THE COMPACT INJECTOR AS THE SECOND INJECTOR OF THE HIMAC

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Abstract

A compact injector, consisting of the permanent-magnet ECR ion-source, the RFQ linac and the Alternating-Phase-Focused Interdigital H-mode drift-tube-linac (APF IH-DTL), was developed for an injector of medical-accelerator. The injector can accelerate heavy-ions having q/m=1/3 up to 4 MeV/u. Beam acceleration tests of the compact injector were successfully made at NIRS, and the results of the acceleration tests proved its excellent performance. The same design was used for the injector, constructed at the Gunma Heavy-ion Medical Center (GHMC) in the Gunma University. Our compact injector was recently installed in the Heavy Ion Medical Accelerator in Chiba (HIMAC), and will be used as the second injector. A new beam-transport line for the compact injector was constructed in conjunction with the existing transport line. The entire injector system of the HIMAC accelerator complex will be presented.

INTRODUCTION

Cancer therapy using energetic heavy-ions as provided by HIMAC has been performed at NIRS since June 1994. With prospective clinical results for more than ten years, projects to construct such the heavy-ion accelerator complex had been proposed over the world. Since the present accelerators, which can accelerate heavy ions up to ~400 MeV/u, are sizable, development of compact and cost-effective accelerators were needed for widespread use of the heavy-ion therapy. In design of the compact accelerator complex, a size of the injector is concern, because the present injector is large in size, and hence would affect total cost of the complex. Therefore, we developed a compact injector for the medical accelerators.

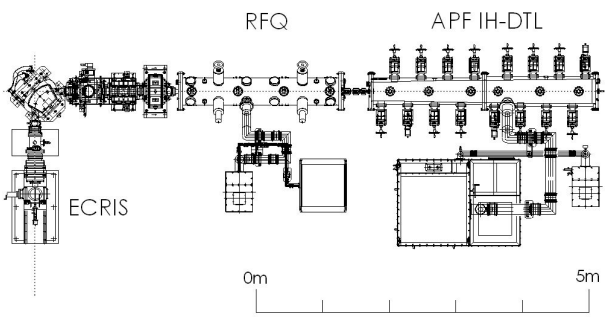

Figure 1: Layout of the compact injector. The total length of two linacs is as short as 6m.

To fulfil such the requirements, we designed a compact injector, consisting of the permanent-magnet ECR ion-source (ECRIS) [1] and two linacs; they are the RFQ linac and APF IH-DTL having the same frequency of 200 MHz[2]. A layout of the compact injector is presented in Figure 1. Beam acceleration tests were made at NIRS[3], the successful results proved its excellent performance.

In addition to the development of the compact injector, several R&D works on a RF cavity and power supply for the synchrotron ring as well as an irradiation port had been made to design the compact accelerator complex[3]. With the successful results of the R&D works, a construction of the first compact complex was initiated at the GHMC in the Gunma University.

Our compact injector was recently installed in the injector room of the HIMAC, and will be used as the second injector. A new beam-transport line was constructed to inject beams into the upper and lower synchrotrons of HIMAC.

In this paper, the present HIMAC injector system as well as an overview of the compact injector is described.

OVERVIEW OF COMPACT INJECTOR

As mentioned in the preceding section, the compact injector consisted of the ECRIS and two linacs. The ECRIS uses the permanent magnets to produce all the required magnetic field, allowing us to design a considerably compact and cost-effective source.

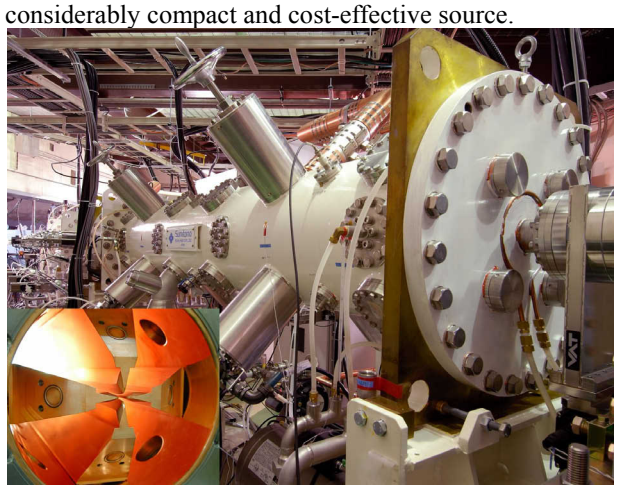

Figure 2: Picture of the compact RFQ linac (view from the upstream).

