PRESENT STATUS OF FFAG ACCELERATORS IN KURRI FOR ADS STUDY

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Abstract

KART (Kumatori Accelerator driven Reactor Test) project is in progress at the Kyoto University Research Reactor Institute (KURRI) since fiscal year 2002. We are now constructing a 150 MeV proton FFAG accelerator complex as a neutron production driver for this project. The developments and the current status of this accelerator complex, including the current status of this project, is introduced.

INTRODUCTION

As a substitute for the 5 MW reactor at Kyoto University (KUR), a neutron source based on the Accelerator Driven Sub-critical Reactor system (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 or a possible fast repetition rate compared to that for synchrotrons. Furthermore, the operation of an FFAG accelerator is expected to be very stable because no active feed back is required for the acceleration. From these features, FFAG accelerators can be a good candidate for the proton driver in ADS system.

The technical difficulties in FFAG accelerators, such as the lack of wide band high voltage RF cavity or the short straight section insufficient for beam injection and extraction, have been solved by the recent developments [5, 6]. The first acceleration of proton with a 500 keV PoP FFAG with RF acceleration has been performed by Mori group [7]. Now they have developed a "return-yoke free" magnet for the 150 MeV FFAG with RF acceleration[6].

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, a practical proton FFAG accelerator complex of $E_p = 20 \sim 150$ MeV as a proton driver for ADSR is constructed in KURRI and 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.

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FFAG ACCELERATOR COMPLEX

The FFAG accelerator complex for KART project 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.

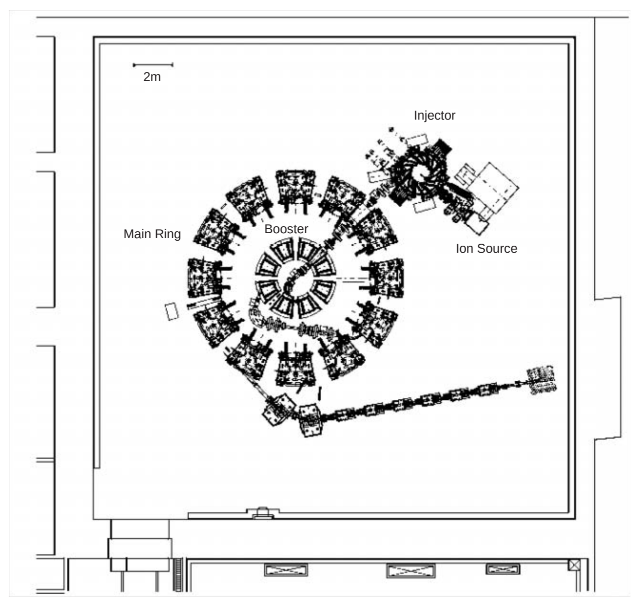

Figure 1: FFAG complex at KURRI.

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 the 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

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

shaped to $\sim 50\mu$s at the beam chopper placed in the transport line between the ion source and the following injector.

The injector FFAG is a 2.5 MeV FFAG with induction acceleration scheme and it has 8 sprial sector magnets with the spiral angle of 42 degrees (Fig. 2). Induction acceleration is suitable for the continuous injection which will be required in the future upgrade in the beam intensity. The spiral sector type is chosen to this injector because of its rather long straight section. FFAG magnetic field with a certain index k is produced by 32 trim coils placed on the pole face along the r direction (Fig. **??**). 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.

Booster FFAG with RF

The beam from the 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 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 less than 100 Gauss from the magnetic field measurement. The beam injection is performed by a

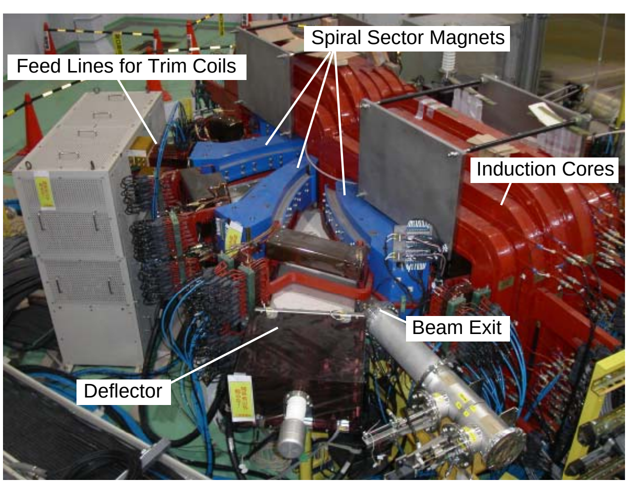

Figure 2: FFAG injector and ion source.

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

labeltrim coils

septum magnet, an inflector electrode and a pair of bump magnets. Acceleration voltage is supplied by an RF cavity with very low Q (~ 1) for the flat output voltage over the acceleration frequency range. The beam extraction is performed by kicker and septum magnets. All the components for beam injection/extraction except the inflector for beam injection are in pulse operation. The booster ring under construction is shown in Fig. 4.

