OPERATION OF KEIGM FOR THE CARBON ION THERAPY FACILITY AT GUNMA UNIVERSITY

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Abstract

Carbon-ion radiotherapy is being carried out at Gunma University Heavy Ion Medical Centre (GHMC) since March 2010. A compact electron cyclotron resonance ion source (ECRIS) for GHMC, so-called KeiGM, supplies carbon 4+ ions for treatment. The general structure of KeiGM was copied from a prototype compact source, so-called Kei2. Based on experimental studies for production of carbon 4+ ions with a 10 GHz ECR source at the Heavy Ion Medical Accelerator in Chiba (HIMAC), so-called NIRS-ECR, the field distribution of the mirror magnet for Kei2 and KeiGM was designed. A microwave source with the traveling-wave-tube (TWT) was adopted for KeiGM, with a frequency range and maximum power of 9.75 - 10.25 GHz and 750 W, respectively. The KeiGM was installed in the GHMC facility in December 2008.

INTRODUCTION

The Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences (NIRS) was the first heavy ion medical dedicated accelerator in the world [1]. Its aim has been to verify effectiveness and safety of heavy-ion radiotherapy. Carbon-ion radiotherapy (C-RT) started in 1994 and has mainly focused on the group of diseases in the whole body that are difficult to cure using conventional radiotherapy. The total number of patients enrolled by August 2009 was over 4,800 and various types of tumors have been treated. These results have clearly demonstrated the advantages of C-RT [2].

The Japanese government approved C-RT as a new treatment method in 2003, and promoted to development of new downsizing technologies under "the 3rd Comprehensive 10 year Strategy for Cancer Control (2004 – 2013)". NIRS carried out R&D studies for various components and designed a hospital-specified C-RT facility [3]. The construction of the Gunma University Heavy Ion Medical Centre (GHMC [4]) was funded by the Japanese government and Gunma prefecture beginning in 2006, and construction started in 2007 at the Centre site in Maebashi, Gunma. The technologies concerned were transferred from NIRS to Gunma University. GHMC will be a demonstration of the new C-RT facility. Gunma University already started a clinical trial since March 2010. A compact electron cyclotron resonance ion source (ECRIS) for GHMC, the KeiGM, is also based on the development of the ECRIS at NIRS [5]. This article presents the operation of KeiGM and the status of their daily treatment.

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CARBON ION THERAPY FACILITY AT GUNMA UNIVERSITY

In the design process, the following policies are considered to be important: (1) only high-energy carbon ions will be used in the facility to reduce the size and cost of the apparatus, and (2) beam characteristics should cover the same clinical beam characteristics as the HIMAC. Major specifications of the facility were determined on the basis of the statistics of clinical data from HIMAC. The reliable and well-established wobbler method with the respiratory-gated irradiation system was adopted for the beam delivery system [6]. It was decided to accelerate only carbon ions, with a maximum energy established at 400 MeV/n. This energy ensures a 25 cm residual range in water and, for example, carbon ions can penetrate the human body and reach the prostate through a patient's pelvis. Another important requirement of the new facility is to have two orthogonal beam lines directed toward the same isocenter. This beam line configuration is required in order to realize sequential beam irradiation from different directions with single positioning of a patient. As a conclusion, GHMC consists of the following parts; an ECRIS, a Radio-Frequency-Quadrupole linac (RFQ), an Interdigital-H mode Drift Tube Linac (IH-DTL), a synchrotron and four treatment rooms. Of these the first room will have a horizontal beam line, the second will have a horizontal as well as a vertical beam line, and the third will have a vertical beam line. The fourth room will be used for developmental studies for advanced irradiation techniques. A fast beam course and energy switching are also required for the same purpose. The major specifications of the facility are summarized in Table 1. The main building of the facility is about 65 m × 45 m, and it was completed at the end of October 2008.

Table 1: Major specifications of the therapy facility.

