FFAGS FOR THE ERIT AND ADS PROJECTS AT KURRI

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Abstract

In Kyoto University Research Reactor Institute (KURRI), we have two FFAG accelerator projects; FFAG storage ring with Energy/emittance Recovery Internal Target (ERIT) and FFAG accelerator complex to study Accelerator Driven Sub-critical reactor (ADS). The FFAG-ERIT has shown that the FFAG accelerator can be a high intensity neutron source with internal target, because of its large energy acceptance. The FFAG accelerator complex for ADS study is under beam commissioning. In the main ring, proton beams will be accelerated up to 100 MeV in this summer.

INTRODUCTION

Kumatori Accelerator driven Reactor Test (KART) project has been started at KURRI from the fiscal year of 2002, aiming to demonstrate the basic feasibility of Accelerator Driven Sub-critical system (ADS) and to develop an 150 MeV proton FFAG accelerator complex as a neutron production driver[1]. The accelerator complex is composed of three FFAG rings; injector, booster, and main ring[2]. The specifications of the each FFAG are summarized in Table 1. As a first stage, the accelerator complex has been planned to output 100 MeV-0.1 nA proton beams in this summer.

The only intense neutron source for BNCT(boron neutron capture therapy) which has been used so far is a nuclear reactor. The expected neutron yield from the accelerator-based neutron source should be about 10^9 n/cm^2/sec, which could be effectively comparable with that from a 5∼10 MW class nuclear reactor. Many groups have investigated epithermal neutrons for BNCT with compact nuclear reactor. In recent years, accelerator-based neutron source for BNCT has been strongly requested, because of the problems associated with reactor installations at hospitals. In KURRI, a scaling type of FFAG accelerator with ERIT concept has been proposed for this purpose.

FFAGS FOR ADS STUDY

Injector

The proton beams of 120 keV are accelerated in the injector FFAG betatron. The injector is composed of eight spiral sector magnets, two acceleration gaps, and electric septa for injection and extraction, respectively. The field distribution in the radial direction can be controlled by trim-coils, and which makes variable energy acceleration possible. We have accomplished the acceleration of proton beams up to 1.5 MeV in the injector. The average output current is about 10 nA.

Betatron tunes are also variable by the trim-coils. We are experimentally investigating fast integer-resonance crossing with the injector. The first experiment showed that the integer resonance was successfully crossed when the crossing speed was high enough [3].

Booster

The booster FFAG adopts multi-turn beam injection by a couple of bump magnets, an electrostatic septum (ES) and a magnetic septum (MS). Captured beam current is about 1∼3 nA with 59 Hz repetition rate. Fast longitudinal matching with bunch rotation method [4] was tried. In the bunch rotation method, the accelerating bucket was rapidly produced after 1/4 synchrotron oscillation in a waiting bucket. Saw-tooth rf was employed for the rotation in order to minimize the filamentation. With the bunch rotation, the quadrupolar synchrotron oscillation could be minimized as shown Fig. 1 and the extracted beam intensity increased at least three times [5]. Final beam energy was estimated to be 11.6 MeV by the revolution frequency and the circumference.

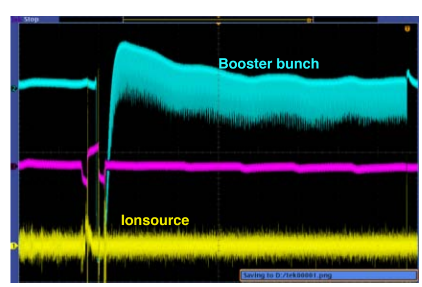

Figure 1: Output signal from current transformer (CT) right after the ion-source (yellow), and Booster bunch monitor (blue); 100 ms/div.

Main Ring

The main ring is composed of 12 return-yoke free magnets. A magnetic material in the straight section gathers the fringing field near by, and thus distorts the closed orbit.

