CONSTRUCTION OF A FFAG ACCELERATOR COMPLEX FOR ADS STUDY

M. Tanigaki*, K. Mishima, S. Shiroya, RRI, Kyoto University, Kumatori, Osaka 590-0494, Japan
Y. Ishi, S. Fukumoto, Mitsubishi Electric Corporation , Kobe, 652-8555, Japan
S. Machida, Y. Mori, KEK, Tsukuba, Ibaragi 305-0801, Japan
M. Inoue, SLLS, Ritsumeikan University, Kusatsu, Shiga 525-8577, Japan

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 Accelerator Driven Sub-critical Reactor system (ADSR) and to develop an 150 MeV proton Fixed Field Alternating Gradient (FFAG) 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 ADSR experiments.

INTRODUCTION

As a substitute for the 5 MW reactor at Kyoto University (KUR), a neutron source based on the ADSR concept has been proposed in 1996[1]. The conceptual design study on ADSR 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 ADSR system.

The requirements towards proton sources for ADSR 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 ADSR. 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 accelators have 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.

* tanigaki@rri.kyoto-u.ac.jp

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 ADSR 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 ADSR.

FFAG ACCELERATOR COMPLEX

In KART project, an FFAG accelerator complex is now under construction as the proton source for ADSR 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 120 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.

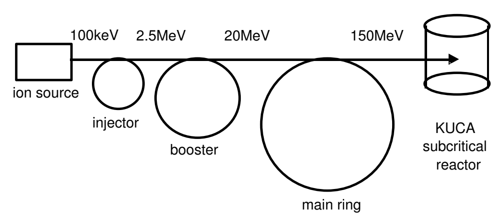

Figure 1: The schematic diagram of FFAG complex at KURRI.

Table 1: Specification of the FFAG complex at KUR

	Injector	**Booster**	**Main**
Focusing	Spiral	Radial	Radial
Acceleration	Induction	RF	RF
k	2.5	2.5	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	1.27 m	4.54 m
r_{ext}	0.99 m	1.74 m	5.12 m

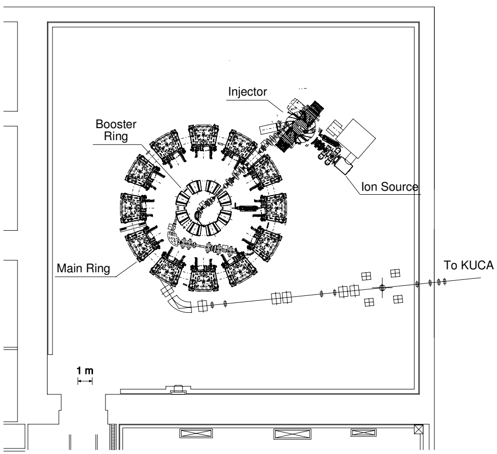

Figure 2: FFAG complex at KURRI.

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. The beam energy of the current FFAG complex can be varied through the change of this k by choosing the proper current set for trim coils.

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.

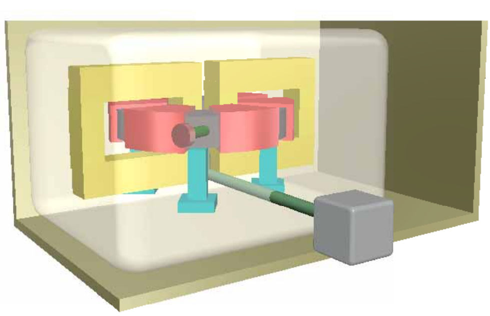

Figure 3: Schematic view of the FFAG injector.

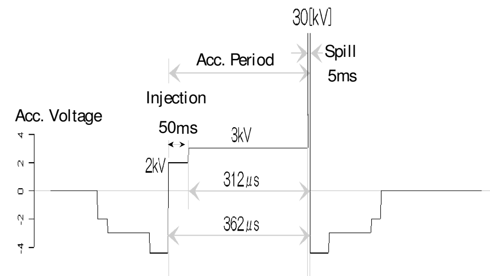

Figure 4: Acceleration pattern of FFAG injector.

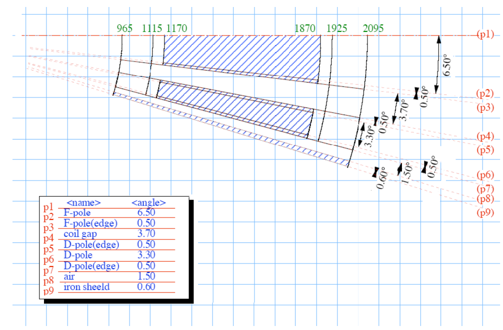

Figure 5: Plane view of the main magnet of the booster ring. Each magnet has DFD structure and the line p1in the figure is the center of the magnet, thus plane symmetry to this line.

