DEVELOPMENT OF H- INJECTION OF PROTON-FFAG AT KURRI

K. Okabe, R. Nakano, Y. Niwa, I. Sakai, Fukui University, Fukui, Japan

Y. Ishi, M. Inoue, Y. Kuriyama, Y. Mori, T. Uesugi,

Kyoto University Research Reactor Institute, Osaka, Japan

J. B. Lagrange, T. Planche, E. Yamakawa,

Graduate School of Engineering, Kyoto University, Japan

Y. Arakida, KEK, Ibaraki, Japan

Abstract

In Kyoto University Research Reactor Institute (KURRI), the Fixed Field Alternating Gradient (FFAG) accelerator for accelerator driven sub-critical reactor (ADSR) system has been constructed and world's first ADSR experiments have started in March 2009. In order to upgrade beam intensity, multi-turn charge exchange injection system for scaling FFAG accelerator is being studied. The 11MeV H- beam is injected from linac and is accelerated up to 100MeV in FFAG main ring. In this paper, the detail of injection system is described and feasibility of such a low energy H- injection system is discussed.

INTRODUCTION

In KURRI, a neutron source based on the ADSR concept has been proposed in 1996 [1]. Aiming to demonstrate the basic feasibility of ADSR, proton FFAG accelerator complex as a neutron production driver has been constructed in 2007. The FFAG accelerator complex for ADSR project consists of spiral type FFAG with an induction acceleration as the injector and two radial type FFAG with RF as the booster and main ring accelerators, respectively. The layout of these FFAG accelerators in the accelerator room is shown in Fig. 1. As a first stage, the FFAG accelerator complex has been achieved to output 100MeV - 0.1nA proton beams [2] and the ADSR experiment has been started in March 2009 [3] using this FFAG complex connected to sub-critical reactor in the Kyoto University Critical Assembly (KUCA).
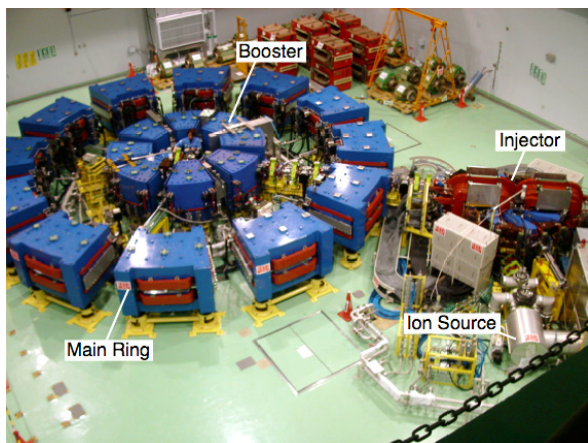

Figure 1: Photograph of FFAG-complex in KURRI.

In the second stage, to raise beam power of the FFAG neutron source, a project about a new injector for FFAG main ring instead of present injector (injector and booster FFAG ring) has been started. As a new injector, linac with H- ion source for FFAG-ERIT [4] is under consideration. The injection scheme is converted from orbit shift multi-turn injection to H- injection. H- injection scheme makes possible to inject a beam at the center of phase space already occupied by a previously injected beam. Therefore, an intense proton beam can be accumulated into the ring without largely increasing the beam emittance.

COMPARISON OF PRESENT INJECTOR AND LINAC

Present injector(Ion-beta + booster)

In the injector FFAG betatron, called Ion-beta, the 120 keV proton beams from the ion source are accelerated. The Ion-beta is composed of eight spiral sector magnets with trim-coils. The field distribution in the radial direction can be controlled by current of trim-coils, and which makes variable energy acceleration possible. The energy of extracted beam from Ion-beta is 1.5 MeV. The average output current is about 10 nA.

The Booster FFAG adopts multi-turn beam injection using horizontal space, by a couple of bump magnets, an electrostatic septum and a pulse-magnetic septum. The captured beam current is about 1 ~ 3 nA with 59 Hz repetition rate. Final beam energy is 11.6 MeV.

New injector(Linac + H- ion source)

The proton linac is AccSys-Hitachi products, compose a 425 MHz RFQ and DTLs. The accelerates H- ions up to 11 MeV. The maximum beam duty factor is about 1.8% where the beam repetition is 200 Hz. The total length is about 5 m and a peak RF power of 1.5 MW is requested in total. The H- ion source is a volume type of H- ion source. The available H- beam current (peak) is about 5 mA. This injector has been developed for FFAG-ERIT system, and installed on the same floor as FFAG accelerator complex. Figure 2 shows linac and ion source in KURRI laboratory room.

