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Overview of 3GeV Rapid Cycle Synchrotron for JAERI-KEK Joint Project

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Abstract

A 3GeV rapid cycling synchrotron (RCS) is designed for the joint project of JAERI and KEK which promotes advanced sciences in early next century based on high intensity proton accelerators. The RCS is required to provide 1MW pulsed protons onto a spallation target for neutron production with a pulse length of less than 1μsec, as well as to provide a high quality protons to the 50GeV synchrotron. The RCS accelerates the bunch of $8.3x10^{13}$ protons from 400MeV to 3GeV with the repetition rate of 25Hz.

1. Introduction

Japan Atomic Energy Research Institute (JAERI) and High Energy Accelerator Research Organization (KEK) agreed to carry out one joint project of a high intensity proton accelerators[1], which will be constructed in Tokai site of JAERI.

The accelerator complex is composed of a 600MeV 50Hz linac including a super-conducting linac from 400MeV to 600MeV, a 3GeV, 25Hz rapid-cycling synchrotron (RCS) and a 50GeV 0.3Hz synchrotron. The linac, which has beam qualities of 50mA peak current and 0.5msec pulse length, provides the proton beam to the RCS and to the transmutation experimental facility, alternately.

The RCS accelerates the protons from 400MeV to 3GeV at initial phase. The injection energy into RCS will be upgraded to 600MeV in future when the super-conducting linac will be proven to produce a stable beam with good qualities. An average beam current is 0.333mA in RCS. The proton beam from RCS is provided to the 50GeV synchrotron by sequential four pulses (5%) among 25Hz pulses during 3.3sec and the rest of pulses (95%) are provided to two experimental areas: a pulsed spallation-neutron area and a muon experimental area, which are located in series.

2. Major Parameters of RCS

The main parameters of 3GeV synchrotron are shown in Table 1. The lattice is designed to have three fold symmetry[2] as shown in Fig. 1. A long straight section is composed of three cells, which have 6m-long free space per each cell. One straight section is dedicated to the injection magnet system and a transverse beam collimation-collector. Another straight section is dedicated to the extraction magnet system. The other straight section is used for the space of the RF cavity system.

Table 1. Major parameters of 3GeV synchrotron

Output energy	3 GeV	Tune	X	7.35
Input energy	400MeV		Y	5.8
Operation frequency	25 Hz	Chromaticity	X	-8.95
Particles	8.3x10^{13} ppp		Y	-8.54
Output power	1 MW	Compaction factor		0.0122
Lattice	FODO	γ_t		9.05
Circumference	314 m	Harmonics		2
Superperiod	3	Radio-frequency		1.4-1.9MHz
Cell number	27	RF voltage		420 kV

