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

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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 $4.17\text{x}10^{14}$ protons per pulse at 1.5GeV is required. Two kinds of a lattice are examined as a lattice of the proton storage ring for neutron science project. One is FODO lattice and the other is Triple Bend Achromatic (TBA) lattice. This paper describes preliminary results of the lattice design for the proton storage ring.

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]. 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 1ms with an average beam power of 5MW with two rings. The study of the proton storage ring whose beam power is 2.5MW has been performed. To achieve a beam power of 2.5MW with an energy of 1.5GeV, it is necessary to accumulate $2.08\text{x}10^{14}$ protons. When the beam injection is completed, accumulated protons are extracted from the ring during 1 turn. The basic parameters of the proton storage ring are shown in Table 1.

Lattice design for high intensity proton storage ring has been performed. Two kinds of a lattice are examined as a lattice of the proton storage ring for neutron science project. One is FODO lattice and the other is Triple Bend Achromatic (TBA) lattice. Each lattice has zero dispersion regions and long straight sections. The betatron variation around the ring of the FODO lattice is smooth[2]. 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 , instabilities, injection scheme, and extraction scheme for each lattice is important to decide which is better lattice for the proton storage ring. This is the main subject for our study of the ring. This paper describes preliminary results of the lattice design for the proton storage ring.

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	$2.08\text{x}10^{14}$ protons / ring
Injection Beam Emittance	2πmm.mrad (100% unnormalized)
Momentum Spread	±0.4%

2 LATTICE

Two kinds of the magnet lattice are studied for the proton storage ring. One is 20 cell FODO lattice and the other is Triple Bend Achromatic (TBA) lattice. 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 FODO lattice and the TBA lattice are shown in Table 2.

The betatron variation around the ring of the FODO 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. This is the main

0-7803-5573-3/99/$10.00@1999 IEEE.

subject for our study of the ring. Parameters of the FODO lattice and TBA lattice are shown in Table2. It is possible to get a dynamic aperture of 4000πmm.mrad and wide tune variations for horizontal tune and vertical tune for each lattice. For the tune variations, there is a strong dependence between horizontal tune and vertical tune for TBA lattice. Therefore the tunability of TBA lattice is not so good, however this is not a serious problem for the lattice.

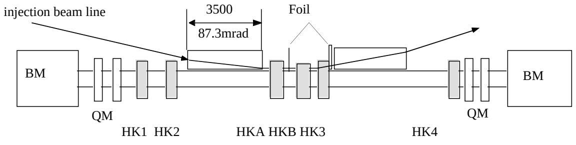
Table 2 Parameters of the FODO lattice and the TBA lattice

	FODO	TBA
Super Periodicity	4	4
Operating Tune	(4.84, 4.78)	(3.75, 2.8)
Chromaticity	(-4.70, -5.28)	(-3.52, -6.01)
Transition Energy	4.51	5.59
Slippage Factor	-0.099	-0.11
Space Charge Tune Shift	<-0.1	<-0.1
Momentum Spread	±0.365%	±0.34%
Physical Acceptance	200πmm.mrad	200πmm.mrad
Dynamic Acceptance	4000π mm.mrad	4000π mm.mrad
Tune Variation	$4.1<\nu_x<5.9$	$2.1<\nu_x<3.9$
	$4.1<\nu_y<5.9$	$2.1<\nu_y<3.9$
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
RF Cavity		
Fundamental Frequency	1.49MHz	1.49MHz
Harmonic Number	1st+2nd+3rd	1st+2nd+3rd
Voltage	30+30+12kV	30+30+12kV
Extraction Kicker Magnet		
Reflection Angle	9mrad	12mrad
Magnetic Field Strength	0.02T	0.03T
Total Magnetic Length	3.4m	3.0m

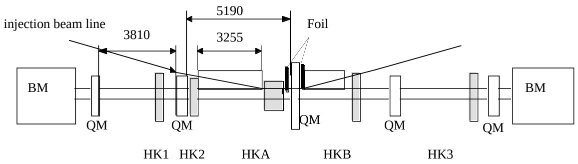
3 BEAM INJECTION SCHEME

There is a main source of beam loss in an injection area and hence 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 $H^- \rightarrow H^{0*}(n) + e^-$ 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 was obvious from this calculation data that the H^0 atoms with $n \leq 4$ 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]. Injection schemes of the FODO lattice and TBA lattice are shown in Fig.1. For the TBA lattice a set of 4 pulsing and 2 fixed field dipole and a set of 4 pulsing and 1 fixed field dipole for FODO lattice will be used to create an orbit bump to paint the injection proton population into the optimum phase space. The optimum distribution will be determined by computer simulation. The H^- ions which missed the stripping foil and H^0 atoms emerging from the foil should be disposed in proper beam dump. A thick stripping foil which is placed in the path of the H^0 atoms converts entire beam to protons. The H^- ions bent by the downstream low magnetic field bending magnet for TBA lattice and by the downstream quadrupole for FODO lattice will travel to the high magnetic field bending magnet, and because of the high magnetic field, they will be stripped to H^0 atoms in the field. A thick stripping foil which is placed upstream the bending magnet strips H^0 atom to protons.



TBA



FODO

Fig.1 Injection scheme of the TBA and the FODO lattice

4 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 3.4m is required in order to realize this extraction process.

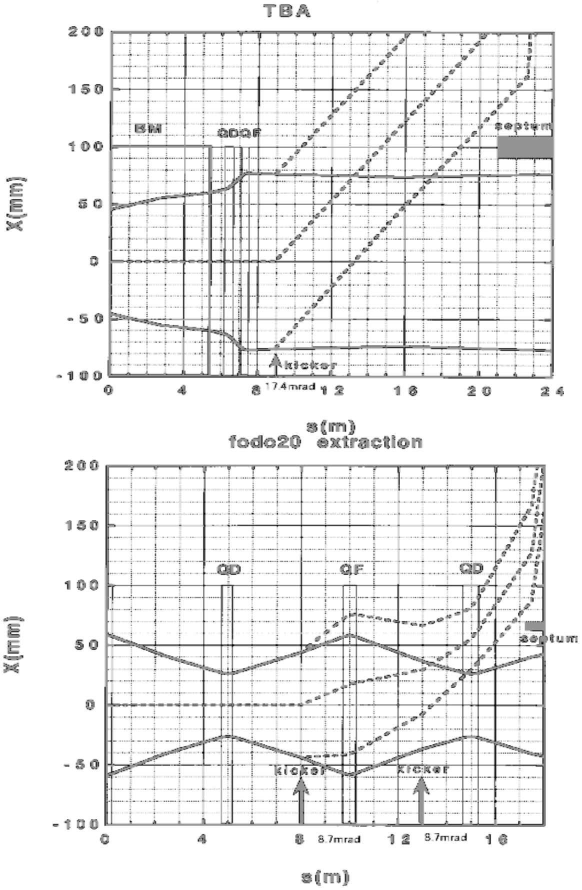


Fig.2 Beam extraction orbits

Figure 2 shows the extraction beam orbit for TBA lattice and FODO lattice. Because there is a long straight section with zero dispersion in TBA lattice, it is easy to install kicker magnets to extract the proton beam from the ring.

5 SUMMARY

Two kinds of a lattice are examined as a lattice of the proton storage ring for neutron science project. One is FODO lattice and the other is Triple Bend Achromatic (TBA) lattice. In order to decide which is better lattice for the proton storage ring, we considered of beam dynamics , injection scheme, and extraction scheme for each lattice. From these considerations, it was not decided better lattice for our proton storage ring. This study will be continued based on these two kinds of lattice.

6 REFERENCES

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