RECENT STUDIES OF THE FFAG-ERIT SYSTEM FOR BNCT

K.Okabe, Fukui University, Fukui, Japan
Y.Mori, Kyoto University Research Reactor Institute, Osaka, Japan
M.Muto, FFAG-DDS Organization, Tokyo, Japan

Abstract

The accelerator–based neutron source using ERIT (Energy/emittance Recovery Internal Target) scheme has been constructed at KURRI (Kyoto University Research Reactor Institute). And the first beam test was successfully completed in March 2008. In this paper, recent study of magnet design and ionization cooling simulation will be presented.

INTRODUCTION

Boron neutron capture therapy (BNCT) is radiation therapy which has a potential ability to selectively kill tumour cells embedded within normal tissue. It makes use of intense thermal/epithermal neutrons to irradiate. Many groups have investigated epithermal neutrons for BNCT with compact nuclear reactor. In recent years, accelerator-based neutron sources for BNCT has been strongly requested, because of the problems associated with reactor installations at hospitals. Reactions such as $^{7}Li(p,n)^{7}Be$, $^{9}Be(p,n)^{9}B$ with low-energy protons are currently being investigated as accelerator-based neutron sources. It is, however, very difficult to realize an accelerator-based neutron source with external target because very high beam current(~10mA) is required.

To overcome this difficulty, the scheme using an internal target placed in the circulating orbit of a ring has been proposed[1]. This scheme, ERIT, utilizes the primary beam efficiently since circulating beam particles hit a thin target many times until they make neutron production reaction or drop out the ring acceptance. The ring has an rf system that recovers the energy lost in the target for every turn. In this scheme, the average accelerating beam current can be relatively small and modest, if long time duration of beam storage is realized.

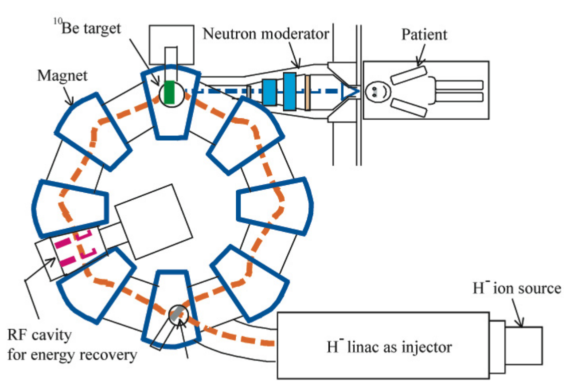

Figure 1: A schematic layout of ERIT scheme.

If the circulated beam hits the target efficiently, the neutron yield should become comparable with that from a nuclear reactor. And the average accelerating beam current can be relatively small and modest, contrary to the case for accelerator-based neutron source with external target.

In this scheme, however, the incident beam will be lost from the ring very quick because the beam energy of the incident protons is lost to ionization of the target atoms turn by turn, and also because the beam emittance in transverse and longitudinal directions are blown up by multiple scatterings and energy straggling with the target electrons. However, these deleterious effects can be cured by ionization cooling[2]. If ionization cooling effect is fully functioning, the neutron production efficiency is improved.

DESIGN OF FFAG STORAGE RING

In ERIT scheme, internal target produces neutrons and the same target is used as material for ionization cooling. The ionization cooling suppresses transverse and longitudinal emittance blow up. For a proton storage ring with ERIT scheme, huge momentum and transverse acceptance of FFAG[3] is a big advantage to circulate a beam whose emittance and momentum spread gradually increase. The ERIT system consists on injector 11MeV H^- linac, beam transport line, a FFAG storage ring, rf cavity for re-acceleration, a Be foil target for neutron production, and an extraction line with moderator for medical use of the neutrons.