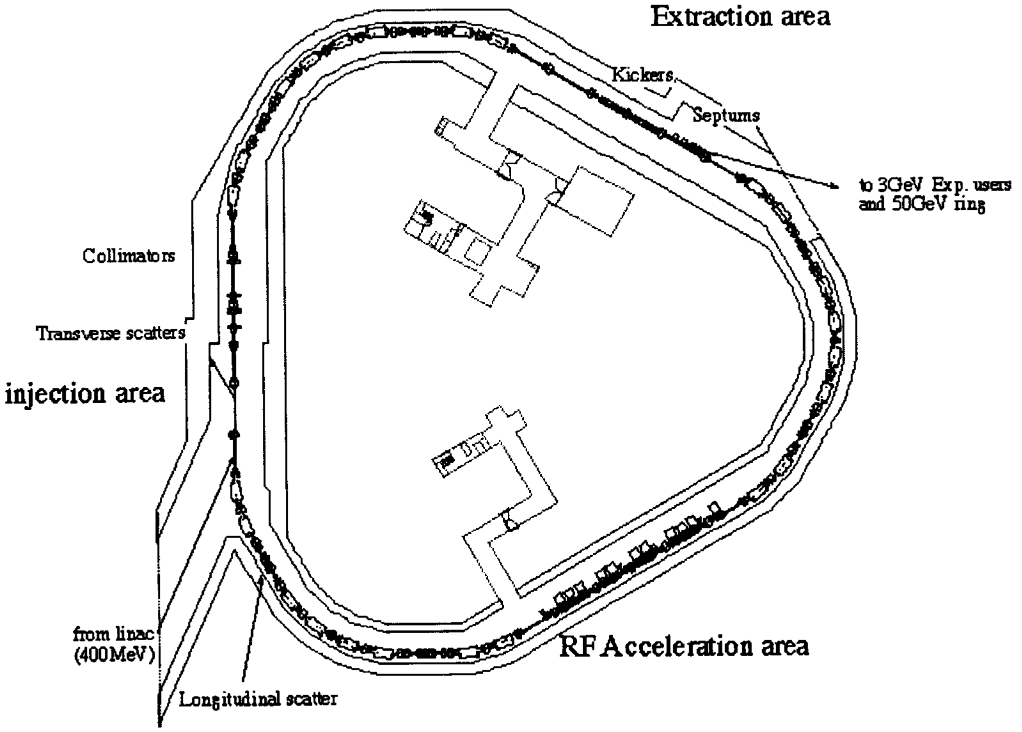

Fig. 1 3GeV Ring Overview

The arc section consists of two modules of three DOFO cells with two missing bends at the center of each module. This arrangement of the bending magnets provides dispersion-free straight sections and also makes momentum compaction factor tunable.

The nominal tunes of x and y direction are 7.35 and 5.8, respectively and they are adjustable in the region of 0.5. The momentum compaction factor is 0.012 in order to have the transition energy far away from the extraction energy of 3GeV. Betatron oscillation amplitude and dispersion function are shown in Fig. 2. The dispersion function at the arc section becomes so large that it is the best place for the longitudinal scraper to remove the particle escaping from RF buckets. The twiss parameters are selected to be satisfy the condition that a beam size should be less than 200mm at any places.

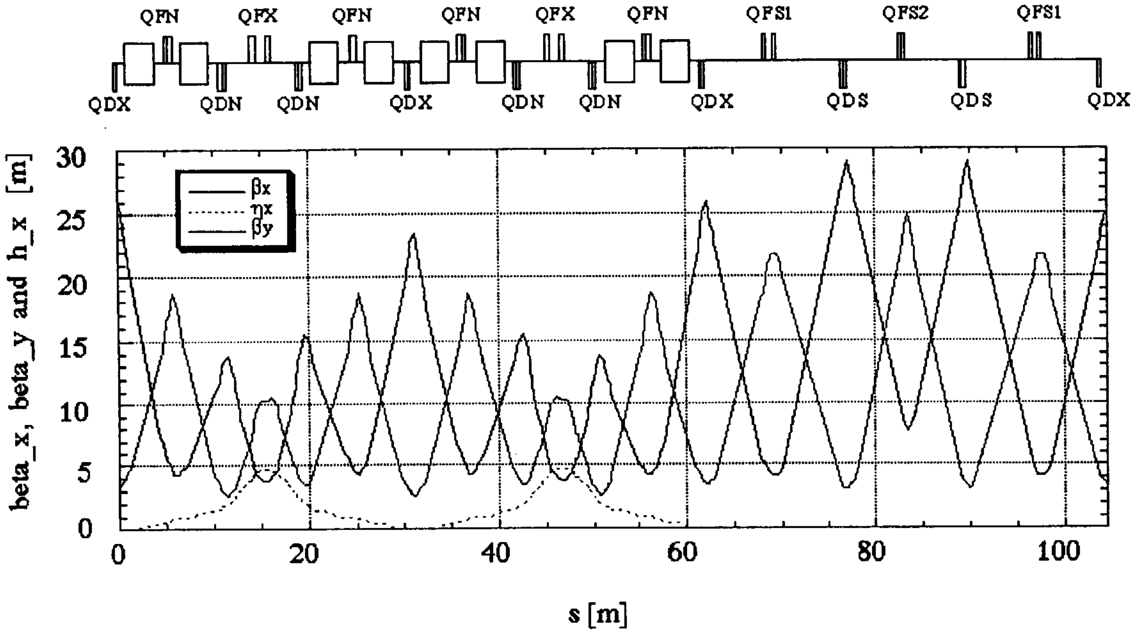

Fig. 2 Twiss Parameters

3. Injection and Extraction

The peak beam current is 50mA injected at the energy of 400MeV and average current is 0.333mA. Macro-pulse length is 0.5msec, which corresponds to the duration of injection. The chopping factor of the proton beam is 54% with 396nsec pulse length every 734nsec. Injected beam parameters are summarized in Table 2.

