FUTURE PLANS OF ADS PROTON DRIVERS AT KYOTO UNIVERSITY RESEARCH REACTOR INSTITUTE

Y. Ishi*, Y. Kuriyama, Y. Mori, T. Uesugi
Kyoto University Research Reactor Institute, Kumatori, Osaka, Japan

Abstract

The accelerator complex using FFAG synchrotrons at Kyoto University Research Reactor Institute has been operated for the ADS experiments connecting the 100 MeV proton beam line with the research reactor facility KUCA (Kyoto University Critical Assembly) since 2009. Number of neutrons produced through the nuclear spallation process strongly depends on the beam energy of the primary protons. If the beam energy is increased from 100 MeV to 400 MeV, the number of neutrons corresponding to single primary proton is increased by a factor of 20. Therefore, the energy upgrade of the accelerator facility is desired by the reactor physicists. A new 400 MeV FFAG synchrotron has been designed. The results of the feasibility study of the 400 MeV ring will be presented.

INTRODUCTION

An Accelerator Driven System (ADS) is a hybrid system which is composed of a nuclear reactor facility and an accelerator facility.It sustains a nuclear fission chain reaction induced by a large amount of spallation neutron obtained by irradiation of a heavy metal target using high energy proton beams generated by accelerators. The nuclear reactor plays the role of neutron booster which amplifies the neutron flux from the target.

These days, especially after the severe nuclear accident in Fukushima Japan, the ADS is paid attention not only as an energy production facility but as a device which transmutes long-lived radioactive materials such as the minor actinide (MA) to other materials whose lifetimes are much shorter than the original ones [1]. In the nuclear fuel cycle, MAs can be processed in a fast breeder. But in terms of the stability of the critical operation, the fraction of the MAs in the fuel system is limited as a few percent. On the other hand, in the ADS, MA can be loaded up to some 30 % because the fuel system is operated as sub-critical.

At the Kyoto University Research Reactor Institute (KURRI), basic experimental studies about the ADS have been started since 2009 using a one of research reactors Kyoto University Critical Assembly (KUCA) [2]. In these studies, the KUCA has been operated in the sub-critical mode and FFAG accelerators has been used as a proton driver. For the further precise studies on the ADS, experiments using different energies of the proton beams are desired. At JAEA, the transmutation experimental facility (TEF) is under consideration. They are planing to use 400 MeV proton beams to investigate physical characteristics in the ADS with rather low power proton beams (TEF-P) as well as the technical engineering with extremely high power beams(TEF-T).

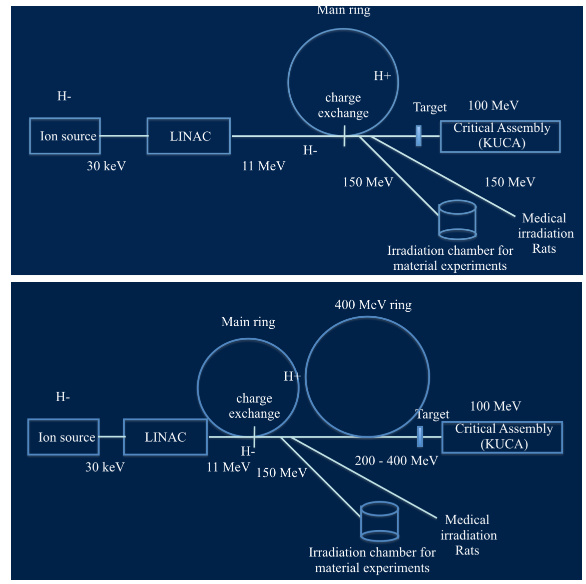

Figure 1: The schematic diagram of the FFAG Accelerator Complex. The upper is the current configuration and the lower is one of the future plans adopting a newly designed 400 MeV ring.

If the FFAG accelerator facility can deliver the beams with the energy between 200 and 400 MeV to the KUCA, fruitful results are expected from the experiments. That is the motivation to design a new energy variable FFAG synchrotron. It is planned to be builded outside the existing 150 MeV main ring at the KURRI FFAG facility. In this report, a design study of this ring will be presented.

Another optional plan adopting the extended ERIT [3] [4] scheme, so called MERIT, for production of secondary particles e.g. muons is also under consideration. The detail of this plan is available in the report [5].

A VARIABLE ENERGY 400 MeV FFAG SYNCHROTRON

The schematic diagram of the KURRI-FFAG accelerator complex is shown in Fig. 1 [6]. The basic requirements and constraints for the design of the 400 MeV ring are as follows: the injection energy is 11 MeV; the extraction energy is continuously variable between 200 and 400 MeV; the ring should be located between the main ring and the wall of the room; therefore, the maximum radius of the orbit is about 8 m; the maximum magnetic field should be less than

