DEVELOPMENT OF FFAG-ERIT SYSTEM FOR BNCT

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Abstract

Applications of FFAG[1], accelerators in medical use have been proposed for boron neutron capture therapy (BNCT). As for BNCT medical applications, an accelerator-based intense thermal or epithermal neutron source has been strongly requested recently. A scaling type of FFAG accelerator with ERIT (energy/emittance recovery internal target) concept has been proposed for this purpose and is now under construction. In this paper, we will present the status of FFAG-ERIT project.

INTRODUCTION

Boron neutron capture therapy is radiation therapy which has a potential ability to selectively kill tumor cells embedded within normal tissue. 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. It is, however, very difficult to realize an accelerator-based neutron source because very high beam current is required.

The scheme using an internal target placed in the FFAG storage ring, which produces high flux of neutrons for BNCT treatment, has been proposed[2].

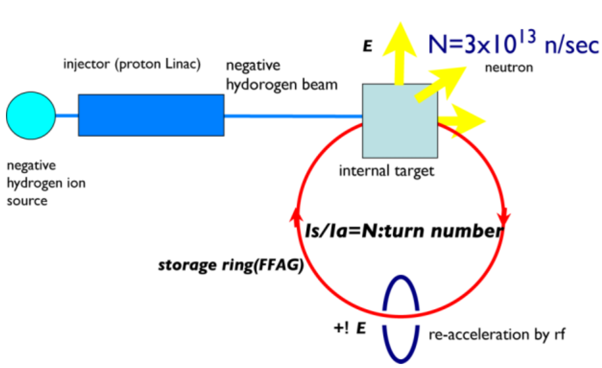

Figure 1: A schematic layout of ERIT system.

If a neutron production internal target such as beryllium thin foil is inserted into the ring and the beam hits the target efficiently, the neutron yield should become comparable with that from a nuclear reactor. The FFAG ring has an RF system that recovers the energy lost in the target for every turn, although there is no net acceleration.

Figure 1 shows a typical layout of ERIT system having injector 11MeV H^- linac, a storage ring for protons, RF cavity for energy recovery, a beryllium foil target for neutron production, and an extraction line with moderator for medical use of the neutrons.

Table 1: Main parameters of ERIT system

ERIT system	Expected turn number	~ 1000 turns
	Be target thickness	~ 5 [μm]
Injector(linac)	Ion spices	H^-
	Kinetic energy	11 [MeV]
	Average beam current	~ 70 [μA]
FFAG storage ring	Injection scheme	H^- injection
	Average beam current	~ 70 [mA]
RF cavity	RF voltage	200 [kV]
	Harmonic number	6

The goal of the ERIT system is to achieve the production of neutrons (flax ~ 10^9 n/cm^2/s) with the reaction ^{9}Be(p,n)^{9}B, which has a cross-section of 500 mbarn at 11MeV. The baseline parameters of ERIT system are displayed in Table 1.

DESIGN OF FFAG STORAGE RING FOR ERIT SCHEME

In this scheme, ERIT, internal target produces neutrons and the same target is used as material for "ionization cooling"[3]. However, the incident proton beam will be lost from the ring because the transverse and longitudinal emittance are blown up by effects of multiple scatterings and energy straggling with the target electron. The ionization cooling suppress these emittance blow up. Huge momentum acceptance and transverse acceptance of FFAG is a big advantage to circulate a beam whose emittance and momentum spread gradually increase.

In order to design the FFAG ring, basic parameters 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. And to study the beam dynamics of FFAG, three-dimensional tracking simulation is adopted.

Table 2: Optimized parameters of FFAG-ERIT ring.

Mean radius	2.35 [m]
Sector number	8
Opening angle	13.5 [deg]
Field index k value	1.92
FD ratio	~ 3
Horizontal tune, Vertical tune	1.76, 2.22
Horizontal acceptance, Vertical acceptance	7000π [mm mrad] 3000π [mm mrad]
Rev. frequency	3.05 [MHz]

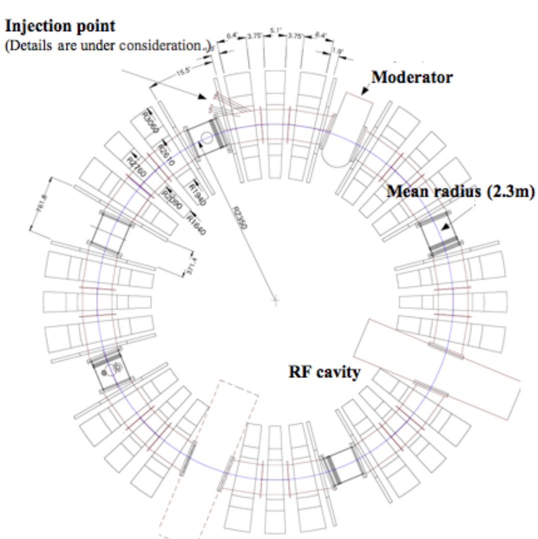

Figure 2: Top view of the FFAG-ERIT storage ring.

