomplish this high repetition rate, the maximum magnetic field strength of the dipole magnets has to be less than 1T . The power supply for each group of the magnets is operated with an independent resonance circuit system.

The lattice design of the booster is presented in detail in this proceedings.[2] The booster ring comprises 48 bending magnets and 48 quadrupole magnets. Parameters of the booster ring are presented in Table 1. Since the ring should be placed in the present KEK-PS tunnel, the superperiodicity of the ring is chosen to be four. There is no transition energy during beam acceleration.

In the 50Hz operation, about 800kV rf voltage is needed for beam acceleration. Thus, a large number of straight sections is necessary for the rf cavity stations. The rf parameters of this ring will be presented in the proceedings.[3] In the present design, there are 24 straight sections and the length of each one is 6.57m.

The requested apertures for each component of the 3GeV booster are summarized in Table 2. In this estimation, the beam emittance of 320 π.mm.mrad at the beam injection for both horizontal and vertical directions, and the momentum spread of +-0.5% and the COD of 5mm are assumed.

Table 1. Parameters of the 3 GeV Booster

Injection enegy	0.2 GeV
Maximum energy	3 GeV
Beam intensity	5 x 10^{13} ppp
Repetition rate	25 Hz
Circumference	339.36 m
Magnetic rigidity	2.15 - 12.76 Tm
Lattice configuration	FODO
Tune	(7.3,4.3)
Transition energy:γ_t	7
Total number of cells	24
Number of B-magnets	48
Number of Q-magnets	48
B-magnet length	1.75 m
Q-magnet length	0.5m
Maximum magnetic field strength of B-magnet	0.95T
Maximum magnetic field gradient of Q-magnet	5.4 T/m
Natural chromaticity	-6.77, -5.84
Hamonic number	4
RF frequency	1.99 - 3.43 MHz
RF voltage	389 kV
Beam emittance (injection)	320 πmm.mrad
Beam emittance (extraction)	53.9 πmm.mrad

Table 2. Apertures of the 3 GeV booster.

	horizontal	vertical
Bending magnet	92.9 mm	95.3 mm
quadrupole magnet	106.0 mm	106.6 mm

Magnets are divided into three groups such as bending, focusing and the defocusing. Each group is excited using an independent resonant circuit. The design of the magnets and their power supplies are summarized in this proceedings.[4]

There are several design constraints for the 50 GeV main ring as shown below.

(1) Max. field of bending magnets :<1.8 T (for normal conducting magnet)

(2) Max. field gradient of quadrupole magnets:< 25 T/m

(3) No transition energy:Less than 1% beam loss during beam acceleration

(4) Small beam size: Eminence at beam injection ~ 54 π.mm.mrad

(5) No dispersion at straight section: Internal gas target experiment and Siberian snakes for polarized beam

(6) Numbers and length of a long straight section: 4, >40m

The circumference of the ring is almost four times larger than that of the KEK-PS ring because of the site limitation. Superconducting magnets are very attractive from the point of view of the site limitation described above, however, there are several problems, such as beam induced quenching, to be overcome. In the present lattice design, we assume to use normal conducting magnets. Thus, the maximum magnetic field strength of bending magnets and the maximum magnetic field gradient of quadrupole magnets are set to less than 25 T/m, respectively.

In an ordinary FODO lattice, the γ_t roughly equals the horizontal tune. Thus, using an ordinary FODO lattice, it is inevitable to have transition energy during beam acceleration up to 50 GeV. One of the features in the main ring design is that an imaginary γ_t lattice is employed.[2] Therefore, no transition energy crossing exists during beam acceleration. When the total integral of the dispersion function in the bending magnets is negative, the momentum compaction factor is negative and γ_t becomes imaginary. In order to realize imaginary γ_t, the arc section of the ring comprises a series of cell units. Each cell unit consists of three DOFO normal cells where the central cell has no bending magnets. To accommodate the dispersion free straight sections, total horizontal phase advance, ψ_{arc}, in the arc is set to integer times 2π. In this design, we set that ψ_{arc}=5x2π. With this optics, γ_t becomes $27i$. In order to avoid a serious radioactivation problem in high intensity mode acceleration, the beam loss should be kept small, therefore, small beam size is desired; bmax should be made small and flat as much as possible. The high intensity mode lattice was also designed from this point of view. Details of the lattice design are presented in this proceedings.[2]

The requested apertures of the 50 GeV ring are summarized in Table 3. In this estimation, the beam emittance of 54 πmmmrad at the beam injection for both horizontal and vertical directions, and the momentum spread of +-0.5% and the COD of 5mm are assumed, respectively.

Table 3. Apertures of the 50 GeV main ring.

	horizontal	vertical
Bending magnet	46.1 mm	43.8 mm
Quadrupole magnet	52.6 mm	44.5 mm

Space charge effects for the beams in the 3 GeV booster and the 50 GeV main ring are anticipated to be very large.[5] Using Laslett tune shift formula, the space charge effects are estimated. The incoherent and coherent space charge limits for both rings are summarized in Table 4. In this estimation, the Laslett tune shift is -0.25.

Table 4. Space charge limit

	Incoherent	Coherent
3 GeV Booster	5.6 x 10^{13}	1.2 x 10^{14}
50 GeV Main Ring	4.7 x 10^{14}	4.2 x 10^{14}

The general parameters of the 50 GeV main ring are summarized in Table 5.

3. Summary

The outline of the JHP circular accelerators are described. In parallel with optimization of the beam optics and dynamics in the both rings, some R&D's for hardwares have already started.

(1) R&D of the rf acceleration system which can stand for heavy beam loading in both rings.

(2) R&D of the magnet power supply with a resonant network for the 3 GeV booster.

(3) R&D of the ceramic beam duct and rf shield for the 3 GeV booster.

References
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[2]Y.Ishi et al., "Lattice design of JHP circular accelerators", in this proceedings.
[3]C.Oomori et al.,"RF systems of synchrotrons for the Japanese Hadron Project", in this proceedings.
[4]T. Adachi et al.,"Design of magnets and power supplies of 3 GeV booster for Japan Hadron Project", in this proceedings.
[5]S.Machida et al.,"Beam dynamics issues in JHP circular accelerators", in this proceedings.

Table 5 Parameters of 50 GeV Main Ring.

Injection enegy	3 GeV
Maximum energy	50 GeV
Beam intensity	4 x 10^{14} ppp
Repetition rate	~1/6 Hz
Circumference	1442 m
Average radius	229.5 m
Magnetic rigidity	12.76 - 170 Tm
Lattice configuration	3 - cell DOFO x 6 module +4 - straight cell
Tune	(24.25, 20.7)
Transition energy:γt	27 i (imaginary)
Total number of cells	88
Number of B-magnets	96
Number of Q-magnets	176
B-magnet length	6.2 m
Q-magnet length	1.5 m & 2 m
Maximum magnetic field strength of B-magnet	1.8 T
Maximum magnetic field gradient of Q-magnet	25 T/m
Hamonic number	34
RF frequency	6.83 - 7.03 MHz
RF voltage	200 kV
Beam emittance (injection)	53.9 πmm.mrad
Beam emittance (extraction)	4.1 πmm.mrad