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 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 our current experimental studies are limited to those with 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.

A Fixed Field Altenating Gradient (FFAG) accelerator, which was orignally proposed by Ohkawa 40 years ago[4], recently attracts much attention because of its advantages such as a large acceptance, especially in horizontal and longitudinal directions or a possible fast repetition rate compared to that for synchrotrons, e.g. 1 kHz. Furthermore, the operation of an FFAG accelerator is expected to be very stable because no active feed back is required for the acceleration.

Regardless of such attractive features, no FFAG accelators have not been realized except a couple of electron models until recently because of the technical difficulties, such as the lack 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 with RF acceleration[6]. Now they have developed a "return-yoke free" magnet for the 150 MeV FFAG with RF acceleration[7]. They have succeeded the first beam extraction from this FFAG accelerator in March, 2005.

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 $\mathrm{E}_p = 20 \sim 150$ 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 acceleration as the injector and two FFAG with RF as the booster and main accelerators, respectively. 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. 1. All of these accelerators will be in pulse operation at the repetition rate of 120 Hz. The beam energy of the current FFAG complex can be varied between $20 \sim 150$ MeV by the change of beam energy from the injector.

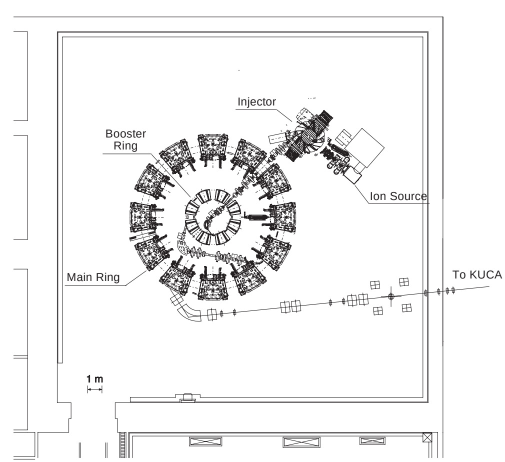

Figure 1: FFAG complex at KURRI.

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Table 1: Specification of the FFAG complex at KUR

	Injector	**Booster**	**Main**
Focusing	Spiral	Radial	Radial
Acceleration	Induction	RF	RF
k	2	2.45	7.5
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	1.86 m	5.12 m

Ion source and injector FFAG with induction acceleration

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 less power consumption. 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 (Fig. 2).

The injector FFAG is a 2.5 MeV FFAG with induction acceleration and it has 12 sprial sector magnets with the spiral angle of 42 degrees. FFAG magnetic field with a certain index k is produced by 32 trim coils which are placed on the pole face along the r direction (Fig. 3). The beam energy of the current FFAG complex can be varied through the change of this k by supplying the proper current set for trim coils. Silicon steel lamination cores are used for the induction acceleration. 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 kicked out from the injector is compressed to 5 μs.

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 is produced by its pole shape with the half gap proportional to $(r/r_0)^k$ in each magnet. In this booster ring, $k = 2.45$ is chosen to minimize the beam excursion and the resonance variation. 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.

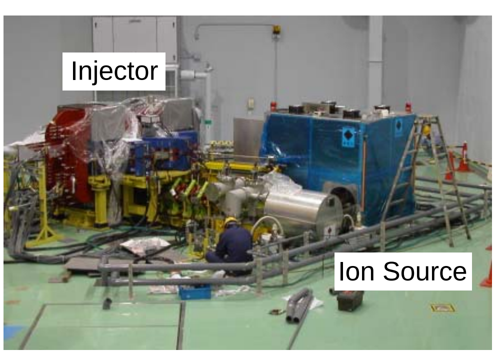

Figure 2: FFAG injector and ion source.

Figure 3: 32 trim coils attached to the pole piece of the injector.

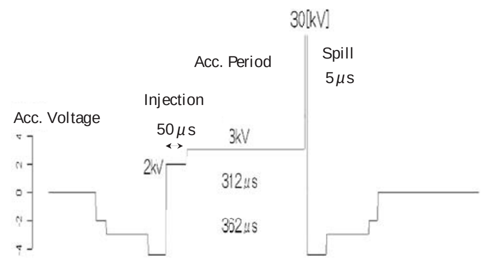

Figure 4: Acceleration pattern of FFAG injector.