Table 1: Specification of FFAG complex for ADS study(design)

	Injector	Booster	Main Ring
Focusing	Spiral, 8 cells	Radial, 8 cells	Radial, 12 cells
Acceleration	Induction	RF	RF
Field index, k	2.5	4.5	7.5
Energy(Max)	0.1-2.5 MeV	2.5-20 MeV	20-150 MeV
P_{ext}/P_{inj}	5.00(Max)	2.84	2.83
Average orbit radius	0.60-0.99 m	1.42-1.71 m	4.54-5.12 m

The main COD source is the rf cavity, which is covered by a magnetic shield to protect the core from the fringing field. In order to correct the COD, a couple of correction magnet is put on both sides of the accelerating gap. The injected beam is kicked into the closed orbit by an electrostatic septum (ES) and a magnetic kicker. Figure 2 shows the circulating beam picked up by a bunch monitor in the main ring. The beam loss right after injection is assumed to be caused by horizontal aperture, which is limited by the ES. One method to increase the intensity is the beam injection without ES. In such case an additional kicker is necessary.

The beam was accelerated with the rf gap-voltage of 2.5 kV and the synchronous phase of 30 degree. A rapid beam-loss was observed at 4 ms at 20∼25 MeV. The beam-loss will be cured by putting locally additional yokes at the orbit. Accelerated beams after the beam-loss were detected by a radial probe with high-sensitivity fluorescent screen at its head. Beam energy can be estimated by the revolution frequency or the orbit radius, using scaling rule with k=7.5. The injected beam energy was 11.6 MeV, capture frequency 1591.84 kHz, and measured beam position was 4430 mm at injection energy. Figure 3 shows the relation between them. The maximum orbit radius was measured by the fluorescent monitor, with changing final rf frequency.

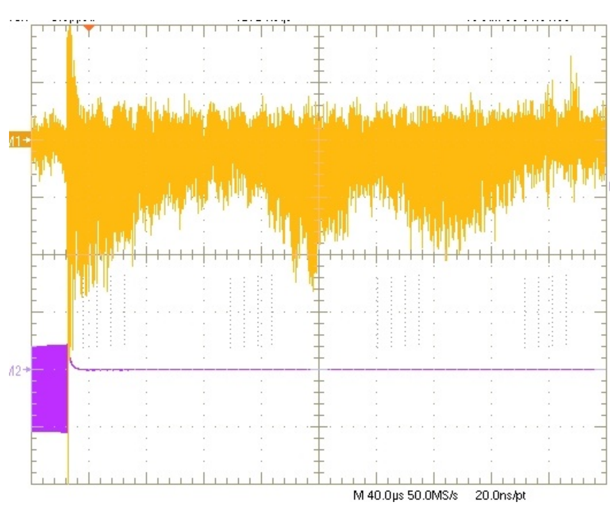

Figure 2: Output signals from bunch monitor of the main ring (yellow) and the booster (magenta); 40 μs/div.

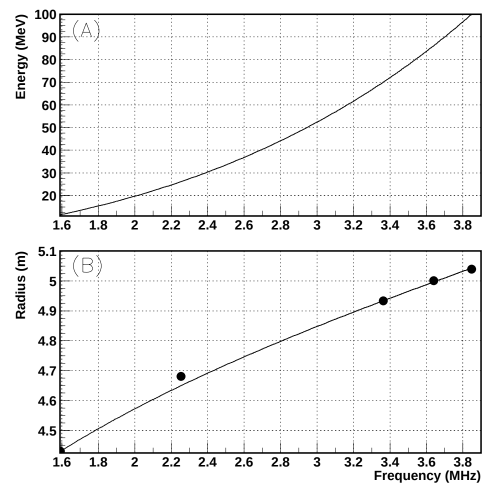

Figure 3: Calculated (A) beam energy and (B) radius at a center of a straight section as functions of revolution frequency; Symbols show the measured values.

FFAG FOR ERIT

Background

For BNCT medical applications, an accelerator-based intense thermal/epithermal neutron source(ABNS) has been strongly requested recently. Requirements for ABNS aiming a hospital size apparatus are a neutron flux of more than 1×10^9 n/cm^2/sec at patient and compact size($<$100 m^2) with no radiation hazard caused by secondary radio activity production. Practical way to satisfy these requirements is to use proton or deuteron induced nuclear reactions with Li or Be target. Even for the proton induced neutron production reactions with Li or Be, the maximum proton energy should be less than 15 MeV, which is threshold energy of spallation reaction to generate tritium produced by fast neutrons. Thus, in ordinary systems of ABNS with an external target which use a cyclotron or proton linac, the requested proton beam current becomes quite high such as about 10 mA for 10 MeV and 50 mA for 3 MeV proton beams, respectively. For such large beam power around 100 kW, serious problems concerning the heat load and radiation damage of the neutron production target also come out. Based on the ERIT scheme, a neutron source for BNCT is under development in Japan as a New Energy Development Organization (NEDO).