The emittance of a linac beam is assumed to be 4πmm*mrad. The injected beam is painted in the area of 144πmm*mrad emittance for both horizontal and vertical planes in the RCS. The aperture size of the collimator and the beam duct are 216πmm*mrad and 320πmm*mrad as shown in Table 3. The collimator size is larger than the painted beam size by a factor of 1.5 to allow the beam brow-up. The duct size is larger than the collimator size by a factor of 1.5 in order to reduce the uncontrollable beam loss. For the magnet design, the thickness of the beam duct is reserved to be 16.5mm including the 1.5mm clearance between the duct surface and the magnet surface.

Table 2. Injected beam for RCS

Repetition rate	25 Hz
Beam current (peak)	50 mA at 400 MeV
Average current	0.333 mA
Macro-pulse width	0.5 msec
Chopping factor	396 nsec / 734 nsec (54%)
Injection	681 pulses
Momentum spread	dp/p < 0.1-0.3% (100%)
Emittance	4πmm*mrad(100%)

Table 3. Emittance

Linac beam	4 πmm*mrad
Injection painting	144 πmm*mrad
Collimator	216 πmm*mrad
Duct size	320 πmm*mrad
Output beam	54 πmm*mrad
Output aperture	216 πmm*mrad

The injection scheme is still under consideration to compromise the feasibility of injection magnets and charge exchange system. One candidate of the injection system is a horizontal bump orbit generated by four bump magnets in the synchrotron and a vertical angle scanning at the fixed location of the charge exchange foil generated by a bump magnet installed in the injection line. Two bump magnets are installed in free space of a half cell in front of one focusing quadrupole magnet and other two magnets in half cell behind of the quadrupole magnet. The bump magnet has the field strength of 0.06-0.07 T. Their power supplies are required to produce a trapezoidal bump field combined with a parabolic painting pattern.

The extraction orbit is design with the large aperture of 216πmm*mrad in order to minimize the beam loss. The extraction system is composed of 9 kicker magnets and 5 septum magnets. The 9 kicker magnets produce the trapezoidal field of 0.03-0.05 T with the pulse length of 1μsec. The kicker magnet becomes very big size with the height of 195mm and the width of 280mm to keep a big aperture for an extracting beam. The magnet length is less than 700mm. The power supplies are required to have the output characteristics of the current of 5kA and the voltage of 60kV.

The septum magnets will be operated in DC to avoid the mechanical breakdown in AC operation, and their DC field is in the range of 0.3-1 T. The septum magnet also becomes very big size with the height of 168mm and the width of 200mm to keep a big aperture for an extracting beam. The magnet length is 900mm. The septum thickness is from 30mm to 225mm.

4. Charge exchange, collimator system and beam duct

The carbon foil stripping is now a most promising candidate for the charge exchange method from negative Hydrogen to positive proton. The stripping foil is installed at the center of the quadrupole magnet which is located in the middle of the bump orbit. The carbon foil with the thickness of 290 $\mu g/cm^2$ has the conversion efficiency of 99.6% for 400MeV negative Hydrogen[3]. The amount of 0.4% of injected Hydrogen remain in the neutral Hydrogen. They are stripped by second carbon foil installed just after the third bump magnet and extracted from the RCS and led into the beam dump. The very small amount of the neutral Hydrogen is in the excited states stripped in the Quadrupole field and maybe lost into the beam duct or into the collimator.

The beam collimator is installed in the same straight section as the injection system. It is composed of one thin target to scatter the halo particles around core beam and several scrappers to clean up the scattered particles. The target is made of tungsten with the thickness of 2mm. The scrapper is made of iron block. The simulation analysis predicts that the 98.5 % of halo particles will be dumped into the scrappers.

To permit a human access for maintenance, the radiation should be kept as low as possible in the beam tunnel. The uncontrollable beam loss through the tunnel is assumed to be less than 1W/m. Some special locations such as the injection section and the extraction section and the beam dump are able to handle larger beam loss by means of preparing thicker radiation shield. Beam Loss is assumed in RCS to be 4kW at the injection section and 1kW at the extraction section. The tunnel size at the arc sections is 6m of width and 3.5m of height. The beam is located at 1.2m away from the floor, and 3.5m away from the wall of the maintenance corridor side. The tunnel width is wider to be 8m at the injection and extraction sections to keep the larger maintenance space.

