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PRESENT STATUS OF THE MEDICAL ACCELERATOR HIMAC

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Abstract

Clinical study of cancer treatment has been going on since June 21, 1994 with HIMAC at NIRS. More than 50 patients have been treated with high energy carbon beams until August 4, 1995. The preliminary results look excellent as expected: very light damage on skin surface and remarkable effects on cancer cells.

HIMAC is operated day and night from 7 p.m. on Monday till 7 p.m. on Saturday for the clinical treatment and for basic experiments. About 1,500 hr. per year are used by clinical trials and 2,500 hr. is open for physical and biomedical users including researchers outside NIRS.

1. Introduction

Clinical trials and biomedical experiments at LBL[1] strongly suggest that the heavy ion therapy is very powerful especially in treating deeply seated tumors. The advantage of the therapy comes from the well known characteristics of heavy ions: a very good three dimensional dose localization in a human body. In a longitudinal dose distribution, a very sharp Bragg peak is observed around the end point of heavy ions. A high value of LET at the Bragg peak is also attractive in the treatment of radio-resistive tumors. Based on the long experience of radiotherapy with protons and fast neutrons, NIRS adopted heavy ion therapy because of these excellent characteristics of heavy ions.

The maximum energy of HIMAC is designed to be 800 MeV/u for light ions with q/A = 1/2 so that silicon ions reach 30 cm deep in water[2],[3]. Two ring structure of the main accelerator of HIMAC will allow further development of the beam quality and performance. Ion species ranging from He to Ar are required for the clinical treatment. In the facility, there are three treatment rooms one of which has both vertical and horizontal beam lines. The other two treatment rooms are equipped with a vertical and a horizontal beam lines, respectively.

2. Commissioning

The HIMAC project was approved in 1987 as one of the major project of "Comprehensive 10 year Strategy for Cancer Control" promoted by Japanese government since 1984. The first beam from the injector was obtained in late March 1993 with singly charged He ions. For the dual synchrotron rings, beam tests were begun in November 1993 with doubly charged He ions. The ions were accelerated to 230 MeV/u with a repetition rate of 1/2 Hz for each ring. Tests of the slow extraction from both rings were successfully completed in December and the extracted beams were transported to three treatment rooms within a few days. The length of the extracted beam spill was typically 300 ms.

After careful tuning of the accelerator system, biomedical and physical experiments were performed for a few months. Final check of the reliability of the total system was done with the carbon beam irradiation on a monkey. Clinical trials of the heavy ion cancer therapy started on June 21, 1994 with 290 MeV/u carbon ions. The first series of the treatment was successfully completed for three patients in August 1994. It takes about 90 seconds for a single fractional treatment, while the precise patient-positioning procedure requires about 20 min. Three treatments per week and total of 18 treatments for each patient were adopted as a protocol of the clinical trial.

The interim diagnosis shows excellent results: radiation damage on the mucous membrane seems very light in spite of the perfect damage of tumors. All of the first three patients got good recovery and already out of hospital. For some other patients, however, no remarkable improvements were observed.

In the second and the third series of the clinical trials, heavy ion treatment was applied to cancers at the head or neck, the lungs, the central nerve system, the uterus, the liver, the prostate *etc*. More than 50 patients are already treated with 290, 350 and 400 MeV/u

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carbon ions. Total of 100 patients will be finished by the end of the fiscal year 1995.

3. Operation of HIMAC

In the early stage of the accelerator operation, all devices were turned off over night except for the vacuum system and the control system. After turning on in the morning, it took only 4 hr. to get the accelerated beam in a treatment room. Most part of the time are spent in tuning of the ion source and LEBT elements. After October 1994, HIMAC is operated day and night from Monday 7 p.m. to Saturday 7 p.m. In the day time of every Monday, weekly maintenance is scheduled. Accelerator Engineering Corporation (AEC) is responsible for the machine operation and the weekly maintenance. Major activities of the accelerator group of NIRS are set toward the improvements of the beam performance.

