CONSTRUCTION OF FFAG ACCELERATORS IN KURRI FOR ADS STUDY

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Abstract

Kumatori Accelerator driven Reactor Test project (KART) has been started at Kyoto University Research Reactor Institute (KURRI) from the fiscal year of 2002, aiming to demonstrate the basic feasibility of ADS (Accelerator Driven Sub-critical system) and to develop an 150 MeV proton FFAG (Fixed Field Alternating Gradient) accelerator complex as a neutron production driver. This FFAG complex will be connected with our Kyoto University Critical Assembly (KUCA) by the end of March 2006 for the basic ADS experiments.

INTRODUCTION

As a substitute for the 5 MW reactor at Kyoto University (KUR), a neutron source based on the ADS concept has been proposed in 1996[1]. The conceptual design study on ADSR(Accelerator Driven Sub-critical Reactor) using the MCNPX code clarified the lack of reliable effective multiplication factor k_{eff} in the proton energy region between 20 MeV and 150 MeV. Since the experimental studies in our institute were performed using KUCA and a 300 keV Cockcroft-Walton accelerator[2, 3], a proton beam source which covers between 20 MeV and 150 MeV is required to extend our study on ADS system.

The requirements towards proton sources for ADS are 1) high beam intensity, 2) high efficiency on power consumption, and 3) high stability in operation. FFAG accelerator, which was orignally proposed by Ohkawa 40 years ago[4], is regarded as a good candidate as the proton driver for ADS. Because of its fixed magnetic field, high repetition rate of beam acceleration and much less power consumption in the accelerator by the introduction of superconducting magnet are expected. Although such attractive features, no FFAG with RF has not been realized except electron models until recently because of technical difficulties such as the production of wide band high voltage RF cavity or the lack of a long straight section for beam injection and extraction. Recently, Mori et al. have developed a wide band RF cavity with FINEMET[5] and succeeded the first acceleration of proton with a 500 keV PoP FFAG synchrotron[6]. Now they have developed a "return-yoke free" magnet for the 150 MeV FFAG synchrotron[7] in which they try to extract the beam from FFAG for the first time.

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On such basis of our study and the technical developments on FFAG, KART project has been approved and started from the fiscal year of 2002. In this project, the basic feasibility of ADS system and the multiplication factor k_{eff} in the energy region of $E_p = 20 \sim 150$ MeV will be studied. Another important aim in this project is to develop a practical FFAG accelerator as a proton driver for ADS.

FFAG ACCELERATOR COMPLEX

In KART project, an FFAG accelerator complex is now under construction as the proton source for ADS study. This complex consists of one FFAG with an induction unit for acceleration as the injector and two FFAG with RF as the booster and main accelerators, respectively. All of these accelerators will be in pulse operation at the repetition rate of 100 Hz. The schematic diagram of our FFAG complex is shown in Fig. 1. Basic specifications for this FFAG complex are summarized in Table 1. The layout of these FFAG accelerators in the accelerator room is shown in Fig. 2.

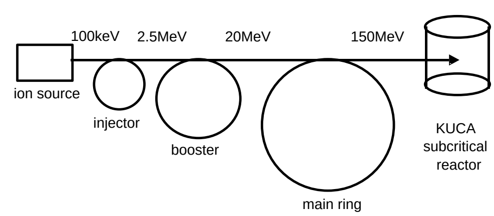

Figure 1: The schematic diagram of FFAG complex at KURRI.