Items	Contents
Ion Species	Carbon ions only
Range	25 cm max. in water (400 MeV/n)
Field Size	15 cm × 15 cm max.
Dose Rate	5 GyE/min. (1.2×10^9 pps)
Treatment Rooms	3 (H, V, H&V)
	No rotational gantries
Fourth Room	Prepared for future developments
Irradiation Techniques	Respiration Gated; Single & Spiral Wobbling Methods; Layer-Stacking Method

KEIGM

KeiGM has been manufactured by Sumitomo Heavy Industries. Fig. 1 shows schematic view of the KeiGM with high voltage platform. The general structure including the magnetic field was copied from Kei2 [7]. Based on experimental studies with a conventional 10 GHz ECR source [8] at HIMAC, the field distribution of the mirror magnet for compact source was designed so that a charge distribution of carbon ions was optimized at 4+. A microwave source with the traveling-wave-tube (TWT) was adopted, with a frequency range and maximum power of 9.75 - 10.25 GHz and 750 W, respectively. Microwave power is fed into the plasma chamber through a rectangular wave guide from the axial direction. A biased disk is also used for optimizing. The plasma chamber is made of copper for a good cooling efficiency, in order to avoid a decrease in the magnetic field due to high temperature. The plasma chamber has an inner diameter of 50 mm. The vacuum pressures of the gas injection side and beam extraction side are 1.1E-6 Pa and 9.0E-7 Pa, respectively. Extraction voltage is 30 kV.

The CH_4 gas was chosen for production of carbon ions. There are two reason for choose the CH_4 gas, (1) enough beam intensity of C^{4+} is obtained for medical use under the CH_4 operation; (2) there is experience of long operation of the source used the CH_4 gas at HIMAC. From our previous experience, other carbon compound gas (e.g. C_4H_{10} and C_2H_2) was better than the CH_4 for increasing the beam intensity of C^{4+} [9].

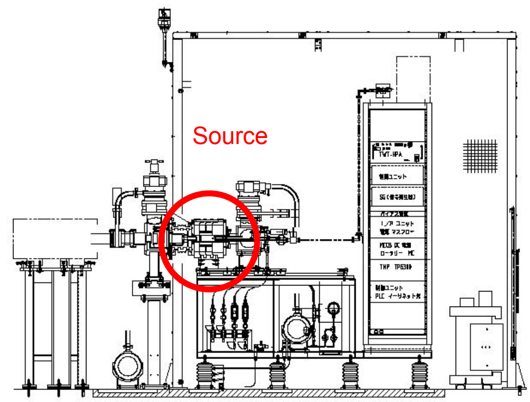

Figure 1: Schematic view of the KeiGM with high voltage platform.

Operation of KeiGM

KeiGM supplied the carbon ions from 7:30 in the morning to 0:00 midnight on weekdays. Fig. 2 shows trend graph of vacuum pressure at injection and extraction side, gas flow, microwave power, extraction voltage, current of the extraction power supply and C^{4+} beam intensity. The ion source starts in order of cooling water, the gas, the extraction power supply, and the microwave. All parameters of the ion source were fixed. The cooling water system for a whole of facility is started at 7:30. In this time, vacuum pressure in the extraction side change form 9.0e-7 Pa to 1.1e-6 Pa. The microwave power is applied to the ion source after 200 sec from start time. Beam intensity keeps changing for about 200 seconds after turning on the microwave power. All of beam parameter, intensity, profile, and so on, is reproduced at 1000 seconds every day.

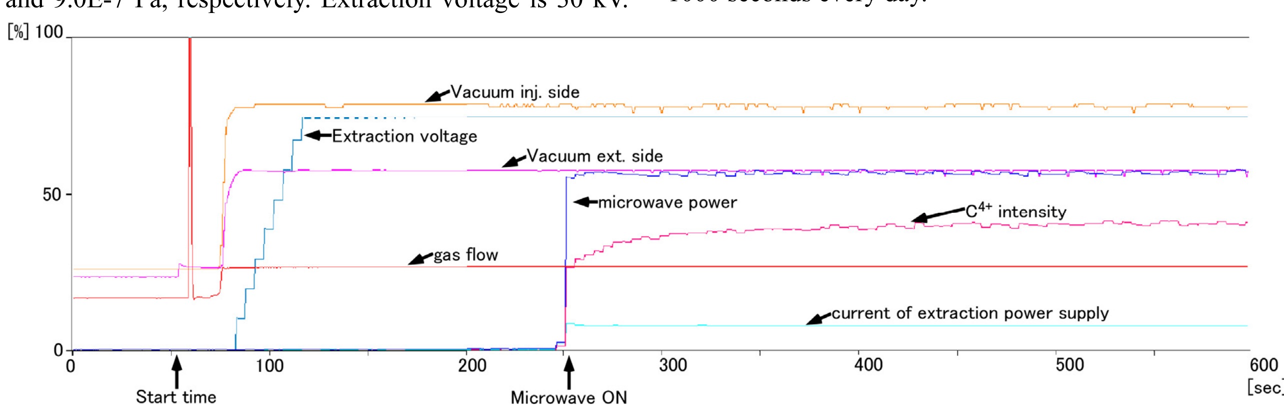

Figure 2: Trend graph of vacuum pressure at injection and extraction side, gas flow, microwave power, extraction voltage, current of the extraction power supply and C^{4+} beam intensity.