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

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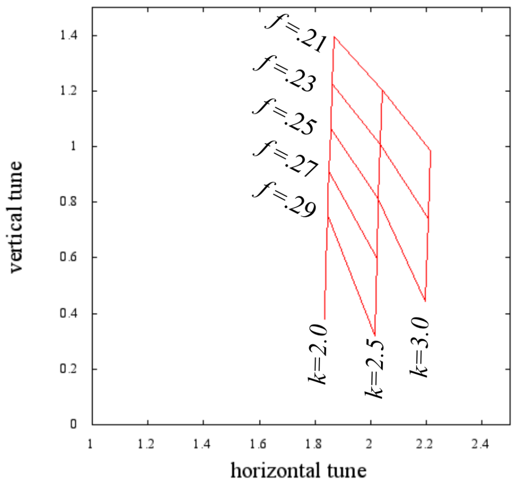

Figure 2: The tune variation with respect to the field index k and the packing factor f. Red lines are contour of those parameters. To avoid integer resonances and keep the beam excursion small , we have chosen parameters k and f as 3.0 and 0.23, respectively.

1.8 T; the lattice should be composed of only positive bends without spiral angle.

According to these conditions, the lattice can be parameterized by very few number of parameters i.e. the number of cells, the field index $k$and the packing factor f.In order to keep enough length for the straight sections, the number of cells is fixed as 8. Parameter search has been performed looking at the variation of the tunes by varying k and f. The tune variation with respect to these parameters is shown in Fig. 2. We have chosen k and f as 3.0 and 0.23, respectively.

Using these parameters, the lattice is fixed uniquely as shown in Fig. 3. The main parameters of the 400 MeV ring are shown in Table 1. The operating point is (2.21, 0.74) as shown in Fig. 4. Since it is close to the resonance excited by skew octupoles, it may be changed according to further investigations.

Table 1: The Basic Parameters of 400 MeV Variable Energy FFAG Synchrotron

Beam species	proton
Injection Energy	11 MeV
Extraction Energy	200 - 400 MeV
Number of cells	8
Field index k	3.0
Packing factor f	0.23
Magnetic field	1.72 T (max.)
Tune	(2.21, 0.74)
Radius of the orbit	7.0 - 8.0 m

To check the stability of the beam with nonlinear FFAG field, particle tracking has been performed through 10 000

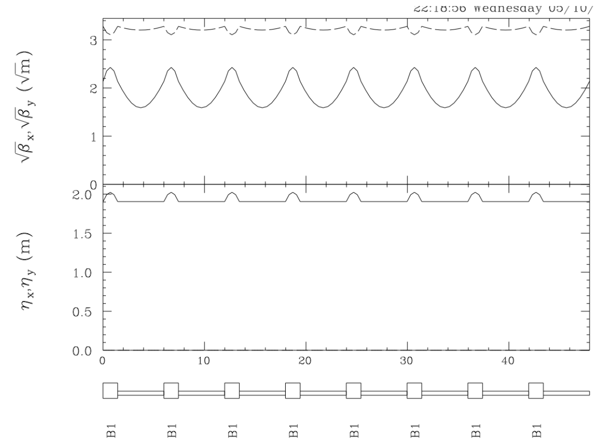

Figure 3: The lattice functions of the 400 MeV ring. Since the spiral angle is zero and no reverse bends are installed, vertical focusing force is generated by only edge focusing of the main magnets.

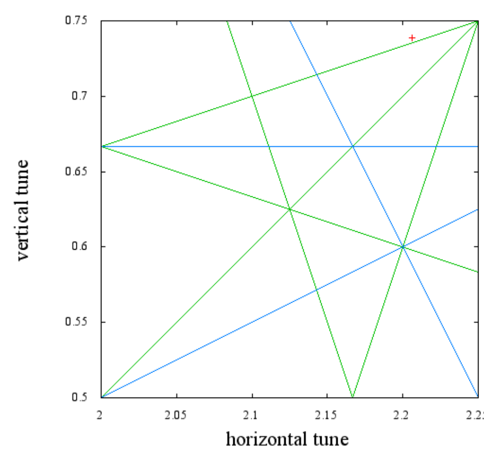

Figure 4: The tune diagram of the 400 MeV ring. Blue and green lines are 3rd and 4th order resonance lines, respectively. The red cross is the operating point. Since it is close to the resonance excited by skew octupoles, it may be changed according to further investigations.

turns using 4th order Runge-Kutta solver (see Fig. 5). A large stable region is guaranteed compared with the beam size estimated as a few cm.

The main concern of this study is variable energy beam extraction in an FFAG synchrotron (see Fig 6). Since the beam orbit excursion from 200 to 400 MeV is about 0.8 m, the extraction elements i.e. the kicker and the septum magnet should be moved by remote controlled mechanism. The main parameter of these elements are shown in Table 2. As shown in Fig. 7 variable energy beam extraction is available in the 400 MeV FFAG synchrotron.

