CONSTRUCTION OF A FFAG COMPLEX FOR ADS RESEARCH IN KURRI

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Abstract

The Kumatori Accelerator-driven Reactor Test project (KART) was undertaken at Kyoto University Research Reactor Institute (KURRI) as of fiscal year 2002, with the aim to demonstrate the basic feasibility of ADS and to develop a 150-MeV proton Fixed-field Alternating Gradient (FFAG) accelerator complex as a neutron production driver. This FFAG complex will be connected with the Kyoto University Critical Assembly (KUCA) for basic ADS experiments by the end of March 2006.

Introduction

As a substitute for the 5-MW reactor at Kyoto University (KUR), a neutron source based on the ADS concept was 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 ADS.

The requirements towards proton sources for ADS are: 1) high beam intensity, 2) highly efficient power consumption and 3) high stability during operation. The FFAG accelerator, originally proposed by Ohkawa 40 years ago [4], is regarded as a good candidate as the proton driver for ADS. Because of its fixed magnetic field, the high repetition rate of beam acceleration and the greatly reduced power consumption in the accelerator engendered by the introduction of a superconducting magnet are expected. Despite such attractive features, no FFAG with RF has yet been realised until recently, except electron models, due to technical difficulties such as the production of a wide-band high-voltage RF cavity or the lack of long straight sections for beam injection and extraction. Recently, Mori, *et al.* developed a wide-band RF cavity with FINEMET [5] and succeeded in the first acceleration of proton with a 500-keV PoP FFAG synchrotron [6]. They have now developed a “return-yoke free” magnet for the 150-MeV FFAG synchrotron [7] in which they try to extract the beam from the FFAG for the first time.

On the basis of our study and the technical developments concerning FFAG, the KART project was approved and commenced as of fiscal year 2002. In this project, the basic feasibility of ADS 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 ADS.

FFAG accelerator complex

In the KART project, a FFAG accelerator complex is now under construction as the proton source for ADS study. This complex consists of one FFAG with an induction unit for acceleration as the injector and two FFAGs 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. A schematic diagram of our FFAG complex is shown in Figure 1. Basic specifications for this FFAG complex are summarised in Table 1. The layout of these FFAG accelerators in the accelerator room is shown in Figure 2.

Figure 1. Schematic diagram of FFAG complex at KURRI

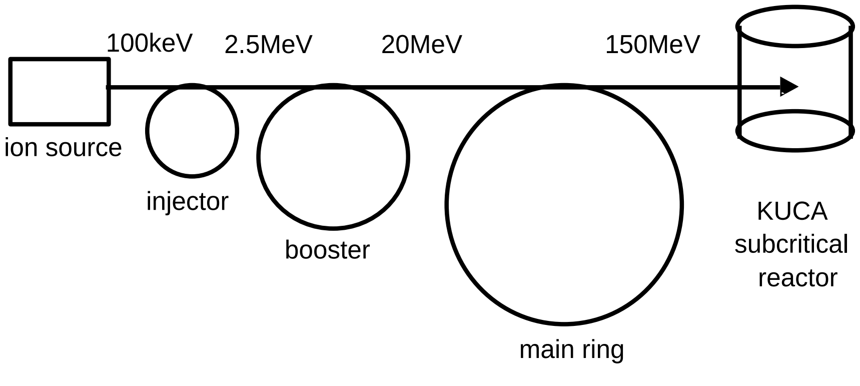


Table 1. Specifications of the FFAG complex

	Injector	**Booster**	**Main**
Focusing	Spiral	Radial	Radial
Acceleration	Induction	RF	RF
k	2.5	4.5	7.6
E_{inj}	100 keV	2.5 MeV	20 MeV
E_{ext}	2.5 MeV	20 MeV	150 MeV
p_{inj}/p_{ext}	5.00	2.84	2.83
r_{inj}	0.60 m	1.42 m	4.54 m
r_{ext}	0.99 m	1.71 m	5.12 m