Fig. 3 shows a long term beam reproducibility from February to June 2010. The beam intensity decreased for 20% every three months. We thought that the operation parameters had not been optimized. Therefore, operation parameters were tuned on May 28. However, the beam intensity has increased slowly from May 28. It seems that the operation parameters are not yet optimized. The beam intensity of C^{4+} was 230 eμA at 30 kV extraction in June 9, 2010. The fluctuation of beam intensity was less than 10%. The operation parameters are as follows; the microwave frequency and power were 9.953 GHz and 300 W, respectively. CH_4 gas was fed, and the gas flow rate was 0.054 sccm. The extraction voltage was 30 kV. The repetition frequency and pulse width were 0.36 Hz and 50 msec, respectively. The voltage of the biased disk was -40 V.

Since at present KeiGM is the only ion source installed, all beams are supplied by KeiGM. In about 1600 hours operation between March and August, there was only one failure. It was due to breaking TWT amplifier after 14000 hours operation. The failure had been repaired by replacing of the amplifier.

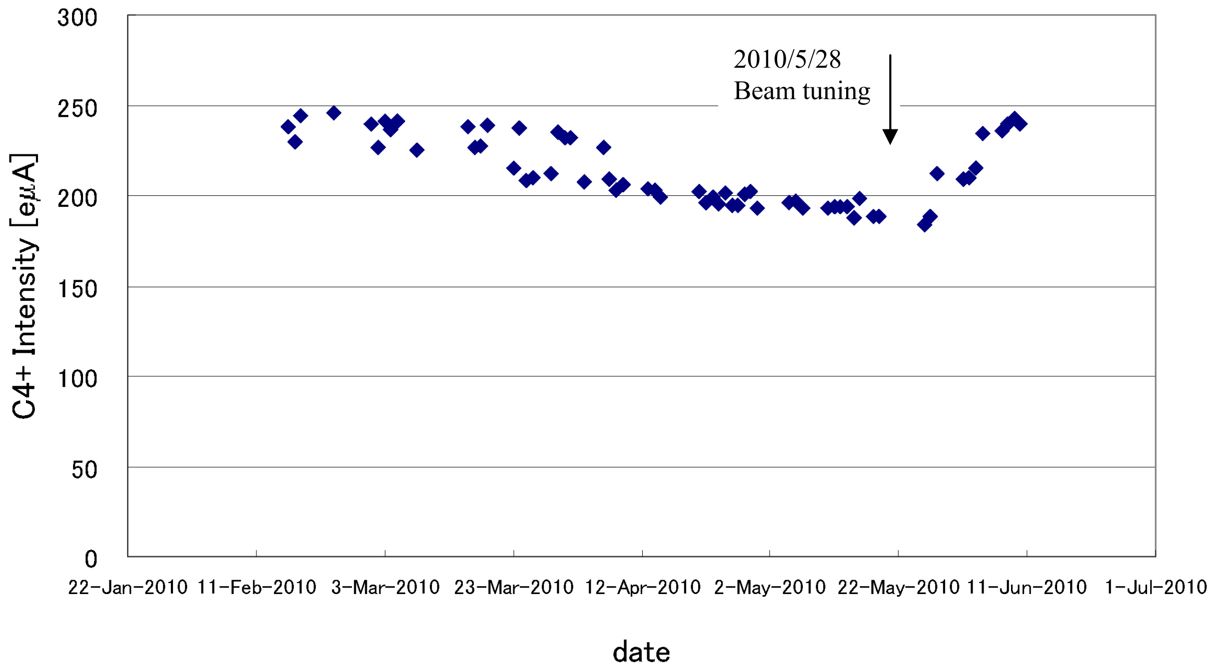

Figure 3: A long term beam reproducibility from February to June 2010.

CLINICAL TRIALS AT GHMC

Carbon ion radiotherapy started on March 16, 2010 at GHMC. Treatment is done in daytime from Monday to Friday. Gunma University has successfully treated the first 12 patients for the clinical trial until June 2010, thus the Japanese Ministry of Health and Labor Welfare approved GHMC as "advanced medicine". Since June 2010, head and neck tumor, lung cancer and prostate cancer on advance medicine were started. The total number of patients enrolled by August 12, 2010 was 41.

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