Comparison of present injector spec and linac spec

Comparison of present injector spec and linac spec are summarized in Table 1. Beam intensity of the linac is

very intense compared to the present injector. Therefore, the extracted beam energy of linac is almost the same as Booster FFAG. Thus, it is not necessary to optimize magnet parameter of the Main Ring.

Table 1: Comparison of present injector and linac

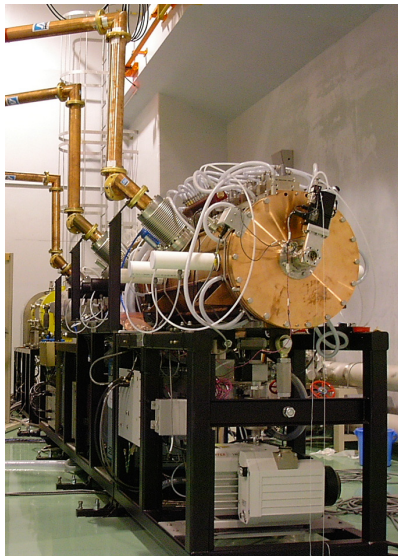|	Ion-beta and booster FFAG	Linac + H⁻ ion source
Ion	proton	H⁻
Extracted beam energy	11.6 [MeV]	11 [MeV]
Beam intensity	$6.00 * 10^8$ [ppp]	$3.12 * 10^{12}$ [ppp]
Rep. rate	30 Hz	1 ~ 200 Hz

Figure 2: Photograph of H⁻ linac in KURRI.

BEAM TRANSPORT LINE AND INJECTION ORBIT

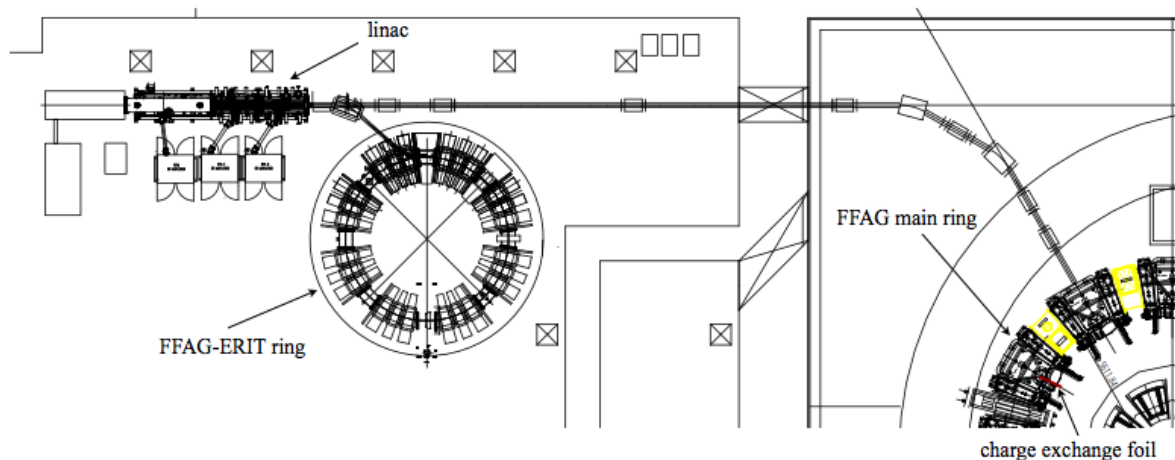Figure 3 shows the beam transport line from H⁻ linac to the FFAG Main Ring. The beam transport line consists on seven quadrupole magnets and two bending magnets, two horizontal steering magnets, two vertical steering magnets and several beam monitors.

Injection beam orbit and phase space shape of matched injection beam have been calculated by particle tracking simulation with TOSCA field map(Fig. 4). A merging method using magnet of FFAG Main Ring was adopted. Injected beams will be merged to circulating beam without any injection septum magnet.
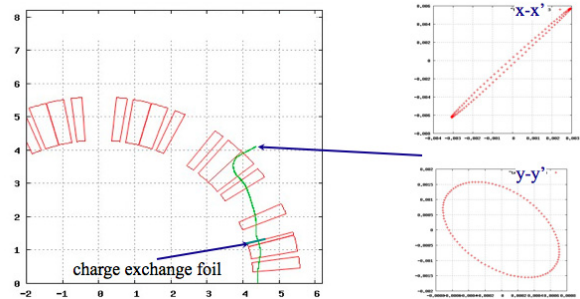

Figure 4: The left figure is a H⁻ injection orbit within main ring(green line). The right figures are phase space shape of matched injection beam at injection point.