Table 1: Specification of FFAG complex

	Injector	**Booster**	**Main**
Focusing	Spiral	Radial	Radial
Acceleration	Induction	RF	RF
k	2.5	4.5	7.6
E_{inj}	100 keV	2.5 MeV	20 MeV
E_{ext}	2.5 MeV	20 MeV	150 MeV
p_{ext} / p_{inj}	5.00	2.84	2.83
r_{inj}	0.60 m	1.42 m	4.54 m
r_{ext}	0.99 m	1.71 m	5.12 m

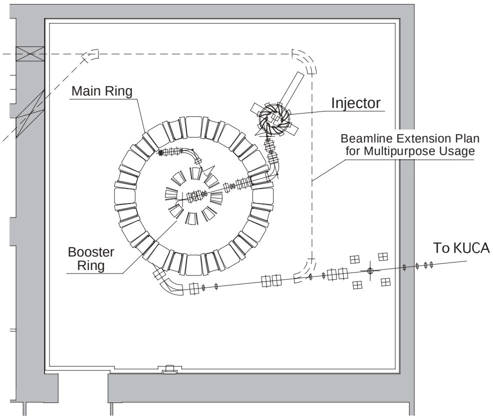

Figure 2: FFAG complex at KURRI.

Ion source

H^+ ions are extracted from the typical multi-cusp type ion source and accelerated to 100 keV, then transported to the injector. Since all of the FFAG complex are operated in pulse mode, the ion source itself is also operated in the pulse mode for high power efficiency. The arc voltage is pulsed at the duty of $\sim 10\%$, then the pulsed beam is shaped to $\sim 50\mu$s at the beam chopper placed in the transport line between the ion source and the following injector.

Injector FFAG with an induction unit for acceleration

In the present FFAG complex, a 2.5 MeV FFAG with an induction unit for acceleration is used as the injector. This FFAG has 12 sprial sector magnets with the spiral angle of 42 degrees. FFAG magnetic field following the function of $B = B_0(r/r_0)^k$ is produced by 32 trim coils which are placed on the pole face along the *r* direction.

A typical pattern of induced acceleration voltage is shown in Fig. 4. In this operation pattern, proton beam from the ion source is accepeted for 50 μs and the beam pulse ejected from the injector is compressed to 5 μs.

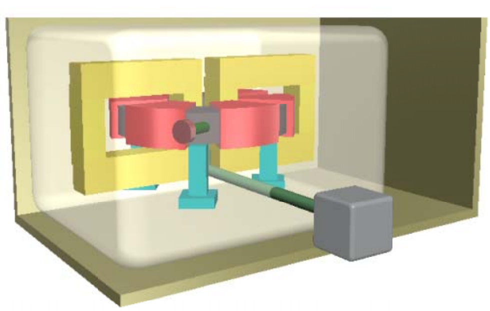

Figure 3: Schematic view of the FFAG injector.

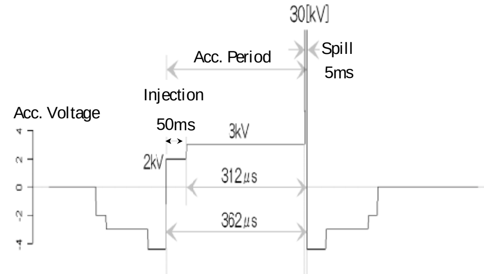

Figure 4: Acceleration pattern of FFAG injector.

Booster FFAG with RF

Injected beam from the FFAG injector at the energy of 2.5 MeV is then accelerated up to 20 MeV in this booster ring. This FFAG with RF is the radial sector type, consisting of 8 cells of DFD magnets. The lattice structure of this booster ring is shown in Fig. 5. These magnets are "return-yoke free" magnets with flat pole face and each magnet has 22 trim coils placed along the *r* direction (Fig. 6) to produce the FFAG magnetic field with a certain *k*. The advantage of using trim coils is that one can easily change *k* by choosing a proper current set to trim coils, which is an important characteristics for the variable energy FFAG accelerators.

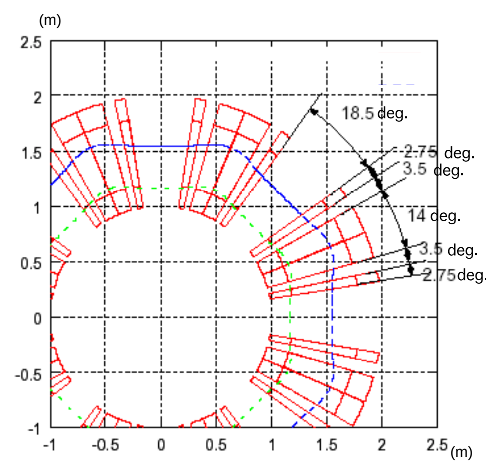

Figure 5: Lattice structure of the booster ring. Green and Blue lines are the beam orbits corresponding to r_{inj} and r_{ext} , respectively.

