# STATUS REPORT OF KURRI FFAG ACCELERATORS*

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### *Abstract*

Present status and developments of FFAG accelerators at Kyoto University, Research Reactor Institute (KURRI) are presented.

## INTRODUCTION

In KURRI, a couple of projects with FFAG accelerator and some studies of FFAG accelerator for various applications have been carried out. Most of them are summarized as follows.

### *Project*

1) Basic experimental study of accelerator-driven subcritical reactor (ADSR) with spallation neutrons generated by 150MeV proton FFAG accelerator complex.

2) Beam power(intensity and energy) upgrade of FFAG proton accelerator.

### *Research and development*

1) Development of compact neutron source with FFAG-ERIT scheme.

2) Study of FFAG hadron accelerator with super conducting magnet with high temperature super conducting coil (HTSC).

3) Development of advanced FFAG accelerator.

Project of ADSR study using a small nuclear reactor(KUCA) where the output power is less than 100W has been started since 2006 and the world first experimental results were obtained in 2009 [1].

FIgure 1 shows a schematic layout of the FFAG-KUCA system for ADSR experiment. The 150MeV proton FFAG was installed at the newly constructed building called " Innovation Research Laboratory " and it is connected to KUCA with a long beam line, which is located just 1m below from the office ordinary people is living. The FFAG accelerator complex is composed of three FFAG rings as shown in Fig. 2. The first experimental result with the uranium fuel cores at KUCA implying the thermal neutron yield as a function of time is shown in Fig.3. As clearly

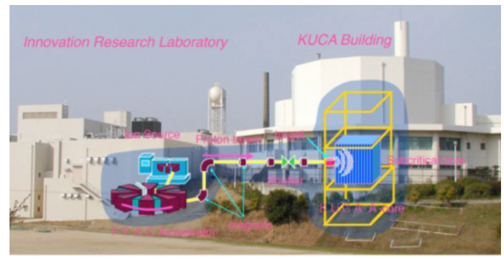


Figure 1: Schematic layout of ADSR experiment with 150MeV proton FFAG accelerator complex at KURRI.

seen from this figure, the thermal neutron yield in the reactor core are multiplied by chain nuclear fission reactions following after very short ( 10nsec) pulsed proton beams from the FFAG accelerator are injected.

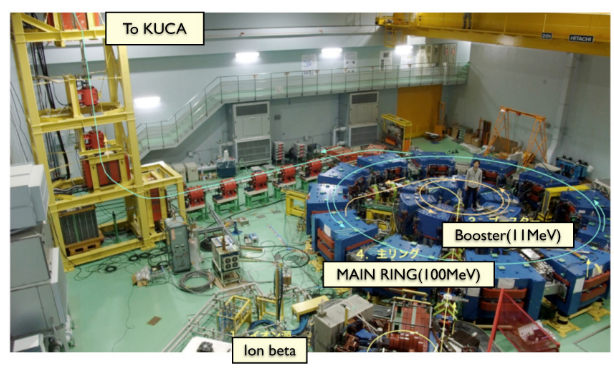


Figure 2: FFAG proton accelerator complex for ADSR study.

In this paper, present status and some future prospects for these projects and studies on FFAG accelerators are outlined.

## ADSR STUDY WITH THORIUM FUEL

A thorium loaded ADSR is one of the most interesting schemes for future safe nuclear energy production from the viewpoint of fuel resource and physical protection of nuclear materials. Recently, we have tried an ADSR experiment with thorium loaded nuclear cores in KUCA. The beam intensity of the FFAG proton accelerator was increased up to about 1nA in the averaged beam current with a new $H^-$ injector (described below), which was measured at the beam transport line to the front of the KUCA core,

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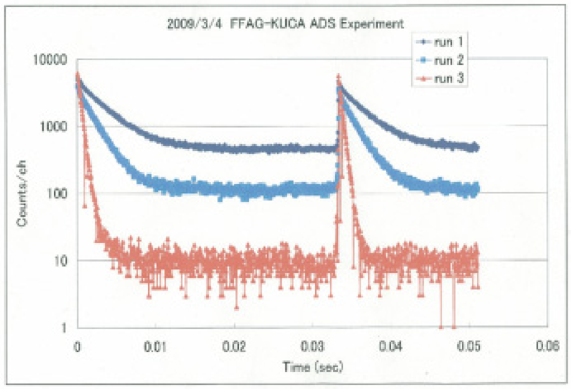


Figure 3: First ADSR experimental result with uranium fuel cores in KUCA.

which reached almost the beam intensity limit claimed by radiation safety.

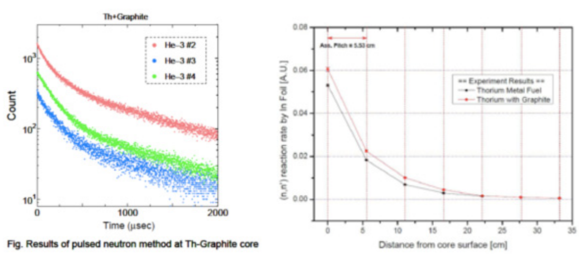


Figure 4: First experimental result with Th-Graphite core in KUCA.

