STATUS AND DEVELOPMENT OF A PROTON FFAG ACCELERATOR AT KURRI FOR ADSR STUDY*

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Abstract

In Kyoto University Research Reactor Institute (KURRI), a fixed-field alternating gradient (FFAG) proton accelerator has been constructed to make an experimental study of accelerator driven sub-critical reactor (ADSR) system with spallation neutrons produced by the accelerator. The world first ADSR experiment was carried out in March of 2009. The proton FFAG accelerator consists of three FFAG rings; injector (spiral sector FFAG), booster(radial sector FFAG) and main ring(radial sector FFAG), respectively. In March 2010, the experiment conducted with a thorium-loaded accelerator driven system using the proton FFAG accelerator was also carried out.

A new injector with H^- ions is under construction, in order to increase the beam intensity of the proton FFAG accelerator. In this scheme, H^- ions accelerated up to the energy of 11 MeV with a H^- linac (RFQ+DTL) are injected into the main ring with charge-exchange injection. In this paper, present status of the proton FFAG at KURRI, especially on the H^- ion injection will be presented.

INTRODUCTION

In Kyoto University Research Reactor Institute (KURRI), The FFAG accelerator complex for accelerator driven sub-critical reactor (ADSR) project has been developed and world first ADSR experiment was carried out in March, 2009 [1]. And in March 2010, the experiment conducted with a thorium-loaded accelerator driven system using the proton FFAG accelerator was also been carried out. In the ADSR experiment, FFAG complex is used as a proton driver and the accelerator complex is composed of three FFAG rings; injector, booster and main ring [2][3], respectively. To increase the beam intensity of the proton FFAG accelerator, new injection scheme with H^- ions has been developed [4]. The construction of this new injection system was completed.

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H^- INJECTION SYSTEM

In the new injection system, a H^- linac is used as an injector for the main ring. This new injection system consists of several apparatus listed below.

- H^- ion source
- Linac : RFQ + DTL
- Beam transport line
- Charge stripping foil system

In this new injection system, H^- ions are accelerated with the H^- linac up to 11 MeV and injected into the main ring with charge-exchange injection. The carbon foil for the charge-exchange is located at the center of the focusing magnet of the main ring. Figure 1 shows schematic view of this new injection system.

In this section, the status of this new injection system is described.

H^- Ion Source

The specifications of the H^- ion source are summarized in Table 1.

Table 1: Specifications of H^- Ion Source

Particle	Negative Hydrogen
Type	Volume type
Extraction Energy	30 keV
Repetition	200 Hz (maximum)
Beam Duty factor	4 % (maximum)
Beam Current	100 μA (average at 200 Hz)
	1 - 5 mA (peak)
Normalized Emittance	$<1\ \pi$mm-mrad

Using beam chopper, which uses static electric field, H^- ions of 30 keV extracted from H^- ion source are chopped. Typically, chopped beam of about 20 μs is injected into the H^- linac.

