AN INTENSE NEUTRON SOURCE WITH EMITTANCE RECOVERY INTERNAL TARGET (ERIT) USING IONIZATION COOLING

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Abstract

Accelerator based neutron source for BNCT(boron neutron capture therapy), which uses an internal target placed into the proton storage ring has been developed at KURRI. In this scheme, the beam and energy degradation caused by the target are cured by ionization cooling. The sytem was completed and the preliminary experiment showed that it worked as expected.

INTRODUCTION

For BNCT medical applications, an accelerator-based intense thermal or epithermal neutron source(ABNS) has been strongly requested recently. Requirements for ABNS aiming a hospital size apparatus are summarized as follows:(1) thernal/epithermal neutron flux of more than $1x10^9$ n/cm^2/sec at patient, (2) no radiation hazard caused by secondary radio activity production and (3)compact size(<100m^2).

Practical way to satisfy these requirements for ABNS in BNCT application is to use proton or deuteron induced nuclear reactions with Li or Be target. Spallation nuclear reactions are not adequate for this purpose because of their large residual radio activity production. Even for the proton induced neutron production reactions with Li or Be, the maximum proton energy should be less than 15MeV which is threshold energy of spallation reaction to generate tritium produced by fast neutrons. Thus, in ordinary scheme of ABNS with an external target, the requested proton beam current becomes quite high such as about 10mA for 10MeV and 50mA for 3MeV proton beams, respectively. For such large beam power around 100kW, serious problems concerning the heat load and radiation damage of the neutron production target also come out.

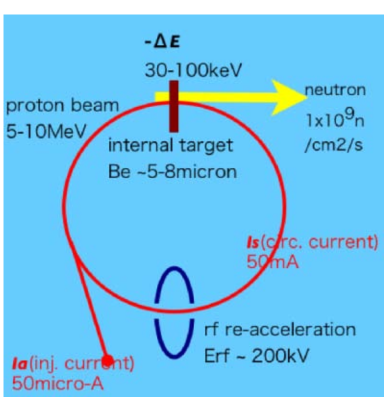


Fig.1 Scheme of ERIT

In order to overcome these difficulties of ABNS with an external target, an ERIT (energy/emittance recovery internal target) concept with a scaling type of FFAG proton storage ring has been proposed for this purpose and is now under construction [1,2,3]. Figure 1 shows a schematic diagram of ERIT. This scheme may also be used to produce intense beams of other secondary particles such as unstable nuclei, muons etc.

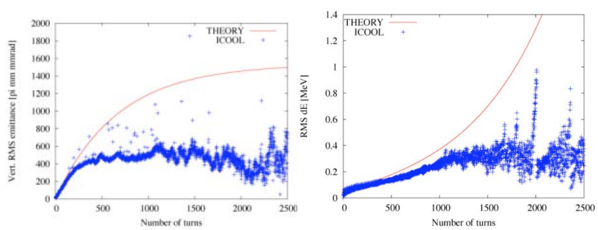
The circulating current of the beam inside a strong focusing ring accelerator, such as an FFAG, is fairly large because the bunch orbits the ring many times with large revolution frequency. For example, in the case of neutron production, when 10^{11} protons at 10 MeV orbit a ring of circumference 10 m, the circulating beam current reaches 70 mA. 10^{11} protons per bunch is a relatively modest number for such strong focusing proton accelerators of this energy. If a neutron production internal target such as a 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.

SCHEME

In this scheme, however, the incident proton beam will be lost from the ring very quickly because the beam energy of the incident protons is lost to ionization of the target atoms turn by turn, and also because the beam emittances, in transverse and longitudinal directions, are blown up by multiple scatterings with the target electrons. These deleterious effects can, however, be cured by ionization cooling [4,5]. The transverse emittance reaches equilibrium because of the ionization cooling which is invoked in this energy recovery internal target scheme. For a 11 MeV proton beam with a 5 µm beryllium target which is placed at the position of beta-minimum of about β=0.9m, the transverse unnormalized rms emittance reaches about 1500 π mm.mrad after 2,500 turns, as presented with a red colour curve in Fig. 2a.