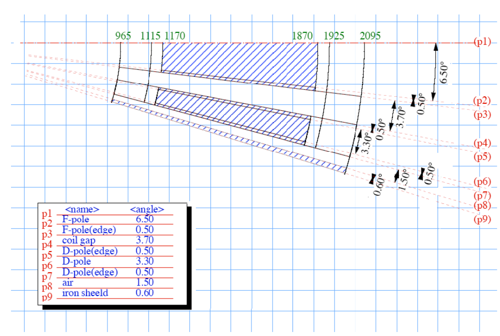

Figure 5: Plane view of the main magnet of the booster ring. The half of the magnet is shown in this figure and the line p1 in the figure is the symmetry plane of this magnet. The window type shield is placed outside the magnet(between the lines p8 and p9).

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Main FFAG with RF

The main accelerator is basically identical to the 150 MeV FFAG with RF at KEK, from which the first beam extraction has been recently succeeded. Detailed discussions on the 150 MeV FFAG at KEK is available in ref. [7]. Although the design of magnets itself is also identical, each main magnet of our main accelerator has an additional return yoke outside the magnet to reduce the fringing field in the straight section. The schematic view of these main magnets is shown in Fig. 6.

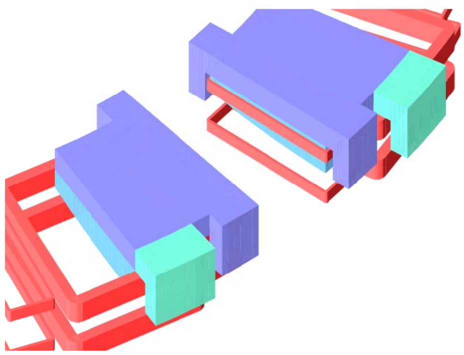

Figure 6: Sector magnets in the main ring generated from the input file for TOSCA. The structure of these magnets is basically identical to those for 150 MeV FFAG at KEK, and an additional return yoke is placed outside each magnet (light blue part).

Control System

The control system for this FFAG accelerator complex consists of conventional PCs and PLCs connected over TCP/IP network, aiming the highly flexible and low-cost control system (Fig. 7). Highly integrated control sequences and human interfaces are prepared by LabView on PC, and low level control sequences are programmed in PLC modules. Since all communications are made over TCP/IP, not only the additional PLCs but also any devices with TCP/IP capability can be easily introduced to this control system.

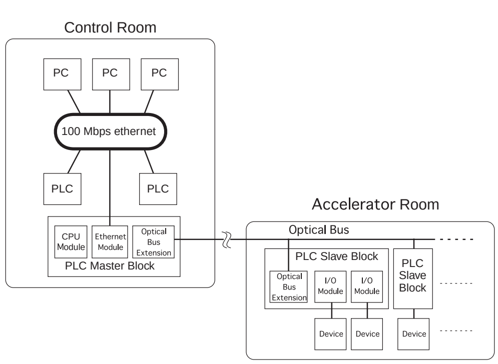

Figure 7: Configuration of the present control system.

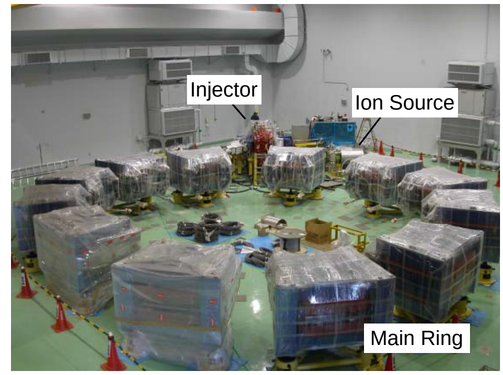

Figure 8: Current status of the accelerator room in "Innovation Research Laboratory".

CURRENT STATUS AND FUTURE PROSPECTS

The construction of "Innovation Research Laboratory" has already been completed in March, 2004. This buliding is not only for FFAG accelerator complex, but also for the multipurpose usage of the beam from the FFAG complex in future, such as nuclear physics, chemistry, material science and cancer therapy.

Currently, magnets of the main ring have been already in the accelerator room and the construction of the ion source and the injector is almost completed (Fig. 8). The test operation of the ion source and the injector is now in progress. The first beam from this FFAG complex is expected in the beginning of 2006. The design work on the subcritical core and the target for the neutron production are also in progress. Modifications in KUCA will be started around the summer of 2005. Basic studies on ADS will be employed in the spring of 2006.

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