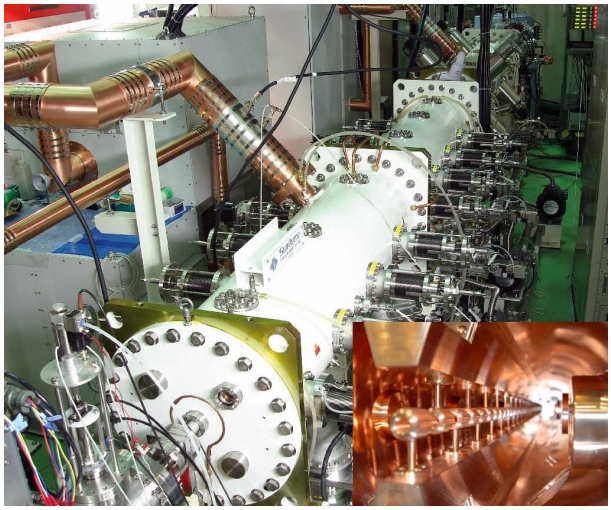

Figure 3: Picture of the APF IH-DTL (view from the downstream).

Although this ECRIS is compact, it can stably produce more than 400eμA of $^{12}C^{4+}$.

Carbon ions of $^{12}C^{4+}$ having the energy of 10 keV/u, as produced with the ECIS, are accelerated with two linacs of the RFQ linac and APF IH-DTL having the same operating frequency of 200 MHz. Major parameters of the linacs are summarized in Table 1, and pictures of the linacs are presented in Figure 2 and Figure 3. Since the both linacs utilize the RF acceleration field to obtain the transverse and longitudinal focusing, no focusing element has to be installed in the cavity, making us to design a simple and compact cavity. Furthermore, since the parameters to be adjusted are only the RF level for each cavity and RF phase between two cavities, the beam tuning can be made with ease. Therefore, it can be concluded that these linac structures are suitable for the medical injector.

Table 1: Major Parameters of the RFQ Linac and the APF IH-DTL

Parameters	RFQ	IH-DTL	Units
Injection energy	0.01	0.61	MeV/*u*
Extraction energy	0.61	4.0	MeV/*u*
Operating frequency	200	200	MHz
q/m	1/3	1/3	-
Cavity length	2.5	3.4	m
Cavity outer diameter	0.42	0.44	m

INJECTOR OF GHMC

An overview of the GHMC facility at the Gunma University is presented in Figure 4. The total area of the facility is 45m×65m, which is roughly 1/3 of that of the HIMAC facility. The construction of the building began at early 2007, and completed at the end of 2008. Beam acceleration tests were subsequently made in summer 2009. With the successful result of the tests, treatments were started since March 2010 as is originally planned. Currently, the GHMC is being in treatment operation.

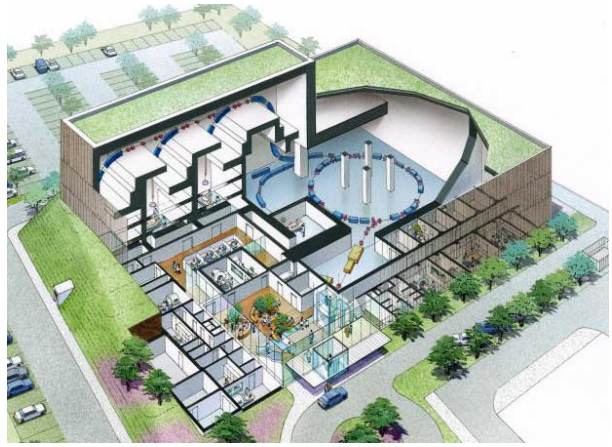

Figure 4: Overview of the GHMC facility at the Gunma University.

