H$^-$ INJECTION STUDIES OF FFAG ACCELERATOR AT KURRI

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Abstract

Aiming to demonstrate the basic feasibility of the accelerator driven sub-critical reactor (ADSR), proton Fixed Field Alternating Gradient (FFAG) accelerator complex as a neutron production driver has been constructed in Kyoto University Research Reactor Institute (KURRI). In order to upgrade beam power of the FFAG accelerator, a project about a new H$^-$ linac injector for FFAG main ring instead of present injector has been proposed and carried out. A charge exchange multi-turn beam injection has been performed at FFAG main ring in KURRI. In this paper, the detail of injection system and beam study of low energy H$^-$ injection at FFAG is described.

INTRODUCTION

A neutron source based on the ADSR concept has been proposed in 1996 at KURRI [1]. The ADSR can be recognized as a “safer system”, because the chain reaction in the sub-critical core is stopped inevitably by stopping the beam from the accelerator. Aiming to demonstrate the basic feasibility of ADSR, proton FFAG accelerator complex as a neutron production driver has been constructed and beam studies have been carried out in KURRI [2]. The FFAG accelerator complex has been achieved to output 100MeV - 0.1nA proton beams [3] and the ADSR experiment has been started in March 2009 [4] using this FFAG complex connected to sub-critical reactor in the Kyoto University Critical Assembly (KUCA).

In order to raise beam power of the FFAG neutron source, a project about a new injector for FFAG main ring instead of present injector (ion-beta and booster FFAG ring) has been carried out. As a new injector, linac with H$^-$ ion source for FFAG-ERIT [5] was introduced. Figure 1 shows the schematic layout of beam transport line, H$^-$ linac and the FFAG main ring. 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.

INJECTOR APPARATUS

The proton linac is AccSys-Hitachi products, compose d of a 425 MHz RFQ and DTLs. It accelerates H- ions up to 11 MeV. The maximum beam duty factor is about 1.8% when 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 of a volume type. 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.

Beam intensity of the linac is $3.12 *10^{12}$ ppp which is about 1000 times more intense compared to the previous 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.

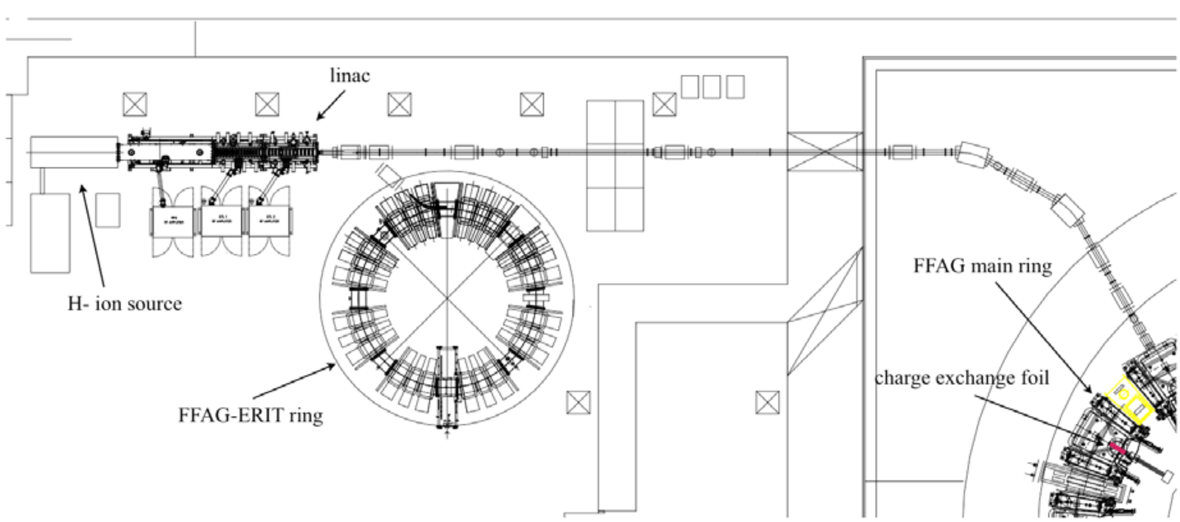

Figure 1: Schematic layout of beam transport line from H$^-$ linac to FFAG main ring.