On the other hand, since there is no cooling effect expected in the longitudinal direction, a large energy spread is inevitable. For example, after 1,000 turns using the same beryllium target, the rms energy spread of the 11 MeV proton beam would be about +-5% as shown in Fig. 2(b). In Fig.2, beam tracking results with ICOOL are also shown. In the beam tracking, the physical aperture(unnormalized rms acceptance) in the transverse direction is assumed to be about 600π mm.mrad. In order to circulate such a large transverse and longitudinal emittance beam in the ring, the FFAG seems to be one of the most suitable accelerators. The FFAG has very large acceptance, especially in momentum space, compared with other types of ring accelerators, because zero chromaticity in the beam focusing is fulfilled. Moreover, the FFAG ring has the functions both of acceleration and storage, which can be ideal for the internal target type of secondary particle source, and it may be applied for generating not only neutrons but other particles such as pions and unstable nuclei, although the ionization cooling efficiency may be small.

Based on the ERIT scheme, a neutron source for BNCT has been under development in Japan as a NEDO (New Energy Development Organization) project since 2005 and will be completed in 2007.



(b)

Fig.2 Emittance growth in transverse (a) and longitudinal (b) directions.

APPARATUS

The ERIT consists of the injector and the proton storage ring in which a thin Be target for generating neutrons is placed. The H- ions are accelerated by the injector and injected into the ring by charge exchange injection with a thin Be target. The beam emittance and energy distorted by the Be target are cured by reacceleration with a RF cavity placed in the ring. Schematic layout of the system is shown in Fig. 3

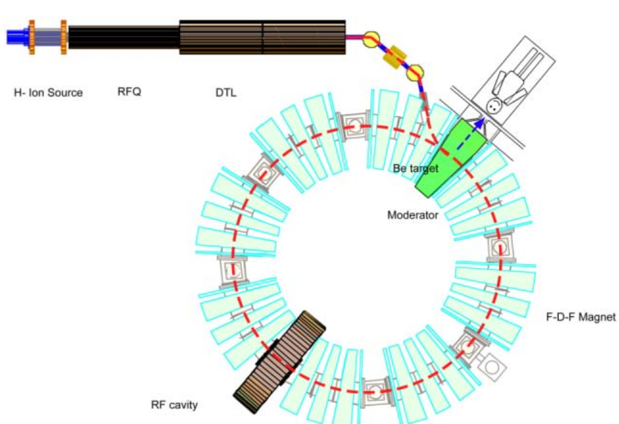


Fig.3 Schematic layout of ABNS with FFAG-ERIT.

The injector is a proton linac brought by AccSys-Hitachi which composes a 425MHz RFQ and DTLs and accelerates H- ions up to 11MeV. The maximum beam duty factor is about 1.8% where the beam repetition is 200Hz. The total length is about 5m and the peak RF power of 1.5MW is requested in total. The H- ion source is a volume type of H- ion source. The available H- beam current(peak) is about 5mA.

The ERIT ring is a rdial focusing type of FFAG proton storage ring where an 8-cell FDF triplet lattice is adopted. Figure 4 shows a photograph of the ERIT ring installed at the experimental room of KURRI. The mean radius of the ring is 2.35m and the packing factor of the magnets occupied in the ring is about 60%. The magnetic fields for F and D magnets at the mean radius are 0.83 and 073 T, respectively. Figure 5 shows a schematic configuration of the FDF triplet magnet. The beam acceptance of the FFAG ring as mentioned above is important to increase an efficiency of neutron production in this scheme. The horizontal and vertical rms acceptance of the ring are 1500mm.mrad and 600mm.mrad, respectively.

The RF cavity to re-accelerate the proton beam is basically TM010 mode and made of cupper-plated iron and the thickness of the cupper is approximately 100micrometer. The rf frequency is about 18MHz and a large capacitive plate is placed inside of the cavity to reduce a size of the cavity less than 2m in diameter even at such relatively low frequency. The measured quality factor was about 9000 which was about 75% of that obtained from 3-D field calculation. The RF cavity is operated in cw mode and the maximum RF voltage of 230kV which is enough for requirement has been obtained with the input RF power of 100kW.

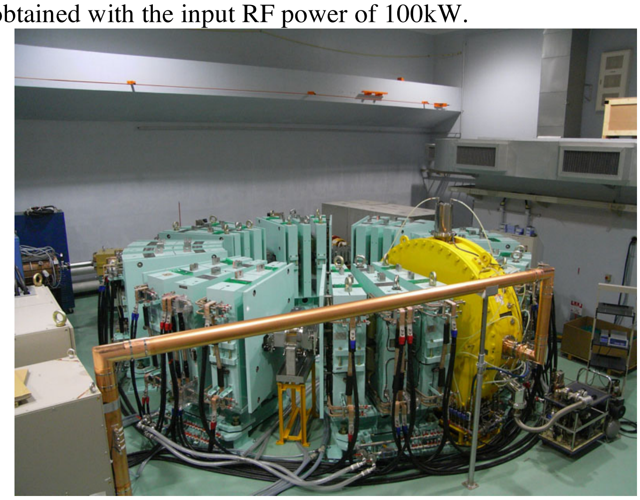


Fig.4 Photograph of FFAG-ERIT.