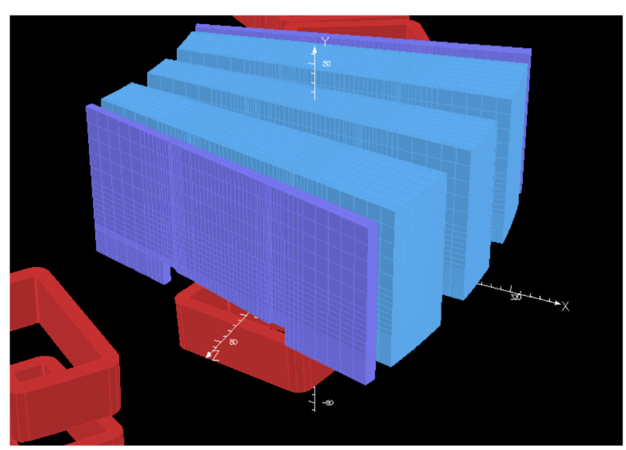

Figure 2: A 3D model of the FFAG-ERIT magnet.

The ERIT ring is a 8 FDF cells radial sector type FFAG proton storage ring. Radial sector type FFAG is more suitable than the spiral sector type for controlling the heating of the vertical direction. Basic parameters of FFAG ring has been determined with the linearized model. The design of the ring magnet was carried out with 3-dimensional magnetic field calculation by TOSCA code. Figure 2 shows one example of 3D model, which used in TOSCA. To study the beam dynamics in FFAG, 3-dimensional full tracking simulation is adopted. We optimize the ring magnet to have large transverse and longitudinal acceptance. Two field clamps are installed at both magnet end, in order to suppress the fringing field effects. And we optimize magnet pole shape with particle tracking simulation.

SIMULATION OF IONIZATION COOLING

The ionization cooling method has been studied for muons at optimal cooling energies. The same methods can be applied to the proton-material interactions at low energies. In order to study the efficacy of ERIT scheme, detailed beam simulation for ionization cooling have been carried out with ICOOL[4]. Figure 3 is simulation results of ICOOL using magnetic field map calculated by TOSCA.

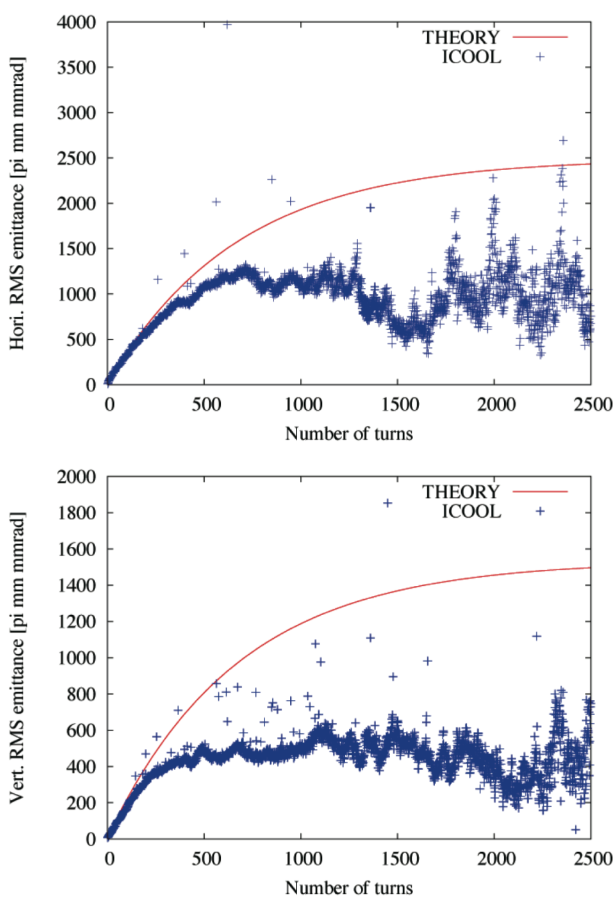

Figure 3: Transverse and longitudinal emittance growth in ERIT.

For a 11MeV proton beam with 5mm Be target, an analytical solution[2] and the simulation results are corresponding well while beam loss is few(~200turns) in transverse direction.