A picture of the compact injector, constructed for the GHMC facility, is shown in Figure 5. It also consisted of the ECRIS and two linacs of the RFQ and APF IH-DTL. Design of the GHMC injector is identical to that of the original injector as developed at NIRS, however minor improvements were made. The GHMC injector has been stably providing beam for treatments without any serious troubles.

COMPACT INJECTOR AS SECOND INJECTOR OF THE HIMAC

A layout in the injector room of HIMAC is presented in Figure 6. The HIMAC injector originally has three ion sources of 10GHz ECRIS, 18GHz ECRIS and PIGIS, low-energy beam-transport (LEBT) line, two linacs, and medium-energy beam-transport (MEBT) line. Heavy ions, produced by any of the three source, are accelerated with the RFQ linac and Alvarez DTL having the same operating frequency of 100 MHz[5]. The linacs can accelerate heavy ions with A/Z=7 up to 6 MeV/u. Lengths of the RFQ linac and Alvarez DTL are 7.3m and 24m, respectively.

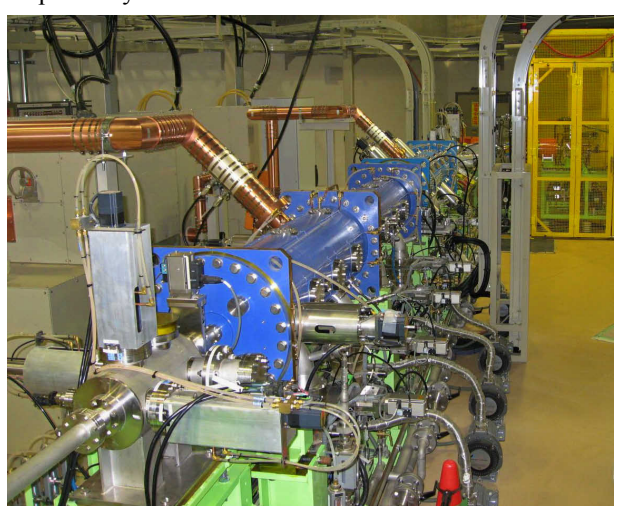

Figure 5: Picture of the compact injector at the GHMC accelerator complex (view from the downstream).

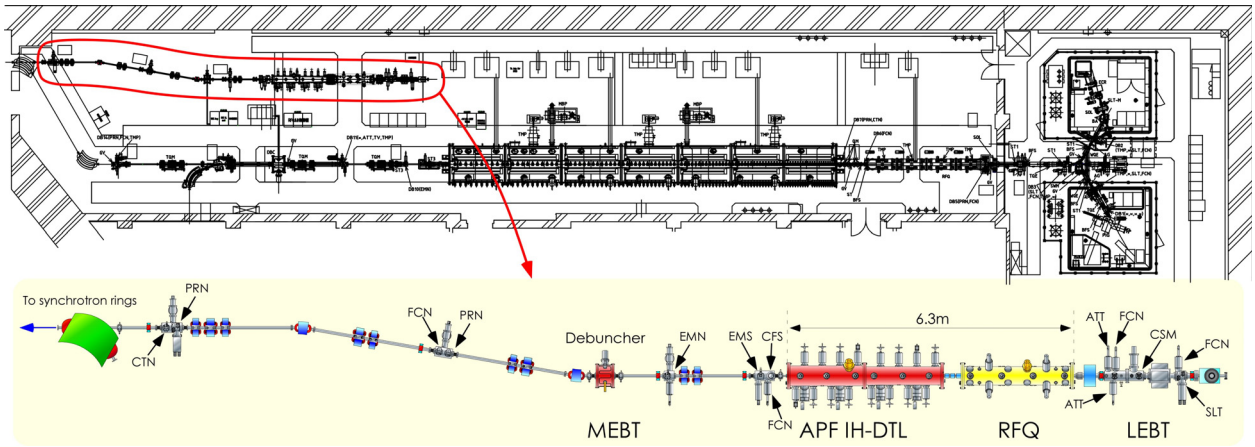

Figure 6: Layout of the HIMAC injector room. The compact injector system was installed, and connected to the HIMAC upper and lower synchrotron rings through a new beam-transport line.