Main FFAG with RF

The main accelerator is basically identical to the 150 MeV FFAG at KEK. Detailed discussions are available in ref. [6]. In our 150 MeV FFAG, the purity of iron in the magnets are increased to accept a high magnetic flux required for acceleration at 200 MeV, aiming the beam energy upgrade by the reinforcement of power supplies in near future.

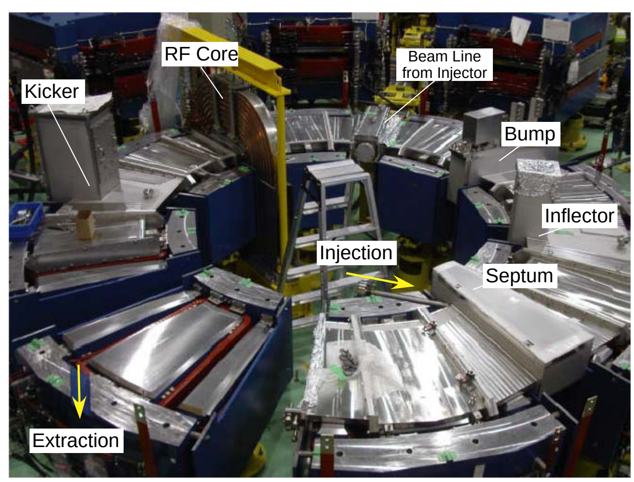

Figure 4: The booster FFAG under construction. DFD structure of the radial sector magnets can be seen in the front-left lattice. The remaining bump magnet and the septum for beam extraction are to be placed in the straight section before the lattice with beam extraction channel.

Control System

The control system for this FFAG accelerator complex consists of conventional PCs and PLCs connected over TCP/IP [8]. With this network-based scheme, the system obtains high flexibility to the changes of hardware configurations both in the accelerator side and control system itself. Highly integrated control sequences and human interfaces are prepared by LabView on PC, and low level control sequences are programmed in PLC modules (Fig. 5). Control parameters and equipment status are flattened to a simple text data set and exchanged between PCs and PLCs over conventional TCP/IP networks. Therefore, any kind of development environments (such as Visual Basic or Java) are welcome to our control system as long as they can handle our simple data format via TCP/IP protocol. We choose LabView as our default environment on PC because of its multi-platform capability and simple programming method. This control system is already in use for commissioning and shows very good performances and high flexibility towards the modifications in the configuration of components of FFAG accelerators.

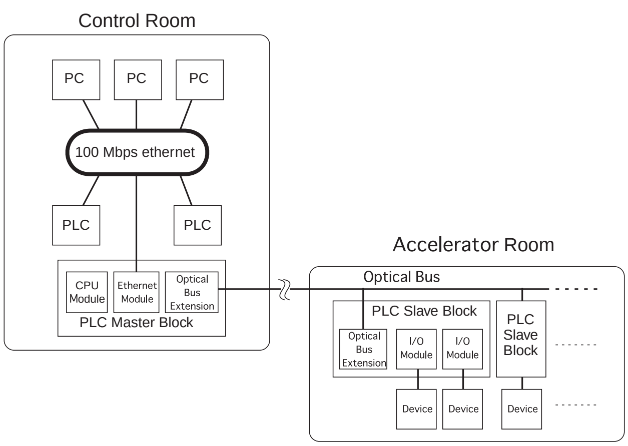

Figure 5: Configuration of the present control system.

CURRENT STATUS AND FUTURE PROSPECTS

The construction of FFAG accelerator complex is in progress since the construction of "Innovation Research Laboratory" was completed in March, 2004. This building 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, the injector and the booster is almost completed (Fig. 6). The test operations of each section or the unit tests are 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. The construction of the beam line which connects this FFAG accelerator complex and KUCA has already been started and expected to complete around this summer. Modifications of fuel assembly and the preparation of the neutron converter in KUCA has already begun for the start of ADS study in this year.

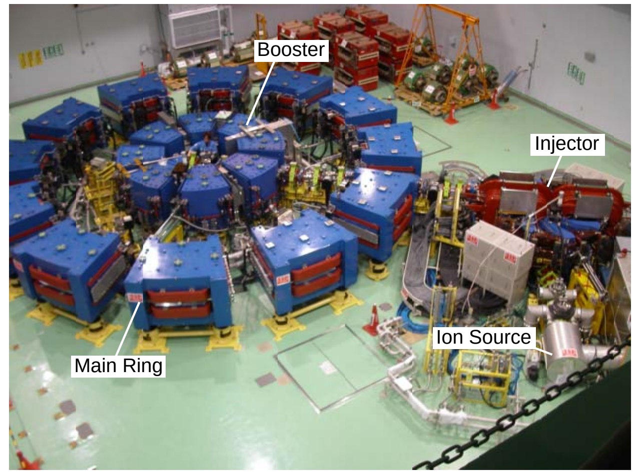

Figure 6: Current status of the accelerator room in "Innovation Research Laboratory".

This paper contains some results obtained within the task 'Feasibility Study on ADSR Using Fixed Field Alternating Gradient (FFAG) Synchrotron as an Energy Amplifier' entrusted from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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