The machine time from 9 a.m. to 7 p.m. of the weekday is scheduled for the clinical trials and from 7 p.m. to the next 7 a.m. is open for users with carbon ions. From Friday 7 p.m. to Saturday 8 p.m., various kind of ion species are accelerated for users in physics and other fields of researches.

An energy change of the synchrotron is required once in a daytime to select the optimum residual range for different patients. After changing the beam energy, the dose uniformity in the irradiation field is checked. Before and after the daily treatment, energy and beam course is changed for the basic experiments.

Total of 37 weeks per year are available as machine time, other 2 weeks are for beam tuning and 13 weeks are scheduled shut down for machine maintenance *etc*. About 1,500 hr. per year was spent by the clinical trials and about 2,500 hr. of machine time is assigned to the basic experiments and beam tuning.

All devices of HIMAC are controllable through a digital computer system. Optimized set of the operation parameters are saved in a specified file and usable in the next operation. With a well established operation file, it takes only 20 or 30 min. to tune a pair of the synchrotron rings. It requires nearly the same time to fix the HEBT parameters including the tuning time for the beam switching. The injector, however, needs more than one hour, because it takes about 30 min. for an ion source to get stable.

The reproducibility of the beam performance is excellent without manual tuning of the magnetic fields. In order to minimize the field variation due to a hysteresis loop, an initializing technique is introduced before setting the magnet currents. During the initializing process, all magnets are excited with the maximum currents of the power supplies. By following the same path of the hysteresis loop, the magnetic fields well reproduces the previous values with only setting the magnet currents.

4. Beam Performance

We have two types of ion sources: a PIG and an ECR sources installed independently on high voltage decks of 60 kV max. The output beam intensities and emittance of both sources are satisfactory for the treatments[4],[5]. The beam transmission efficiencies through the low energy transport line and the RFQ are attained to be around 80% and 90%, respectively, in daily operation. An example of the output beam signal of the injector is given in Fig.1 together with rf pulses for RFQ and DTL.

The two synchrotron rings are operated independently from each other except that the magnets must be excited 180° out of phase. The dipole field changes from 0.11 T at injection energy to 1.5 T at maximum with a ramping rate of 2 T/s (max). The betatron tunes are chosen typically at 3.68 and 3.13 for horizontal and vertical directions, respectively. A typical operation pattern of the ring magnets is 200 ms for a flat base, 700 ms for rise and falling time and 400 ms for a flat top. In Fig. 2, an example of oscilloscope signals is given for a bending magnet excitation pattern (top), a bump magnet for beam extraction (2nd), beam signal in the synchrotron ring (3rd) and the extracted beam signal (bottom). In the signal of the extracted beam, very big intensity fluctuation can be observed. This fluctuation is due mainly to a current ripple of the synchrotron magnets, because no feedback system is applied to stabilize the extracted beam intensity.

High frequency components of the beam ripple are suppressed appreciably after careful tuning of the synchrotron magnet power supplies. At the flat top, voltage ripples of the power supplies of Q_F and bending magnets are kept extremely low values of less than 1×10^{-6} and 1×10^{-5}, respectively (50 Hz). A beam ripple, however, remains at high level. By reducing the sextupole fields for chromaticity correction, satisfactory beam spill is obtained as shown in Fig. 3. This fact means that the fluctuation of the bending field may affects strongly on the beam ripple through the sextupole fields.

The whole control system works very well and even a very low intensity beam of a few hundred particles per second can be stably accelerated without $\Delta\phi$ and Δr feedback loops.

In order to get a high efficiency of the treatment room usage, it is required to switch the accelerated beam from one treatment room to the other room in a very short time. The beam switching must be done without introducing the beam into the treatment room. The reproducibility of the beam position should be better than ±2.5 mm at the isocenter. Such precise beam positioning is realized with a special sequence in the switching magnet excitation. The new technique for beam switching takes only 5 min. and will be adopted in the actual treatment in near future.