Booster FFAG with RF

The beam from the FFAG injector 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 main magnet of this booster ring is shown in Fig. 5. The FFAG magnetic field with a certain k is produced by its pole shape with the half gap proportional to $(r/r_0)^k$ in each magnet. The window frame type magnetic shield is attached to the both sides of the magnet to reduce the fringing field at the straight sections. In the current design, the fringing field at the center of the straight section is expected at most $\sim$ 70 Gauss from the 3D calculation of the magnetic field with TOSCA.

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. Detailed discussions on magnet design is available in ref. [7]. Since a wideband RF cavity can produce the acceleration voltage $\sim$10 kV at most, we prepare a room for an additional RF cavity in the ring to increase the repetition period of acceleration in the future. There are also some differences in the magnets used in the main ring. Although the pole shape itself is identical to the 150 MeV FFAG accelerator at KEK, each main magnet has an additional return yoke outside of the magnet to reduce the fringing field in the straight section. The schematic view of these main magnets is shown in Fig. 6. For the beam energy upgrade by the reinforcement of power supplies in near future, the purity of iron in the magnets are increased to accept a high magnetic flux required for 200 MeV acceleration.

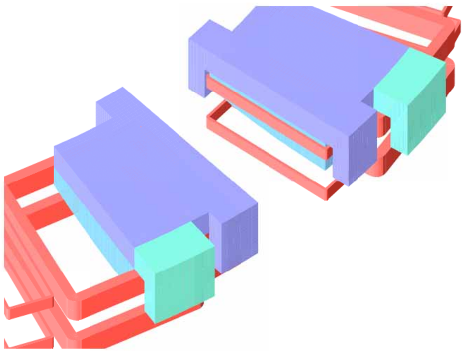

Figure 6: 3D view of sector magnets in the main ring generated from the input file for TOSCA. The structure of this sector magnet is basically identical to the one in the 150 MeV accelerator at KEK and an additional return yoke is placed outside of the magnet(light blue part).

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};

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

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.

Currently, the preliminary studies on ADSR have been performed using the critical assembly and the Cockcroft-Walton accelerator in KUCA. For example, numerical experiments have been performed on the criticality of our subcritical core with a collimator as a guide of high energy neutron flux to the center of the core[9]. The results are in good agreement with the experimental results using the neutron flux produced by the Cockcroft-Walton accelerator in 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.

REFERENCES

[1] K. Kawase and M. Inoue, "Neutron Factory Project at KURRI", APAC 1998, Tsukuba, Japan, p. 104

[2] S. Shiroya, H. Unesaki et al., "Neutronics of Future Neutron Source Based on Accelerator Driven Subcritical Reactor Concept in Kyoto University Research Reactor Institute (KURRI)", Int. Seminar on Advanced Nucl. Energy Systems toward Zero Release of Radioactive Wastes, 2nd Fujiwara Int. Seminar, Nov. 6-9, 2000, Shizuoka, Japan, *Abstracts* p. 58.

[3] S. Shiroya, H. Unesaki et al., Trans. Am. Nucl. Soc., 2001 Annu. Mtg., June 17-21, 2001, Milwaukee, Wisconsin, p. 78.

[4] T.Ohkawa, Proc. of annual meeting of JPS(1953)

[5] Y. Mori et al., "A new type of rf cavity for high intensity proton synchrotron using high permeability magnetic alloy", EPAC 1998, p. 299.

[6] M. Aiba et al., "DEVELOPMENT OF A FFAG PROTON SYNCHROTRON", Proceeding of EPAC 2000, Vienna, Austria, p. 581

[7] T. Adachi et al., "A 150MeV FFAG SYNCHROTRON WITH "RETURN-YOKE FREE" MAGNET", PAC 2001, Chicago, the United States, p. 3254

[8] M. Aiba et al., "Beam Injection and Extraction in 150 MeV FFAG", Proceeding of EPAC 2002, Paris, France, p. 1076

[9] C.H. Pyeon, Y. Hirano et al."PRELIMINARY STUDY ON ADSR BY USING FFAG ACCELERATOR IN KUCA", Proceedings of Global 2003, New Orleans, the United States, p. 2193