A CONCEPTUAL DESIGN OF THE PROTON STORAGE RING FOR THE NEUTRON SCIENCE PROJECT AT JAERI

Michikazu Kinsho, Fumiaki NODA, Joichi Kusano, and Motoharu Mizumoto
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken 319-1195, Japan
email : kinsho@linac.tokai.jaeri.go.jp

Abstract

The goal of the proposed Neutron Science Project (NSP) at JAERI is to provide a short pulsed proton beam of less than 1µs with an average beam power of 5MW. To achieve such purpose, a proton storage ring operated at 50Hz with $4.17x10^{14}$ protons per pulse at 1.5GeV is required. The preliminary study of the ring for the specification of the neutron science project is described in this paper.

1 INTRODUCTION

Japan Atomic Energy Research Institute, JAERI, has been proposing the Neutron Science Project (NSP) which is composed of research facilities based on a proton linac and a proton storage ring with an energy of 1.5GeV[1]. The proposed NSP is aiming at exploring new basic researches and nuclear technologies such as condensed matter physics and nuclear waste transmutation based on a proton accelerator. In the proton storage ring, the pulsed beam from the linac is accumulated, and high intensity pulsed beam is produced for the neutron scattering experiment. The goal of the proton storage ring is to provide a short pulsed proton beam of less than 1µs with an average beam power of 5MW with two rings. The study of the proton storage ring whose beam power is 2.5MW and the high energy beam transport (HEBT) line which connects the 1.5GeV linac to the proton storage ring has been performed[2]. The beam coming out of the linac is a 1.5GeV H^- beam and 1.86ms long with a peak current of 30mA. The beam is chopped to the pulse length of 400ns with 270ns gap. The beam is compressed by means of a multi-turn charge exchange injection. When a harmonic number of the ring is 1, a circumference and a revolution frequency are 185.4m and 1.49MHz, respectively. The single bunch in the ring is contained by rf cavity. To achieve a beam power of 2.5MW with this beam structure, it is necessary to accumulate 2777 bunches. This corresponds to $2.08x10^{14}$ protons. When the beam injection is completed, accumulated protons are extracted from the ring during 1 turn. The average current circulating in the ring with 1.49MHz revolution frequency becomes 49.75A. Basic parameters of the proton storage ring are shown in Table 1.

At such a high average current, a beam loss of a very small fraction makes a very high radioactivity around the ring. It is necessary to examine reduction and localization of the beam loss with sufficient consideration of the divergence of the beam by the space charge force, the resonance phenomena by the tune shift, longitudinal instability, e-p instability and so on. This paper describes the preliminary study of the proton storage ring and HEBT line.

Table 1 Basic parameters of the proton storage ring

Beam Average Power	2.5 MW / ring
Kinetic Energy	1.5 GeV
Average Current	1.67 mA / ring
Repetition Frequency	50 Hz
Linac Peak Current	30 mA
Linac Pulse Length	3.72 ms
Number of Turns Injected	2777 turns/ ring
Injected Pulse Length	400 ns
Injected Beam Gap	270 ns
Harmonic Number	1
Revolution Frequency	1.49 MHz
Circumference	185.4 m
Magnetic Rigidity	7.51 Tm
Circulating Current	49.75 A / ring
No. of Circulating Protons	$2.08x10^{14}$ protons / ring

2 HIGH ENERGY BEAM TRANSPORT LINE

The High Energy Beam Transport line (HEBT) connects the 1.5GeV linac to a proton storage ring. A major requirement of this line is to have low uncontrolled beam loss in the ring in order to allow hands on maintenance. To achieve such low beam losses in the ring, the beam must be prepared very carefully before injection. The HEBT not only matches the beam into the ring, but also determines the beam quality at injection. The HEBT has following functions : (a) matching of the beam from the linac into the transport line, (b) horizontal and vertical betatron and momentum collimation, (c) focusing the H^- beam to the correct spot size for injection, and (d) halo cleanup. To reduce the probability of uncontrolled beam losses, HEBT is equipped with many beam halo scrapers. The maximum magnetic field in dipole and quadrupole is kept less than 1.8kG to keep H^- stripping losses to acceptable levels. The design of HEBT system has been performed.

The HEBT consists of two matching sections and an achromat region. Figure 1 shows an example of the magnet lattice for the achromat region in the HEBT. This lattice has two dispersion free regions and one high dispersion region. There are horizontal and vertical collimators in these dispersion free regions and momentum collimator in high dispersion region in order to clean up a beam halo.