5. Future Developments

HIMAC facility is open for many researchers who are interested in the heavy ion science as well as heavy ion therapy. In many researches, HIMAC is required to accelerate heavier ions with a variety of energies and with high quality. In order to meet these demands, third ion source of 18 GHz ECR source is now under development. Ions from these three ion sources will be accelerated simultaneously with so called time sharing acceleration scheme and delivered to a medium energy experimental room, the upper synchrotron ring and the lower synchrotron ring.

A secondary beam will be available within a few years to investigate the possibility of precise check of the ion stopping position in a human body. The positron emitters, such as ^{11}C, are considered to be effective for this purpose. The beam course will be open for other scientific fields.

Further sophisticated irradiation schemes, such as a spot scanning method or a three dimensional irradiation method, are also important in improving the effectiveness of the heavy ion therapy. An irradiation treatment synchronized with human breathing is our first target to reduce the unwanted dose to the normal cells around the tumor. The treatment will be realized with a quick response of the rf-knockout beam extraction from the synchrotron ring[6].

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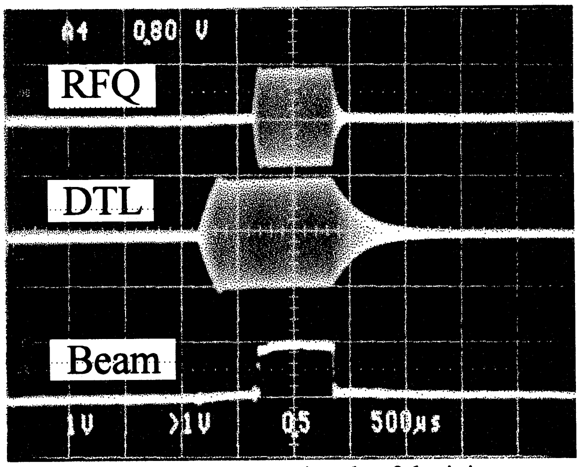

Fig.1: An example of beam signals of the injector.

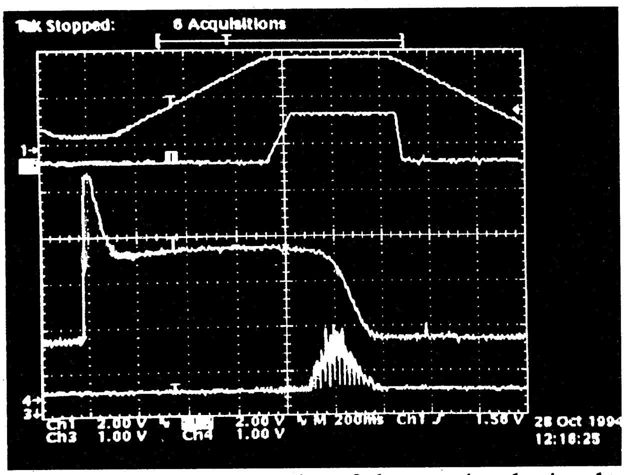

Fig.2: A typical example of beam signals in the synchrotron. See text for more details.

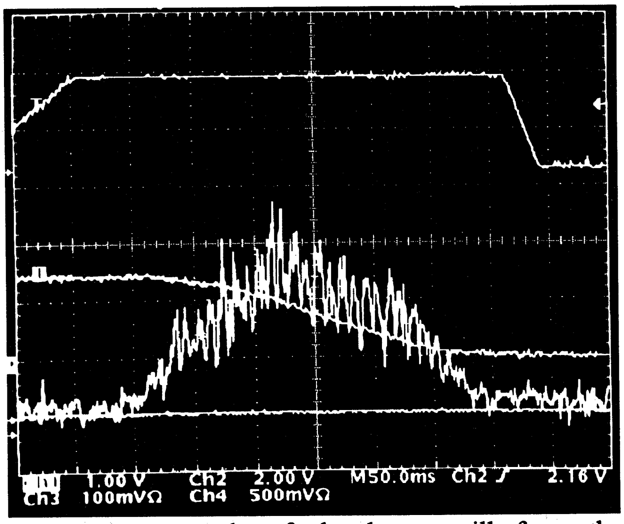

Fig.3.: An example of the beam spill from the synchrotron. See text for explanation.