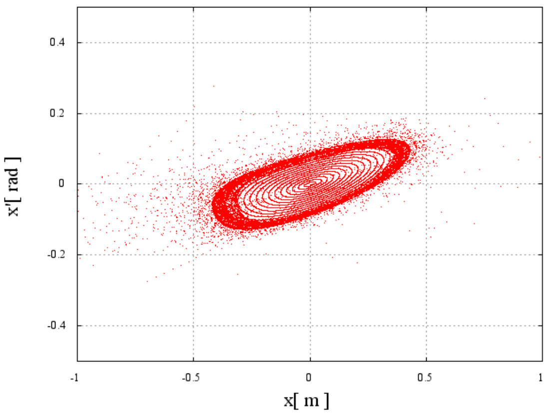

Figure 5: The horizontal phase space structure. Particle tracking has been performed through 10 000 turns using 4th order Runge-Kutta solver. A large stable region is guaranteed compared with the beam size estimated as a few cm.

Table 2: The Main Parameters of the Beam Extraction Elements

	kicker	septum
Magnetic field	0.2 T	0.7 T
Length	0.5 m	1.0 m
Kick angle	30 mrad	220 mrad

SUMMARY

A new 400 MeV proton FFAG ring has been designed outside the existing main ring in the FFAG accelerator complex at KURRI. The purpose of the new ring is to deliver the different energy beams from 200 to 400 MeV to a sub-critical fuel system for the basic study of ADS. In order to satisfy the requirements of reactor physicists, the energy of the beam should be variable. It has been shown that the variable energy extraction scheme can be realized using the movable kicker and septum magnet and the merging magnets.

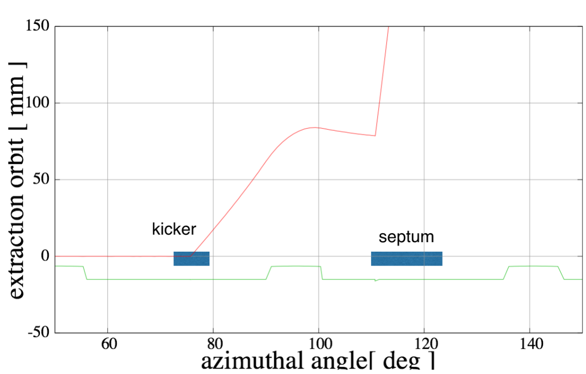

Figure 6: A scheme of the beam extraction from the 400 MeV ring. The kicker magnet kicks the beam by 30 mrad with the magnetic field of 2 kG to make 75 mm turn separation at the septum magnet. The phase advance between the kicker and septum magnet is about 90° . Both of them should be moved by remote controlled mechanism inside the vacuum chamber in order to extract the beams at different energies.

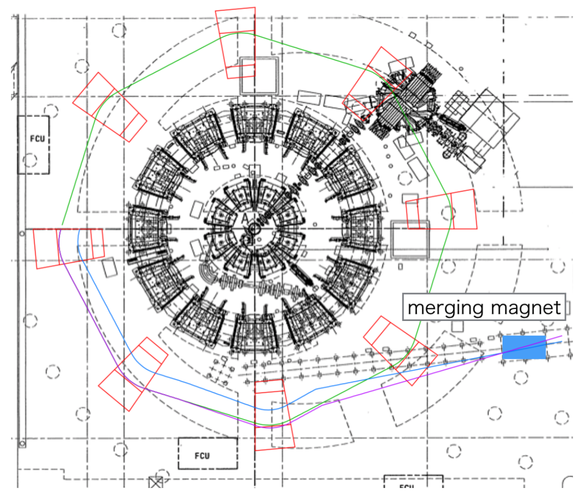

Figure 7: Footprint of the extracted beams. Red lines show the main magnets of the 400 MeV ring. The blue and purple lines show the trajectories of protons extracted at 200 MeV and 400 MeV, respectively. These lines are crossing at the merging magnet indicated by a blue box. By adjusting the magnetic field of the merging magnet, the beams with any energies between 200 and 400 MeV can be extracted and transported through the same beam line to the KUCA.

REFERENCES

[1] K. Tsujimoto *et al.*, "Accelerator-Driven System for Transmutation of High-Level Waste" *Progress in Nuclear Energy*, vol. 37, p.339–344(2000).

[2] C. H. Pyeon *et al.*, "First Injection of Spallation Neutrons Generated by High-Energy Protons into the Kyoto University Critical Assembly" *J. Nucl. Sci. Technol.*, vol. 46, no. 12, p. 1091(2009).

[3] Y. Mori, *Nucl. Instr. Meth.*, A, vol. 536, p. 591(2006).

[4] T. Uesugi *et al.*, " FFAGs for the ERIT and ADS Project at KURRI ", in *Proc. 11th European Particle Accelerator Conference (EPAC'08)*, Genoa, Italy, June 2008, paper TUOBM04, p. 1013–1015.

[5] Y. Ishi *et al.*, "KURRI FFAG'S FUTURE PROJECT AS ADSR PROTON DRIVER", in *Proc. 21st International Conference on Cyclotrons and their applications(CYC2016)*, Zurich, Schwitzerland, Sep 11 2016, paper THC01, p. 366–370.

[6] Y. Ishi *et al.*, "Present Status and Future of FFAGs at KURRI and the First ADSR Experiment", in *Proc. 1st International Particle Accelerator Conference (IPAC'10)*, Kyoto, Japan, May 23 2010, paper TUOCRA03, p. 1327–1329.

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