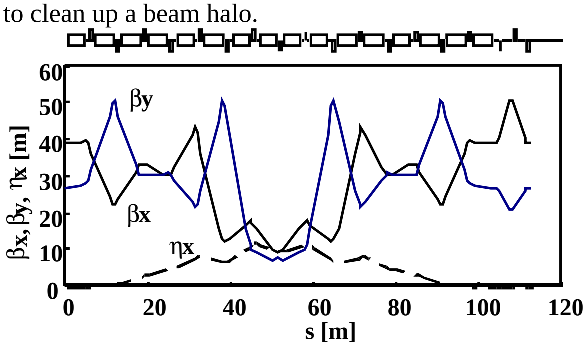

Fig. 1 Magnet lattice for the achromat region in the HEBT

3 STORAGE RING

Magnet Lattice

Two kinds of the magnet lattice are studied for the proton storage ring. One is 20 cell FBDO lattice and the other is Triple Bend Achromatic (TBA) lattice. The betatron function and energy dispersion function have been evaluated by using the lattice analysis program "MAD" developed at CERN. The calculated data are shown in Fig. 2. A large transverse beam emittance is required in the ring to restrict the transverse space charge tune shift. The chosen values for an un-normalized 100% transverse emittance of an injected H^- beam, a ring acceptance and a collimator acceptance are 2πmm-mrad, 530πmm-mrad, and 200πmm-mrad, respectively. This transverse emittance restricts the space charge tune shift to less than 0.1. The parameters of the 20 cell FBDO lattice and the TBA lattice are shown in Table 2.

The betatron variation around the ring of the FBDO lattice is smooth. Such a property will minimize the possible envelope oscillation for beams with large space charge tune shift. There are long straight sections in the TBA lattice. Such a property will give enough space for injection, rf cavity, and extraction. The consideration of beam dynamics for each lattice is important to decide which is better lattice for the proton storage ring. As the next step, we will simulate the beam dynamics for each lattice with beam tracking code.

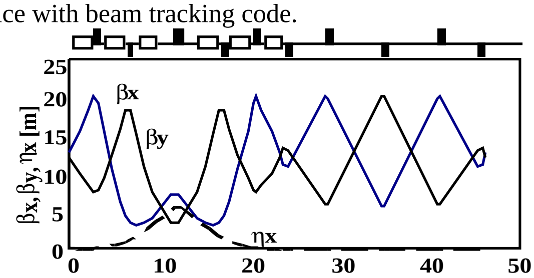

Fig. 2 (a) Beta function and dispersion function of the 20 cell FBDO lattice

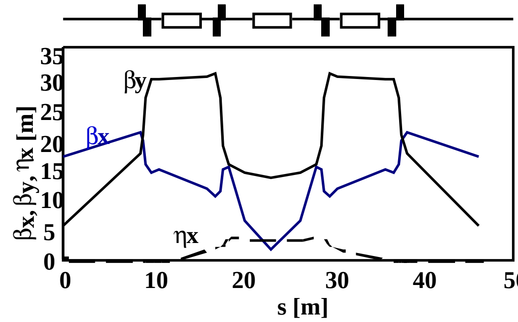

Fig. 2 (b) Beta function and dispersion function of the Triple Bend Achromatic lattice

Table 2 Parameters of the 20 cell FBDO lattice and the TBA lattice

	20 Cell FBDO	TBA
Super Periodicity	4	4
Operating Tune	(3.7, 3.4)	(2.75, 2.75)
Chromaticity	(-3.5, -4.0)	(-3.52, -6.01)
Transition γ	4.4	5.59
Acceptance	200πmm.mrad	200πmm.mrad
Δp/p	±0.5%	±0.5%
Magnets		
Bending	1.0T	1.0T
QD	-2.4 ~ -4.1T/m	-4.0 ~ -7.3T/m
QF	2.5 ~ 3.3T/m	6.0 ~ 8.4T/m

Beam Injection

There is a main source of beam loss in an injection area and this is the most critical item for the ring because the main loss is due to H^- or H^+ beam intersection with a stripper foil during and after injection. H^- injection method in which H^- beam is converted to H^+ beam with the stripping foil located in the injection magnet is adopted for the storage ring. In this method H^0 atoms emerging from the stripper foil are in a distribution of excited states resulting from the stripping reaction H^-->H^0*(n) + e^- where *n* is the principal quantum number. The lifetime of H^0 atoms depends on the Stark state in the magnet [3]. The lifetime of 1.5GeV H^0 atoms was calculated[2]. It is obvious from these calculation data that the H^0 atoms with n_4 remain as H^0 and may be removed from the ring, and atoms with n>5 rapidly become H^+ and are accepted in the ring with the injection magnet whose strength of the magnetic field is 0.15T. The injection scheme which should be adopted to reduce the beam loss in the ring has been studied.