The compact injector as developed at NIRS was recently installed in the injector room of the HIMAC accelerator complex. The compact injector is located parallel to the existing HIMAC injector as shown in Figure 6. A platform was constructed above the compact injector; the compact ECRIS as well as a high-voltage deck were placed on the platform, and were vertically aligned, mostly due to the space concern. A high-voltage of 30kV is applied on the high-voltage deck so as to extract ions from the ECRIS. The ions were then deflected by 90 degrees with the analyzing magnet, as shown in Figure 7, and only carbon ions of $^{12}C^{4+}$ having 10 keV/u was selected. Phase-space distributions of the analyzed ions are matched with the acceptance of the RFQ linac with focusing elements, such as an electrostatic quadrupole triplet and a solenoid, installed in the LEBT line.

An RF power source for each of the compact RFQ linac and APF IH-DTL consisted of three stage amplifiers. All the RF amplifiers as well as a low-level RF system were placed on the platform. Each of the compact linac is connected to each of the final stage amplifiers with a coaxial wave guide.

Carbon ions having 4.0 MeV/u, as accelerated with the compact linacs, are then injected to a new beam-transport line. The transport line was connected to the existing beam-transport line as can be seen in Figure 6 and Figure 8. The compact injector is being commissioned, so as to provide various ions kinds for the synchrotron rings from both the existing and compact injectors with the time-sharing operation.

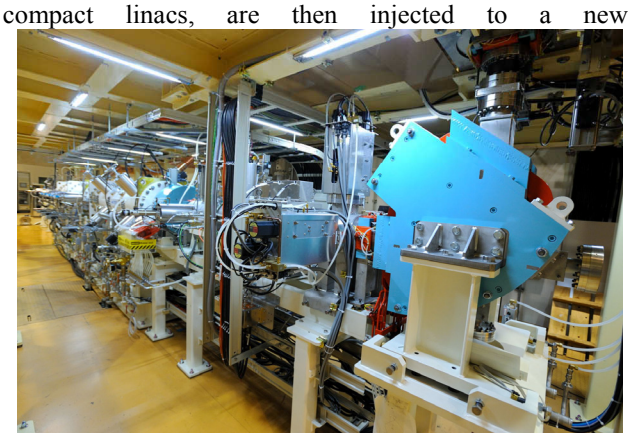

Figure 7: Picture of the compact injector system. The ECRIS as well as all the RF amplifiers for the linacs was placed on the platform.

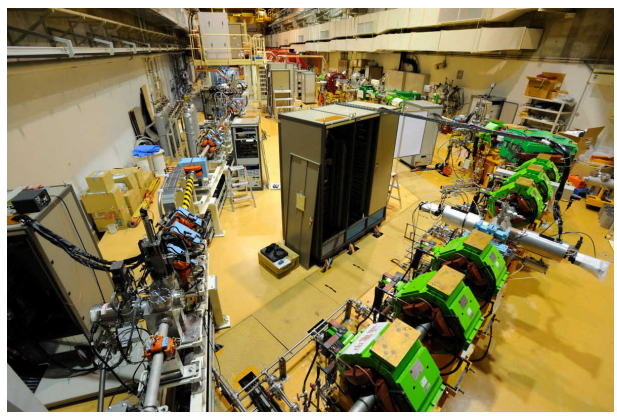

Figure 8: Picture of the HIMAC injector room (view from the downstream). The existing (right) and new (left) beam-transport lines to the synchrotron rings are seen.

SUMMARY

The compact injector was installed in the HIMAC so as to utilize as the second injector. The commissioning is being made, and will be used to provide treatment beams.

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