BEAM TRANSPORT LINE AND INJECTION ORBIT

Figure 2 is a photograph of beam transport line. The beam transport line consists on eight quadrupole magnets and two bending magnets, four horizontal and vertical steering magnets and several beam monitors (Fig. 1).

Figure 2: Photograph of beam transport line.

Figure 3 shows the beam optics of beam transport line from H⁻ linac to the FFAG main ring.

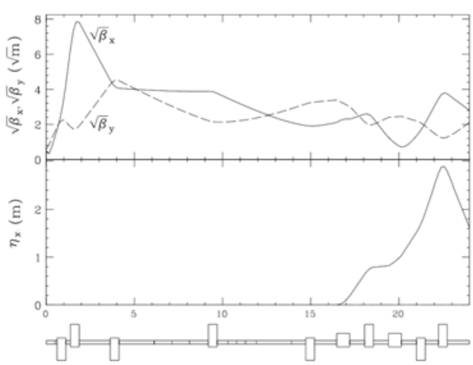

Figure 3: The beam optics of H^- beam line. (SAD)

The charge exchange foil is mounted in a steel gap chamber of FFAG magnet. Figure 4 shows the layout of charge exchange section and injection beam orbit in the FFAG main ring.

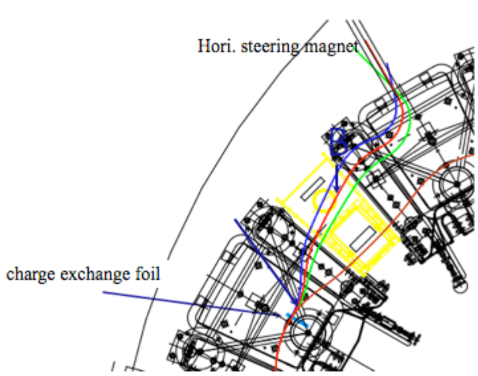

Figure 4: This figure is a H^- injection orbit within main ring(red line). Brown line is a closed orbit of circulating beam.

Injection beam orbit and phase space shape of matched injection beam have been calculated by particle tracking simulation with TOSCA field map. The twiss parameter of injection beam is matched with the circulating beam. A merging method using a magnet of FFAG main ring was adopted. Injected beams will be merged to circulating beam without any injection septum magnet. Thus, there is no pulse devices on injection orbit. In this way, transverse beam painting is not planed at this time.

CHARGE EXCHANGE FOIL

The energy of injected beam (11MeV) is relatively lower than other proton machines which adopt charge 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 ~ 20 μ g.cm^{-2} carbon foil. Because this thin foil is too brittle, sensitive handling is required. The stripping efficiency of 11MeV H- beam is about 98 % at 10 μ g.cm^{-2} thickness carbon foil.

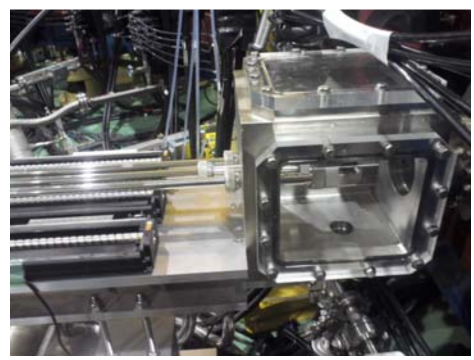

Figure 5: Photograph of installed foil installer machine with mounted carbon stripping foil. The thickness of this foil is 20 μ g.cm^{-2}.

The foil installer is shown in Fig. 5. Three foils will be are stored in the vacuum. In order to avoid the foil damage during installing, foil change box is separated from main ring chamber. Because carbon thin foil is too brittle, a vacuum is produced slowly by rotary pump through a slow leak valve. And foil position is remote controlled.

BEAM STUDY OF H⁻ INJECTION

Foil Escaping Process

In charge exchange injection in FFAG main ring, injection beam energy is low compared with any other machine adopted charge exchange injection [5]. Thus, energy loss in the stripping foil are substantial problems. The mean energy loss of 11 MeV proton beam is about 680eV at 20 μ g.cm^{-2} carbon foil.

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 essential. The rf gap-voltage of rf cavity in main ring is over 4 kV. This gap-voltage is enough to accelerate injected beam which lost energy in stripping foil.