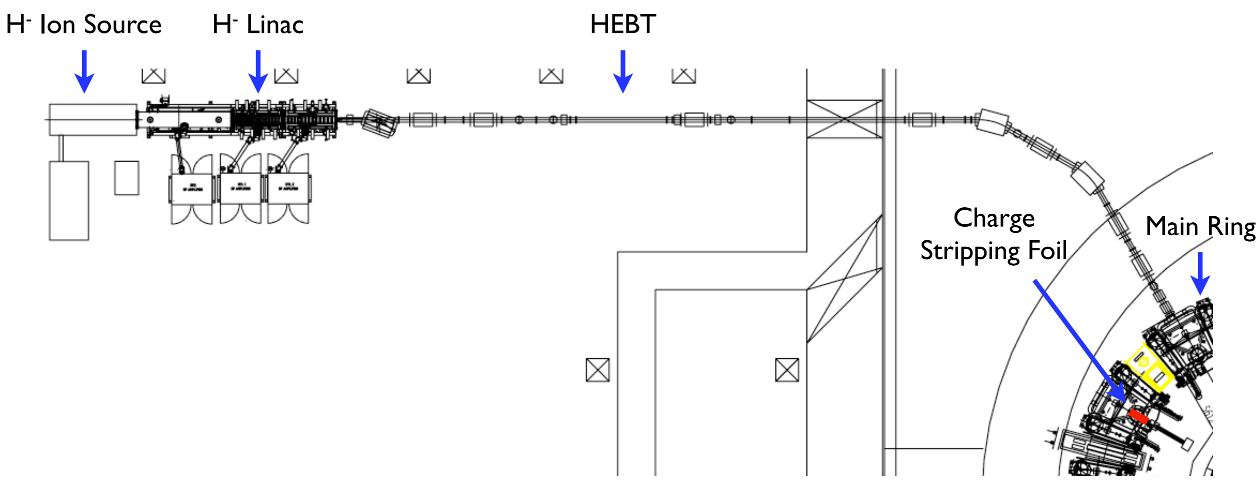

Figure 1: The schematic view of the H$^-$ beam injection system.

H$^-$ Linac

H$^-$ linac, purchased by Hitachi, consists of a RFQ and two DTLs. The H$^-$ beam is injected into the H$^-$ linac and accelerated up to 11 MeV. The specifications of the H$^-$ linac are summarized in Table 2.

Table 2: Specifications of H$^-$ Linac

Particle	Negative Hydrogen
Injection Energy	30 keV
Extraction Energy	11 MeV
Beam Current	5 mA (peak)
Beam Pulse Width	100 μs (max)
Repetition Rate	1 - 200 Hz

Extracted proton beam of 11 MeV from the H$^-$ linac is transported to the main ring through H$^-$ beam transport.

H$^-$ Beam Transport

The H$^-$ beam transport, called HEBT (= high energy beam transport), is consists of 7 quadrupole magnets, 2 bending magnets and 6 steering magnets. The H$^-$ beam of 11 MeV is transport to the main ring from the linac through HEBT. Figure 2 shows the photographs of the HEBT system.

The left one in Fig. 2 shows the H$^-$ linac and the first part of the HEBT system and the right one presents the last part of the HEBT system, respectively. As shown in the picture, the H$^-$ beam is injected into the center of the focusing magnet of the FFAG main ring.

Charge Stripping Foil

As a charge-exchange injection, carbon foils, XCF-10 made by the Arizona Carbon Foil Co., Inc., are used. For the purpose of improving the strength of the carbon foils, two sheets of the carbon foil of 10 μg/cm^2 are laid one on top of another. The specifications of the carbon foil are summarized in Table 3.

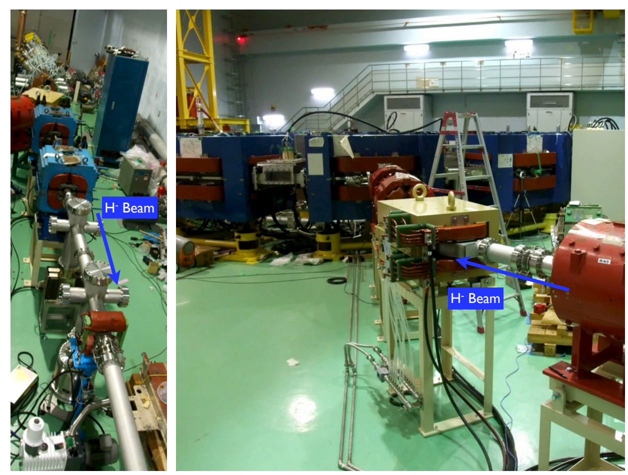

Figure 2: Photographs of the HEBT system.

Table 3: Specifications of the Charge Stripping Foil

Material	Carbon
Effective area	25 mm x 25 mm
Thickness	20 (= 10 + 10) μg/cm^2
Average Energy Deposit	760 eV
Efficieny of charge stripping	$\sim$100 %

In Fig. 3, the photographs of the carbon foil and its assembly are shown. The upper one in Fig. 3 shows the carbon foil attached to the aluminum foil support. The carbon foil is installed into the vacuum chamber of the main ring, as shown in Fig. 3.