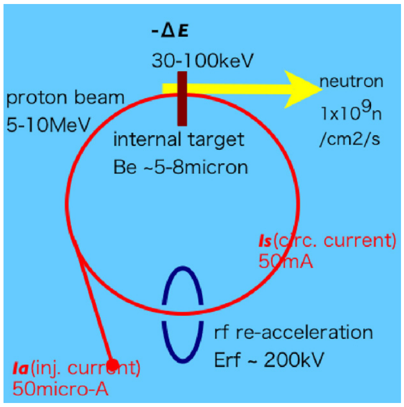

Figure 4: Scheme of ERIT.

ERIT Scheme

In order to overcome these difficulties an ERIT concept with a scaling type of FFAG proton storage ring was proposed for this purpose and is now under construction [6, 7, 8].

Figure 4 shows a schematic diagram of ERIT. The circulating current of the beam is high compare to the extracted beam current, because the bunch orbits the ring many times. When neutron is produced by interaction with an internal target, the neutron flux can be comparable to the nuclear reactor. In this scheme, however, the incident proton beam is lost very quickly due to the interaction with the target atoms turn by turn through the energy loss and emittance blow up. These deleterious effects can be cured by ionization cooling [9, 10]. The transverse emittance reaches equilibrium because of ionization cooling which is invoked in the ERIT scheme.

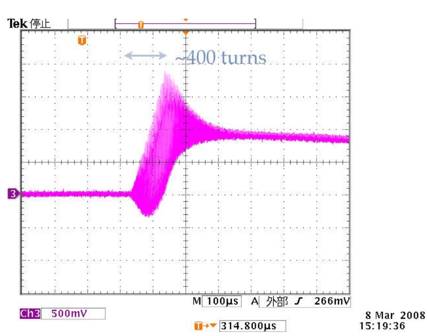

Figure 5: Beam accumulation and survival in the FFAG ring.

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. One rf cavity is placed in the ring for re-acceleration.

The ion source is a volume type of H^- ion source. The available H^- beam current (peak) is about 5 mA. The injector is a proton linac, provided by AccSys-Hitachi, consists of a 425 MHz RFQ and DTLs. H^- ions are accelerated there up to 11 MeV. The maximum beam duty factor is about 1.8 % where the beam repetition is 200 Hz. The total length is about 5 m and the peak rf power is 1.5 MW.

The ERIT ring is a 8 FDF cells radial sector type FFAG proton storage ring. The mean radius of the ring is 2.35 m and the packing factor of the magnets in the ring is about 60 %. The beam acceptance of the FFAG ring is important to increase an efficiency of neutron production in this scheme. The horizontal and vertical acceptance of the ring are 7000 mm-mrad and 3000 mm-mrad, respectively.

The rf cavity is made of copper-plated iron; the thickness of the copper is approximately 100 μm. The RF frequency is about 18 MHz and cavity diameter is less than 2 m even at such relatively low frequency. The rf cavity is operated in cw mode with the input power of 100 kW. The peak gap voltage thus obtained is 230 kV, which satisfies the requirements.

Experiment

The beam experiment has been carried out to demonstrate the principle of the ERIT scheme. The injected beam was a pulsed beam with duration of 130 μsec, which was equivalent to about 400 turns in the ring. The beam behaviour in the ring was measured by an electrostatic bunch monitor. Figure 5 shows a typical beam accumulation measured by the bunch monitor. The measured decay time is more than 100 μsec.

SUMMARY

The FFAG complex for ADS study has been constructed. A beam was successfully accelerated in the Main ring, with the repetition rate of 59/2 Hz.

The FFAG-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 ERIT-scheme as expected. Yield and spectrum of moderated neutrons are under optimization.

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