A large transverse beam emittance is required not only to restrict the transverse space charge tune shift but also to reduce the circulating proton beam intersection with a stripping foil. To obtain the large transverse emittance the phase-space painting is also considered [4].

Radio Frequency Cavity

Though the acceleration of the beam is not carried out in the rf cavity, the rf cavity is required for maintaining the bunch structure in the storage ring. The injection beam is chopped to be the pulse length of 400ns with 270ns gap. When a harmonic number of the ring is 1, a revolution frequency is 1.49MHz. The necessary cavity voltage is the sum of voltage V_p which is proportional to the momentum spread of the injection beam and voltage V_{sc} which supplements the decreasing voltage by the space charge effect. The V_p voltage is about 13.5kV by assuming that the momentum spread which is estimated from the Keil-Schnell criterion is to be _0.41%. The necessary V_{sc} voltage changes according to the accumulated number of beam bunches. When all beam bunches are accumulated, the V_{sc} voltage becomes about 7.5kV under the condition that the longitudinal distribution is parabolic. The rf voltage is raised from 13.5kV to 21kV to maintain the beam bunches during injection.

The storage process is simulated using beam tracking code which has been developing at JAERI. The stored beam distribution at each turn is calculated assuming that the distribution of injection beam is uniform and this beam is stored for 100 turns. The rf voltage at start is 13.5kV and increases to 21kV during the injection. The longitudinal motion with the first and second harmonic (dual harmonic) rf bucket is simulated for reducing the space-charge force at the beam center and increasing the bunching factor. The rf voltage of second harmonic is taken to be 10.5kV which is half of the first harmonic voltage. Figure 3 shows the beam distribution at the end of injection in a longitudinal phase space. In this figure, the solid curve shows the separatrix for the sum of the dual harmonic rf voltages. This result shows that the density distribution is close to uniform shape, and bunching factor is about 0.45. As the next step, we will estimate the effect of beam loading, the effect of the barrier bucket and necessity of longitudinal painting.

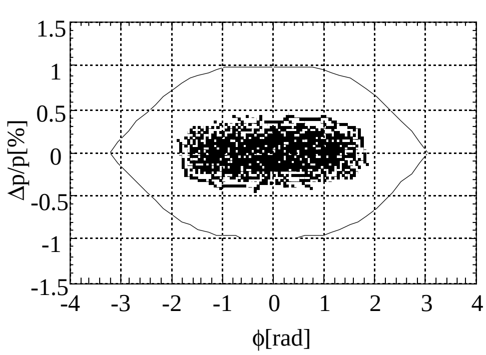

Fig. 3 Beam distribution in a longitudinal phase space

Beam Extraction

The fast extraction method is used from the request of the neutron scattering experiment. In this extraction method, when injection of all bunches is completed, accumulated beam is extracted from the ring during 1 turn. An interval between bunches is 270ns from the injection beam pulse structure which is chopped to 670ns bunch width with 60% duty cycle. It is necessary that the magnetic field of a kicker magnet is enough to extract the beam from the ring to less than 270ns and is kept with the strength to more than 400ns. In fact, the required field rise time of kicker magnet is less than 150ns considering the increase of the beam bunch due to synchrotron oscillation and divergence by the space charge effect during multi-turn ring injection. When the un-normalized 100% emittance and beta function are 200πmm-mrad and 15m, respectively, the reflection angle becomes about 8.7 mrad. A kicker magnet of 0.02T and 3.3m is required in order to realize this extraction process.

4 UPGRADE PATH

The phase I construction of the NSP project is a 1.5MW spallation neutron source. The upgrade from 1.5MW to 2.5MW will be achieved by increasing a peak current or a pulse length of the linac beam. The upgrade from 2.5MW to 5MW will be accomplished by providing a second ring to aim the beams from both rings at the same target. In this case, the beam transport system has to combine the beam bunches from the two rings into a single pulse of less than 1μs duration.

5 REFERENCES

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