Injection Experiments

In order to determine that the injected beam is merged to the circulating orbit in FFAG main ring, single turn injection by chopped injection beam without rf acceleration was studied. Figure 6 shows bunch signal which was observed by electrostatic pickup monitor inside the main ring. Pulse length of injected beam is about 400nsec, revolution frequency of 11MeV beam is 1.557MHz in the main ring. Injection beam is chopped shorter than revolution period. Injected beam circulated over 100 turns by steering magnet and foil position optimization. However, after a few turns, the injected beam is gradually lost by the effect of injection mismatch.

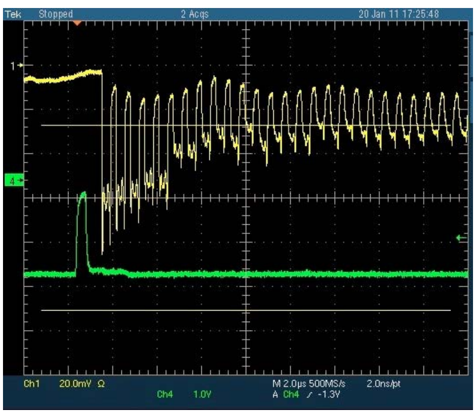

Figure 6: Beam signal of bunch monitor (yellow). Green signal is chopper output signal.

The signal of multi-turn injected beam was observed in Fig. 7. Frequency of rf cavity is constant. The rf amplitude is over 4 kV, rf frequency is 1.557MHz, harmonic number is one. Pulse length of injection beam is 5 µsec, injection turn number is about 8 turns.

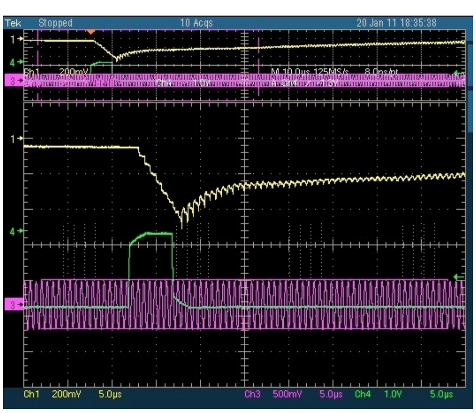

Figure 7: Signal of multi-turn injected beam. Yellow line is circulating beam signal, green line is chopper signal and pink line is signal of output rf voltage.

From Fig. 7, circulating beam current was increase during multi-turn injection. However slow beam loss is observed. The reason for such beam loss, the longitudinal mismatch between the injection long pulse beam and rf bucket.

Figure 8 shows bunch signal of circulating beam with rf acceleration after charge exchange injection. Injected beam was accelerated from 11 MeV to 100 MeV in FFAG main ring. The rf frequency was slowly changed from 1.557 MHz during this process, synchronous phase is 30 degree. The foil escaping of injected beam by was performed beam by rf acceleration. H- injection was successfully carried out as shown in Fig. 8. To improve injection efficiency, optimization of injection miss-match and rf accelerate pattern is ongoing.

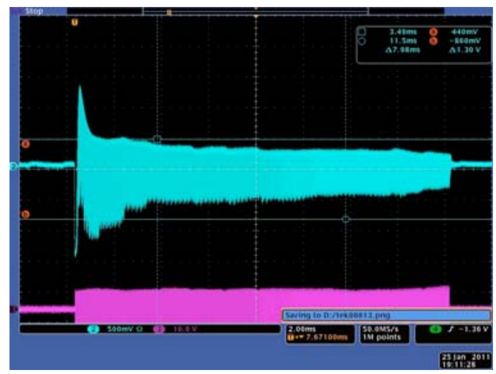

Figure 8: Beam signal of bunch monitor during acceleration (blue). Pink line is signal of output rf voltage.

SUMMARY

In order to raise beam power of the FFAG neutron source, a project about a new injector for FFAG main ring has been carried out. The beam intensity of the linac is very intense compared to the previous injector. The H- beam transport line has been developed and constructed. The stripping foil is a 20 μ g.cm^{-2} carbon foil and a foil installer machine has been developed. H- injection orbit and circulating orbits was established in FFAG main ring. From experimental result, orbit shift to escape the stripping foil was demonstrated by rf acceleration. H- injection was successfully carried out. And Injected beam was accelerated from 11 MeV to 100 MeV in FFAG main ring.

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