Figure 4 shows some preliminary experimental results at Th-Graphite core in KUCA. It looks obvious that more intensive and detail studies are necessary in future. The accelerator control system was totally renewed with EPICS based accelerator control system under collaboration with the KEK control group [2]. The previously used control system was based on LabVIEW, which was sometimes very unstable, especially under heavy network traffic condition and seems to be not so adequate for time-varying accelerator such as synchrotron and FFAG accelerators. Using the EPICS based control system, the operation of FFAG accelerator becomes stable and reliable. Figure 5 shows a photograph of the control room of FFAG proton accelerator at KURRI. Typical graphics showing the status of devices with EPICS control system of the FFAG accelerator at KURRI is presented in Fig. 6

## BEAM POWER UPGRADE

Higher beam power operation in the 150MeV proton FFAG accelerator is strongly demanded for various applications with intense spallation neutrons such as advanced study for ADSR , material sciences, solid state physics, nuclear data and so on in future, although the beam intensity for the present ADSR basic experiment with KUCA

Figure 5: Photograph of the control room of 150MeV proton FFAG accelerator at KURRI.

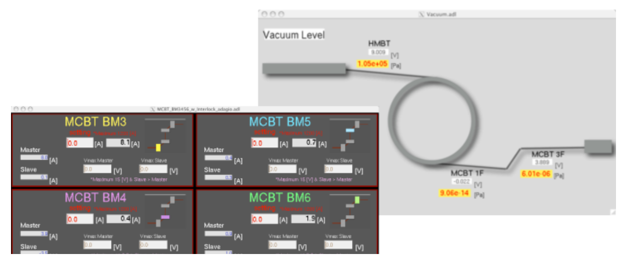


Figure 6: Typical graphics shown on the control console with EPICS based accelerator control system.

was almost reached to the level of radiation safety limit. The beam intensity for proton FFAG accelerator can be increased with the charge exchanged multi-turn injection with $H^-$ ion beam just as that for proton synchrotron. Fortunately in KURRI, an $H^-$ ion linac was constructed for the neutron source with ERIT-FFAG scheme(described below) and now is operational at the next room of the 150MeV proton FFAG accelerator. This linac has a capability to operate with the large beam duty factor where the maximum repetition and duration of the beam are 100Hz and 70 μsec, respectively. The beam energy of the linac is 11MeV which allows to inject the beam into the main ring of the proton FFAG accelerator. In 2010, a new beam line to transport the $H^-$ ion beam from the linac to the main ring of FFAG accelerator shown in Fig. 7 was constructed [3]. Since the magnetic field of the FFAG accelerator is static, the $H^-$ ion beam can be injected into the ring from outside passing through a couple of ring magnets where the careful beam optics designs are necessary. The charge stripping carbon foil is located almost at the center of the main ring magnet. In the preliminary experiment, we have succeeded in injecting and accelerating the beam at the main ring FFAG accelerator and obtained an order of magnitude large beam current in the main ring.

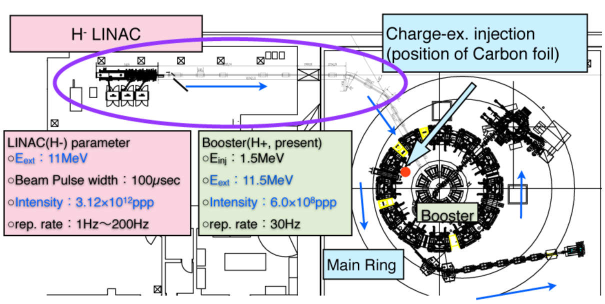


Figure 7: Schematic layout the $H^-$ ion injection system.

## RESEARCH AND DEVELOPMENT

Various research and development studies on FFAG accelerator have been carried out. A compact neutron source with ERIT-FFAG scheme using ionization cooling as shown in Fig. 8 has been developed [4, 5] and it was experimentally clarified to obtain the neutron yield of more than $5 \times 10^8$ n cm$^{-2}$sec$^{-1}$. Design study of compact FFAG accelerators using super conducing magnets with high temperature super conducting(HTSC) coils has been carried out for future ADSR study and also for hadron therapy. Figure 8 shows an example of design of the compact FFAG accelerator for carbon therapy using super conducting magnets with HTSC coils [6].

Figure 8: Compact neutron source with ERIT-FFAG scheme.

In the beam optics and dynamics points of view in zero-chromatic (scaling) FFAG accelerator, we have found various interesting subjects such as zero-chromatic straight section [7] and fixed rf frequency acceleration in scaling FFAG accelerator using serpentine [8], stationary bucket [9] and harmonic number jump beam acceleration for advancement of this type of accelerator.

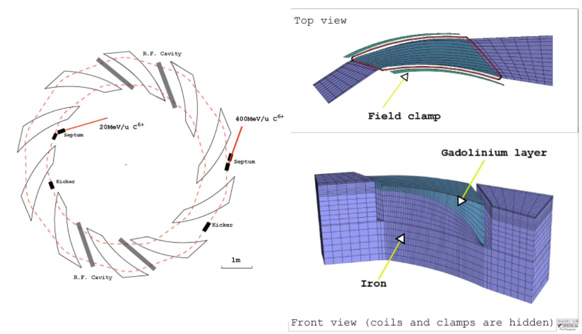


Figure 9: Schematic layout and magnet configuration of super conducting FFAG accelerator for carbon therapy.

## SUMMARY

Present status of KURRI FFAG accelerators and some developments for various applications have been described. The authors would appreciate the FFAG accelerator and KUCA groups in Kyoto University, Research Reactor Institute for their cooperations.

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