Optimized ring parameters are shown in Table 2. Figure 2 shows top view of FFAG storage ring, which is radial sector type magnet and Figure 3 shows RF cavity for ERIT scheme.

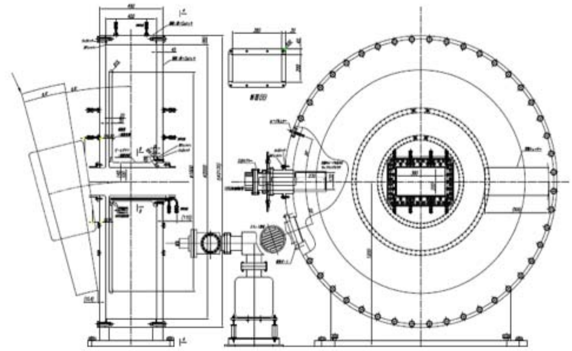

Figure 3: RF cavity for the FFAG-ERIT ring.

SIMULATION OF IONIZATION COOLING EFFECT

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. The lifetime of protons in a low-energy storage ring with cooling foil is extended by ionization cooling and this enables large neutron production.

In order to study the efficacy of ERIT scheme, detailed numerical simulation for ionization cooling are needed. Figure 4 is simulation results of ICOOL[4] using magnetic field map calculated by TOSCA. An analytical solution and the simulation results are corresponding well while beam loss is few(~200turns). According to analytical solution, horizontal equilibrium emittance is about 2500mm.mrad and vertical one is 1500mm.mrad.

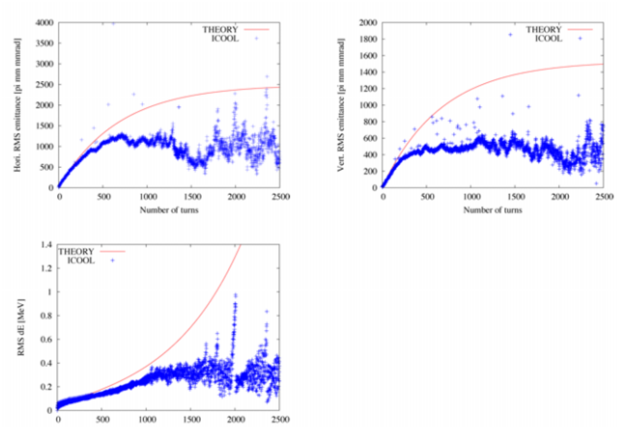

Figure 4: Transverse and longitudinal emittance growth in ERIT.

On the other hand, since there is no cooling effect expected in the longitudinal direction, a large energy spread is inevitable. In reality, the beam life is limited by the vertical acceptance of the beam. The beam simulations have been carried out with ICOOL and the results are also shown Fig. 4.

Figure 5 presents the particle survival as a function of turn number. It can be seen from this figure, the average number of turns for beam survival is about 900 turns.

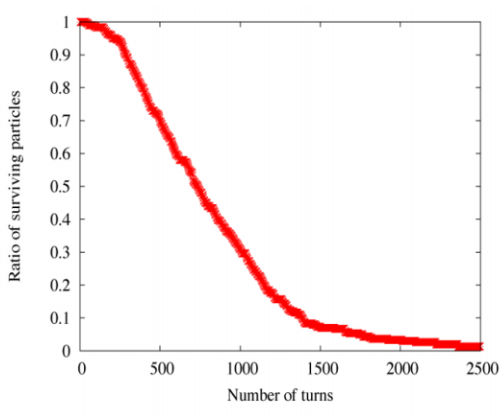

Figure 5: Mean surviving turn number in ERIT.

SUMMARY

The design of FFAG-ERIT storage ring has been completed. From ionization cooling simulation, it have been confirmed that the mean surviving turn number more than 900 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 is in process.

ACKNOWLEDGMENTS

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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.