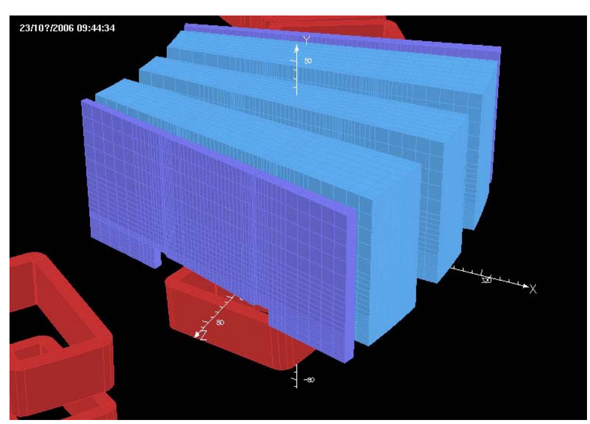


Fig.5 Schematic layout of FDF triplet magnet.

EXPERIMENT

The beam experiment has been carried out after to examine the principle of the ERIT scheme especially on the beam accumulation based on ionization cooling. The injected beam from the linac was a pulsed beam whose duration was 130μsec which was equivalent to about 400turns in the ring. The beam behaviour in the ring was measured by an electrostatic bunch monitor which was placed at the straight section. Figure 6 shows a typical beam accumulation measured by the bunch monitor and it is clearly seen from this figure that the beam accumulation and survival are well enhanced by emittance and energy recovery caused by RF cavity as expected. In Fig. 7, the beam bunch configuration is also presented Neutrons generated at the Be target were moderated and detected successfully by a neutron monitor in this preliminary experiment.

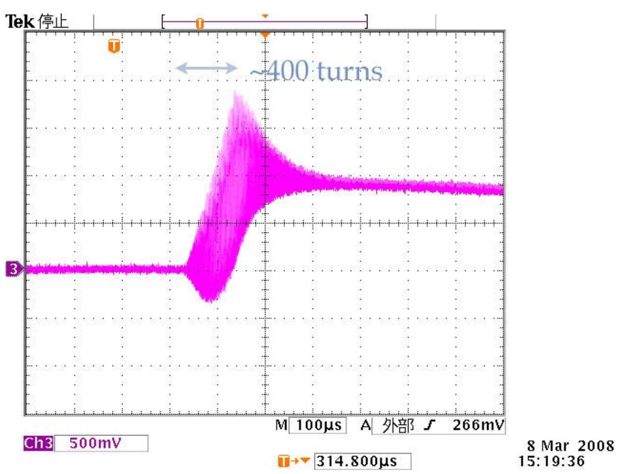


Fig.6 Beam accumulation and survival in the FFAG ring.

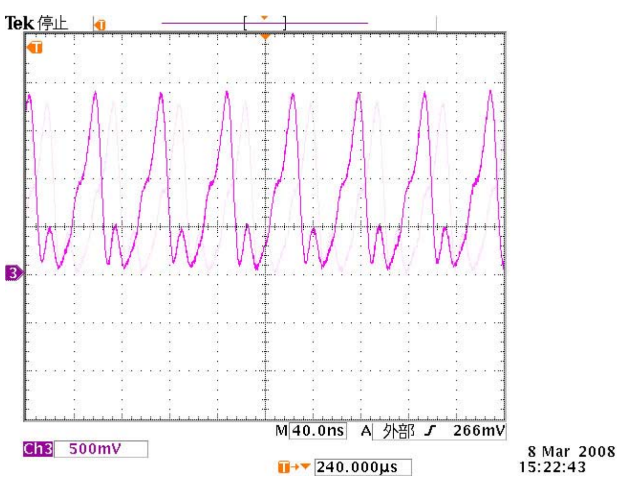


Fig.7 Beam bunch configuration.

SUMMARY

The accelerator –based neutron source for BNCT using ERIT has been developed and the first beam test was successfully completed. The beam accumulation and survival in the FFAG storage ring were increased by emittance and energy recovery with ionization cooling scheme with RF reacceleration as expected. Yield and spectrum of moderated neutrons are under optimization.

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