CHARGE EXCHANGE INJECTION FOR THE FFAG MAIN RING

In order to increase the intensity in proton accelerator, charge exchange injection is now widely used for high intensity machines. The advantage of charge exchange injection is that it can circumvent the constraints imposed by Liouville's Theorem on conventional multi-turn injection, because the injected ion changes charge state within the accelerator. However, it is important to reduce the foil hitting probability during injection, since this leads to foil heating, emittance growth and beam energy losses.

Carbon stripping foil

The energy of injected beam (11MeV) is relatively lower than other proton machines which adopt charge

Figure 3: Schematic layout of beam transport line from H⁻ linac to FFAG main ring.

exchange injection. Therefore, very thin stripping foil is required for this injection, in order to prevent a foil overheating and large energy loss in the stripping foil. The stripping foil is assumed to be a $10 \sim 20 \mu$ g.cm^{-2} carbon foil. Figure 5 shows 10μ g.cm^{-2} carbon foil mounted on foil holder. Because this thin foil is too brittle, sensitive handling is required.

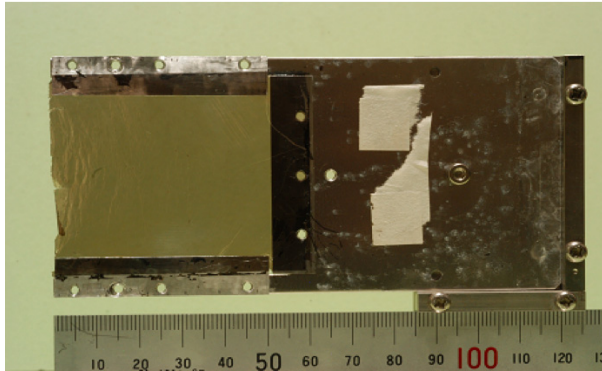Figure 5:   Photograph of mounted carbon stripping foil. The thickness of this foil is 10μ g.cm^{-2}.

Injection scheme

Because of low energy charge exchange injection, energy loss and emittance growth in the stripping foil are substantial problems. The mean energy loss of 11MeV proton beam is about 340eV at 10μ g.cm^{-2} carbon foil. However, energy loss in the foil is recovered by RF acceleration. The rf gap-voltage of rf cavity in Main Ring is over 2.5 kV. This gap-voltage is enough to re-accelerate injected beam which lost energy in stripping foil. In order to reduce foil hitting probability during injection, H- beam is injected off-center by about 10 mm parallel shift of injection line.

As an escaping method from stripping foil, orbit shift by acceleration is available in FFAG accelerator. In this scheme, no pulse device such as bump magnet for injection is needed. However, to escape from stripping foil rapidly, rf cavity with high gap-voltage become sessential. Table 2 shows turn separation by rf acceleration. The stripping foil is 20μ g.cm^{-2} carbon foil, and dispersion function η is 0.54 m. From Table 2, the upgrade of rf gap-voltage will be required for faster orbit shift.

Table 2: Turn separation by rf acceleration.

	$V_{rf} = 2kV$	$V_{rf} = 4kV$
Bucket height [keV]	33	81
Energy gain [keV]	1.00	2.80
Orbit shift/turn [mm]	0.025	0.059
Turn number(10mm shift)	400	169

SUMMARY

In order to upgrade beam intensity of KURRI-FFAG, multi-turn charge exchange injection system for scaling FFAG accelerator is being studied. The beam intensity of the linac is very intense compared to the present injector. The design of beam transport line is almost completed. The stripping foil is assumed to be a $10 \sim 20 \mu$ g.cm^2 carbon foil. Orbit shift to escape the stripping foil will be performed by rf acceleration. However, the upgrade of rf gap-voltage is required for faster orbit shift. Design and development is ongoing to demonstrate H$^-$ injection for KURRI-FFAG.

REFERENCES

[1] K. Kawase et al., APAC 1998, Tsukuba, Japan, 104-106 (1998).
[2] T. Uesugi et al., Proc. of EPAC08, Genova, 2008.
[3] C.H. Pyeon et al., J. Nucl. Scie. Technol. Vol. 46 (2009) , No. 12 p.1091-1093.
[4] K. Okabe et al., Proc. of EPAC'06, Edinburgh, 2006, pp.1675-1677.