The requirements for beam duct are high vacuum pressure with a small out-gassing rate, high reliability with a long lifetime, low eddy current with a good RF shield. The vacuum pressure should be less than 10^{-7} Pa to minimize vacuum pump maintenance. The perturbation of magnetic field should be less than 10^{-4} due to the eddy current through the beam duct. The Ohmic loss also should be as small as possible to avoid the heat-up of the beam duct as well as the beam tunnel.

One candidate for the beam duct is ceramic which has characteristics of low permeability and enough strength. TiC will be coated inside the duct to reduce the electron emission. The RF stripes will be installed outside the duct to decrease the impedance for the beam and to reduce the microwave emission from the beam. R&D study is under way for evaluating characteristics of ceramic such as an aging effect of the strength under high radiation environment.

5. Resonant magnet and RF system

The major parameters of main magnets are summarized in Table 4. The maximum field strength of the bending magnets is 1.1T to keep linearity during the acceleration. For the same reason, the maximum gradient of quadrupole and sextupole magnets is 5.2T/m and 36T/m^2, respectively. The size of the bending magnet becomes so large as shown in Fig. 3. There are ten families of power supplies; one for bending magnet, 7 for quadrupole magnets and 2 for sextupole magnets to have maximum knobs for tune control. The coil current is controlled by the resonant power supply system using the inductance and capacitance.

Table 4. Main Magnets Parameters

Bending magnet	
Number	24
Angle	15°
Type	Rectangular
Length	3.05 m
Radius	11.6 m
Field	0.27-1.1T
Gap height	210mm
Quadrupole magnet	
Number	66
Families	7
Length	0.53- 0.78m
Field gradient	1.2-5.2 T/m
Bore diameter	270-330mm
Sextupole magnet	
Number	18
Families	2
Length	0.4 m
Field gradient'	9-36T/m^2
Bore diameter	270mm

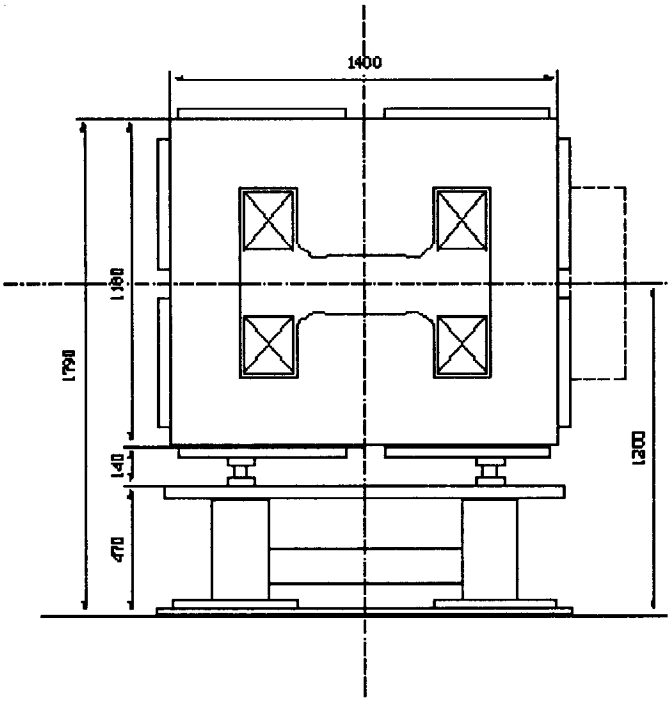

Fig.3 Bending Magnet

The RF accelerating system has the frequency range of 1.36MHz to 1.86MHz during acceleration from 400MeV to 3GeV[4]. To reduce the ring size, the magnetic alloy RF cavities were developed to produce of 40M/m. One cavity has the length of 1.65m with three gaps and produces 43kV field gradient. To obtain the required 421kV, ten cavities are installed in one straight section.

6. Conclusion

Design study of 3GeV RCS(rapid cycle synchrotron) is under way to accelerate high intensity protons from 400MeV to 3GeV with the output power of 1MW. The lattice is aimed to be compact with a circumference of 314m and to minimize a number of the straight sections for injection, extraction and RF system with three-fold symmetry. In order to achieve high intensity acceleration, the proton beams are injected with multi-turns (681turns) from the linac, and the beam size of RCS becomes so large that all of devices become large and difficult to manufacture. R&D works are under way in a lot of devices such as resonant magnets, injection/extraction pulse magnets, RF system, beam ducts and the charge exchange system.

REFERENCE

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