Main FFAG with RF

The main accelerator is identical to the 150 MeV FFAG with RF which is now tested at KEK, except some modifications to achieve the high repetition rate (100 Hz) in the acceleration in the current FFAG complex. Detailed discussions on magnet design is available in ref. [7]. Since a wideband RF cavity can produce the acceleration voltage ~10 kV at most, we need to have two RF cavities in the ring to complete the acceleration of injected beam bunch

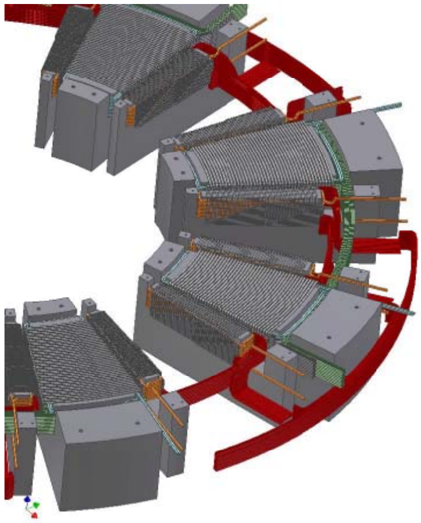

Figure 6: 3D view of sector magnets in the booster ring sliced at the median plane. 22 trim coils are placed along the *r* direction on the flat pole face of each magnet to produce a FFAG field with variable *k* index.

from the booster within each repetition period of $\sim 100\ \mu$s. Another diffenence is in the magnets used in the main ring. The cross section of return yoke and the purity of iron are increased to accept a high magnetic flux required for 200 MeV acceleration, expecting the beam energy upgrade by the reinforcement of power supplies in near future.

REACTOR PHYSICS STUDY ON ADSR IN KURRI

The power *P* of ADSR is proportional to the intensity of neutron source *S* and the effective multiplication factor k_{eff};

$$P \propto S/(1-k_{eff}). \quad (1)$$

Since ADSR is operated at k_{eff} just below and very close to 1, slight difference in k_{eff} results in a large discrepancy on the output between the calculation model and the actual reactor. Therefore, the improvement of the simulation code or the reliable nuclear data is very important for the stable and safe operation of ADSR.

We set the main purpose of KART project to the study on the energy-dependent neutronics features for the proton energy between 20 and 150 MeV using the FFAG accelerator complex, such as the reliable nuclear data for the reliable k_{eff} or the flux distribution in the ADSR core. This is because our conceptual study on ADSR with MCNPX code revealed the lack of reliable nuclear data for the estimation of k_{eff} at the proton energy between 20 and 150 MeV.

The paremeter *S* will be used for the compensation of k_{eff} change through the fuel burn in the ADSR operation. Since *S* can be varied either the beam energy or the beam current, we plan to perform the evaluation of merits and demerits of power control methods with the combination of FFAG complex and KUCA.

CURRENT STATUS AND FUTURE PROSPECTS

The construction of the building for the FFAG complex named “Innovation Research Laboratory” has been completed at the end of March 2004. This buliding is designed not only for FFAG accelerator complex, but also for the multipurpose usage of the beam from the FFAG complex such as nuclear physics, chemistry, material science and cancer therapy.

Currently, the magnets for the FFAG accelerators are being manufactured. The FFAG complex itself will be constructed from the fall of 2004. The first beam from this FFAG complex is expected around the spring of 2005. As for KUCA, the design work on the subcritical core and the target for the neutron production are now in progress. Modifications in KUCA will be completed around the summer of 2005. Basic studies on ADS will be employed just after the beam line between the FFAG complex and KUCA will be ready, expected around the fall of 2005.

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