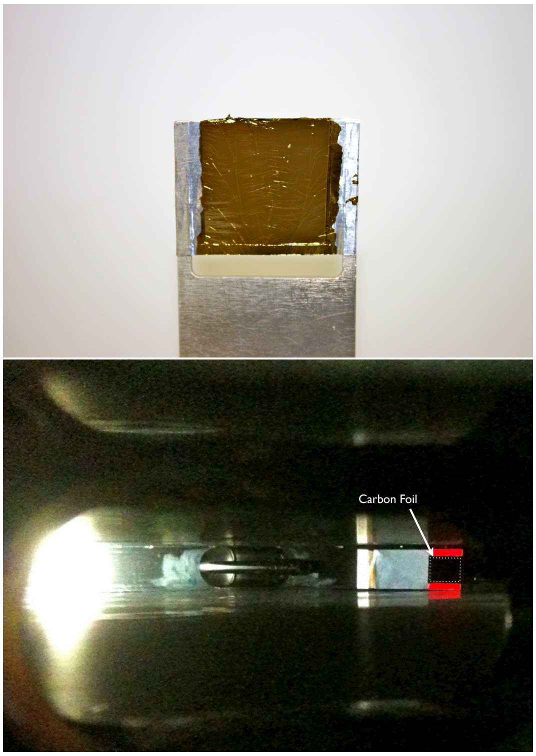

Figure 3: Photographs of the carbon foil for the charge-exchange injection.

MAIN RING

In the main ring, the H^- beam of 11 MeV is converted to H^+ beam at injection and accelerated up to 100 MeV within 16.4 ms. The specifications of the main ring are summarized in Table 4.

Table 4: Specifications of the Main Ring

Lattice	Radial, 12 cells
Field index, k	7.5
Average orbit radius	4.54 - 5.12 m
Betatron tune (design)	Horizontal 3.71
	Vertical 1.38
Injection Energy	11 MeV
Extraction Energy	100 MeV
Acceleration	RF
RF Voltage	4 kV
Synchronous phase	30 deg
Revolution frequency	1.6 - 3.9 MHz
Repetition rate	30 Hz (max)
Transparency	30 %
Intensity	3 nA (circulating)
	1 nA (extraction)

The orbital radius changes during the acceleration in the FFAG ring. Using this feature of the FFAG accelerator, the proton beam circulating in the main ring moves away from the charge stripping foil by acceleration without having the injection bump system.

In Fig. 4, measured beam output signal from the bunch monitor in the main ring is shown. As shown in Fig. 4,

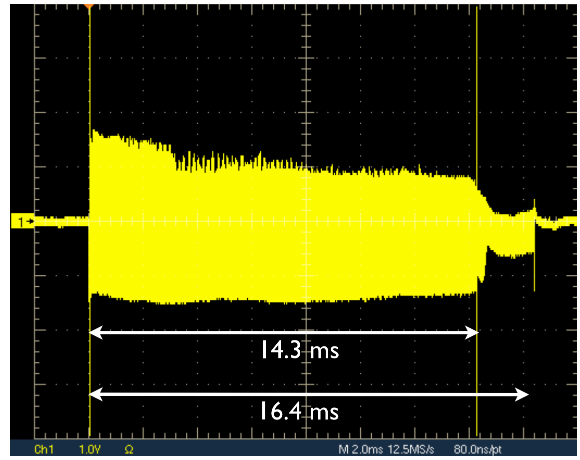

Figure 4: Output signal from the bunch monitor in the main ring.

beam loss is observed during the acceleration at the point of 14.3 ms after beam injection. The beam loss changes periodically, thus the beam loss seems to be caused by the charge-up problem in the main ring. More detail study is needed to overcome this problem.

CONCLUSION

The H^- injection system for the main ring, which was limited by radiation safety of the proton FFAG accelerator at KURRI, has been constructed and the ADS experiment using this new system was carried out in February of 2011. The beam intensity of 0.5 nA at the neutron production target placed in the reactor was achieved.

We have a plan to increase the averaged beam intensity of the proton FFAG accelerator up to 10 nA next year. The improvement of beam survival in the main ring is one of the most important subject.

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