In longitudinal direction, injected beam was a pulsed beam with duration of 90 μsec, which was equivalent to about 300 turns in the ring. This duration time is longer than rf bucket length in FFAG ring. Injected beam fluctuates causing emittance growth during bunching (i.e. rf capture). Figure 4 shows presents the particle survival as a function of turn number. Red points is longitudinal matched beam, blue one is mismatched(coasting) beam at injection.

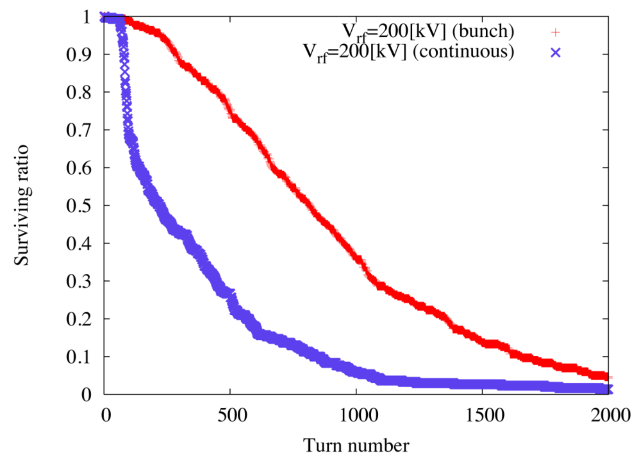

Figure 4: presents the particle survival as a function of turn number.

It can be seen from this figure, the average turn number for beam survival of matched beam is about 900 turns. However, mismatched beam is rapidly lost from the ring, because longitudinal emittance growth is increased during rf capture process.

Table 1: Main parameters of ERIT system.

Mean radius	2.35 [m]
Sector number	8
Max. B field	0.9 [T]
Field index k value	1.92
FD ratio	~ 3
Horizontal tune, Vertical tune	1.74, 2.22
Horizontal acceptance, Vertical acceptance	7000π [mm mrad] 3000π [mm mrad]
Rev. frequency	3.01 [MHz]
rf voltage	200kV
Harmonic number	6

Fabrication and installation of FFAG-ERIT system at KUURI is completed. Figure 5 shows a photograph of the ERIT system installed at the experimental room of KURRI.

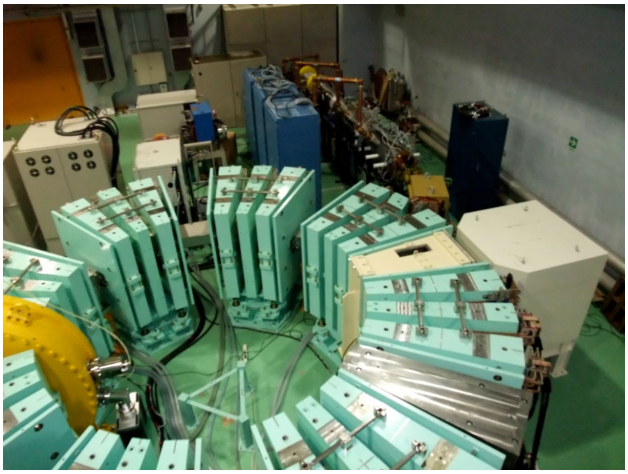

Figure 5: Photograph of FFAG-ERIT accelerators.

SUMMARY

The design of FFAG-ERIT system has been completed. From ionization cooling simulation results, it have been confirmed that the mean surviving turn number more than 500 turns can be achieved. This surviving turn number almost satisfies requirement of ERIT scheme. This machine is expected to be the prototype of next generation intense neutron source. Fabrication and installation at KUURI have been completed. And experimental beam study is now doing.

REFERENCES

[1] Y. Mori, Nuc. Inst. Meth. **A** 562 (2006) pp. 591.
[2] D. Neuffer, Nucl. Inst. Meth. **A** 532 (2004) pp. 26.
[3] K. R. Symon et al., Phys. Rev. 103 (1956) pp.1837.
[4] R. Fernow, Proc. PAC1999 (1999) pp. 3020.