Figure 2. FFAG complex at KURRI

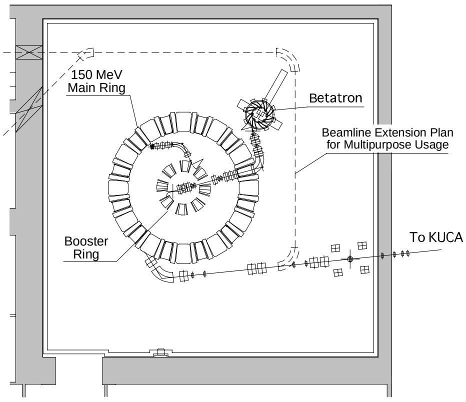
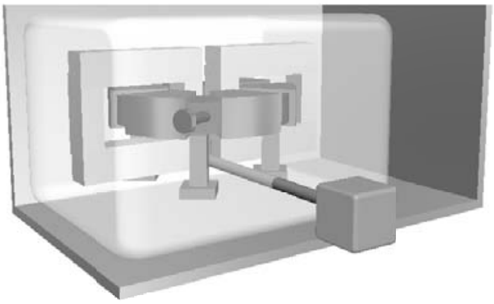


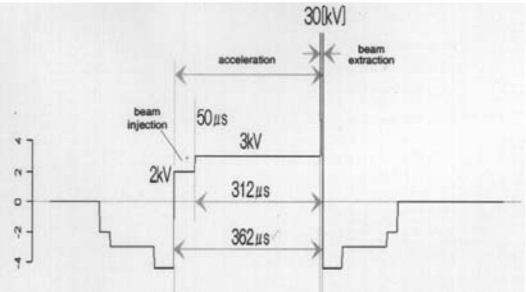
Figure 3. The schematic diagram of the FFAG complex at KURRI



H^+ ions are produced in a typical multi-cusp type ion source, then extracted and accelerated to 100 keV. Since all of the FFAG complexes are operated in pulse mode, the beam is bunched by an electrostatic beam chopper in the transport line.

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 a spiral angle of 42°. A typical pattern of induced acceleration voltage is shown in Figure 4. In this operation pattern, the compression of injected beam pulse is achieved by the abrupt increase of induced electric field. In the current plan, the beam pulse ejected from the injector is compressed to 5 μs; it was originally 50 μs.

Figure 4. Acceleration pattern of the FFAG injector



The beam from the FFAG injector at the energy of 2.5 MeV is then accelerated up to 20 MeV in this booster ring. This FFAG synchrotron is the radial sector type, consisting of eight cells of DFD magnets. The lattice structure of this booster ring is shown in Figure 5. These magnets are "return-yoke free" magnets with a flat pole face, and each magnet has 22 trim coils placed along the r direction to produce the magnetic field following the function of $B = B_0\ (r/r_0)^k$. The advantage of using trim coils is that one can easily change k by choosing a proper current set to trim coils, which is an important characteristic for the variable-energy FFAG accelerators. A 2-D simulation of a FFAG magnetic field calculated by POISSON is shown in Figure 6.

Figure 5. Lattice structure of the booster ring

Green and blue lines are the beam orbits corresponding to r_{inj} and r_{ext}, respectively

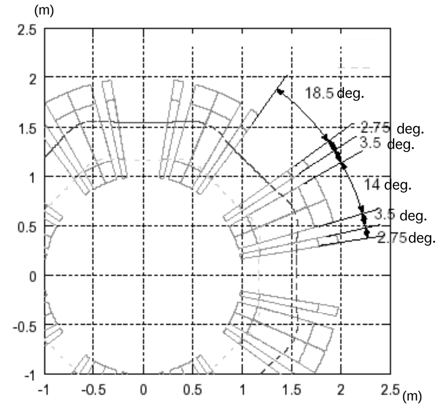
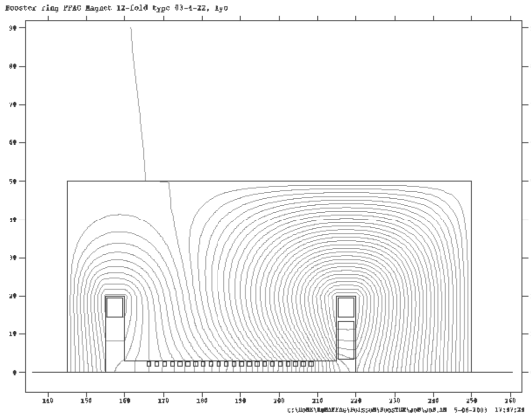


Figure 6. A typical 2-D simulation of magnetic field for the magnet in the booster ring



The main accelerator is identical to the 150-MeV FFAG synchrotron which is now being tested at KEK [7], with the exception of some modifications to achieve the high repetition rate in the acceleration in the current FFAG complex. Two RF cavities are placed in the main ring to compensate the low acceleration voltage (~10 kV) from the wideband RF cavity. This is because we must complete the acceleration of the injected beam bunch from the booster within each repetition period of ~100 μs. Another difference is in the magnets, i.e. the cross-section of return yoke and the purity of iron are increased to accept a high magnetic flux required for 200-MeV acceleration, expecting a beam energy upgrade through the reinforcement of power supplies in the near future.

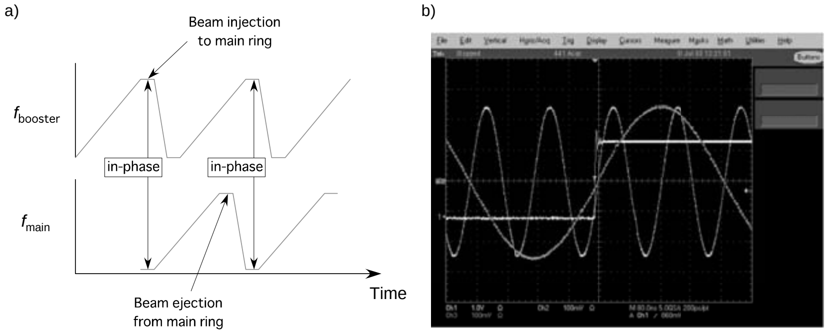
Beam injection and extraction

The advantage of the FFAG accelerator is its fast acceleration and high repetition rate due to its fixed magnetic fields. Therefore, a beam injection and extraction fast enough to follow up such a high repetition rate is required in the practical FFAG accelerator. Detailed discussion on the beam injection and extraction for the 150-MeV FFAG synchrotron has already been made by Aiba, *et al.* [8], and the fast beam extraction with kicker and septum magnets will be employed both in the booster and main accelerators. In the case of FFAG betatron, kicking out of the beam is achieved by producing an abrupt increase in the magnetic field at the induction core.

Such RF signals can easily be produced by a signal generator (SG) based on DSP, in which the waveform itself can be programmed as much as the memory in the SG allows. A typical example of a RF signal generated by Tektronix AWG420 is shown in Figure 7.

Figure 7. a) A typical RF sweep pattern of the booster and main rings in the current FFAG complex. b) An example of RF outputs from Tektronix AWG420 programmed to follow the RF sweep pattern shown in a).

In b), blue and violet waves are the RF signals and the yellow gate signal shows the desired in-phase timing. In this case, both RF signals are programmed to have the same phase of 0° on a desired timing.



Current status and future prospects

The construction of the building for the FFAG complex, designated as the “Innovation Research Laboratory” will be completed at the end of March 2004. This building is designed not only for the FFAG accelerator complex, but also for multi-purpose usage of the beam from the FFAG complex, including nuclear physics, chemistry, material science and cancer therapy.

The FFAG complex itself will be constructed in the fall of 2004. The first beam from this FFAG complex is expected by the end of March 2005. Basic studies on ADS will be employed just after the beam line between the FFAG complex and KUCA will be ready, expected by the end of March 2006.

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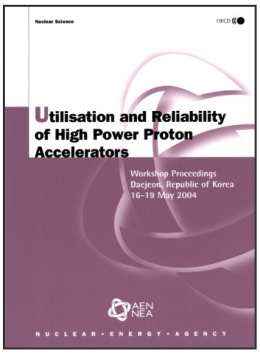

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