STATUS OF THE HIMAC INJECTOR

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Abstract

Clinical studies of cancer treatment began in June, 1994, using heavy-ion beams from a medical accelerator, HIMAC. About 150 patients had already been treated by the end of July, 1996. HIMAC is operated 24 hours per day from Monday through Saturday. Experiments on basic research, including physics, chemistry, engineering, and biology are carried out during the night and on weekends, while the day time is devoted to clinical trials. A combination of two synchrotron rings and two pulse-operated switching magnets (SWM) allows three user groups to share the beam time (two beams from the synchrotron and one from the injector), if all groups utilize the same ions. To remove this restriction, a system involving a time-sharing mode, which allows the delivering of different ion species to three user groups, was designed and is being installed. Three ion sources have been prepared, and all magnets between the ion sources and the SWM of the synchrotron rings will be replaced by pulse-operated magnets. Excitation of the magnets and the RF power of the linear accelerators will be controlled pulse to pulse so that three kinds of beams with different q/A values can be accelerated under optimum conditions.

Introduction

Heavy-ion beams have excellent properties for applications to cancer treatment: a large biological effectiveness and good dose localization. A clinical study was, however, carried out at Bevalac, LBL, on a limited scale. To investigate the effectiveness and extent of heavy-ion therapy, a medical accelerator, HIMAC (Heavy Ion Medical Accelerator in Chiba), was constructed at NIRS, Japan. A clinical study using heavy-ion beams from HIMAC began in June, 1994. Since then, about 150 patients had been treated by the end of July, 1996.

HIMAC is a facility having a synchrotron with two identical rings, an injector, three treatment rooms, and four experiment rooms. The synchrotron accelerates ion beams from He to Ar up to a maximum energy of 800 MeV/u for q/A = 1/2 ions; the energy corresponds to a range of 30 cm in tissue for Si beams. The treatment rooms have vertical (rooms A and B) and/or horizontal courses (rooms B and C). Beams from the two rings are transported to these courses according to a treatment schedule.

Accelerators which can deliver heavy-ion beams with energies ranging from 100 MeV/u to 800 MeV/u are very scarce in the world. Therefore, applying HIMAC beams to basic research was strongly desired, without interfering with clinical studies. High-quality treatment also requires detailed knowledge of beam-material interaction processes. Thus, basic-research programs started in the fall of 1994.

New Devices and Course

The HIMAC injector, shown in Fig. 1, comprises an RFQ and Alvarez linacs (DTL) operated at a frequency of 100 MHz. Two types of ion sources, 10 GHz ECR and PIG, are in operation. The linacs can accelerate ions with q/A ≤ 1/7, and a charge stripper is installed downstream of the DTL. Details concerning these accelerators and ion sources were described at a previous conference [1, 2]. A new device was recently installed and a new course was

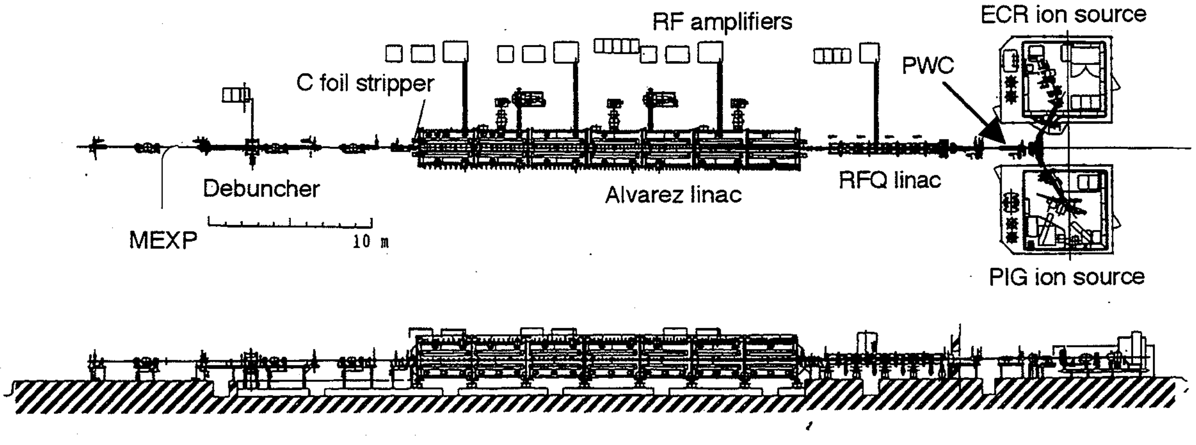

Fig. 1. Layout of the HIMAC injector

constructed.

Pulse-Width Controller

A pulse-width controller, which varies the beam-pulse width from 1 μs to 0.7 ms, was installed upstream of the RFQ linac (see Fig. 1). An electric field of 2 kV, applied between two electrodes, deflects the beam direction, and unnecessary beams are stopped by beam slits. The purpose of the system is twofold: (1) While the pulse width required for synchrotron injection is on the order of 0.1 ms or less, the ion sources require a longer operation time for a stable beam supply. Unnecessary beams may be harmful to the linacs due to beam loading and possible contamination of linac electrodes. (2) A variety of experiments in the MEXP course (see a next section) require beam pulses having a much different width.

Medium-Energy Experiment Course

A new beam course, the medium-energy experiment course (MEXP), was constructed downstream of the DTL, as shown in Fig. 2. The new course enables users to utilize the beams from the DTL (6 MeV/u), which attract a lot of concern. The MEXP course can be branched off from the transport line by using a pulse-operated magnet (SWM2), so that it can be run in parallel with the synchrotron operation. Although MEXP users must use the same ion species as synchrotron users, they can obtain different lengths of beams from those injected to the synchrotron using the pulse-width control system described above.

Operational Schedule of the Injector

Daily Operation

The HIMAC is operated 24 hours per day from Monday through Saturday. The day time (from 9:00 to around 20:00) from Tuesday through Friday is devoted to clinical trials or related data compilation. Monday is dedicated to a weekly inspection, the conditioning of new beams, and the technical training of operators. Experiments on basic research are being carried out during the night and on weekends.

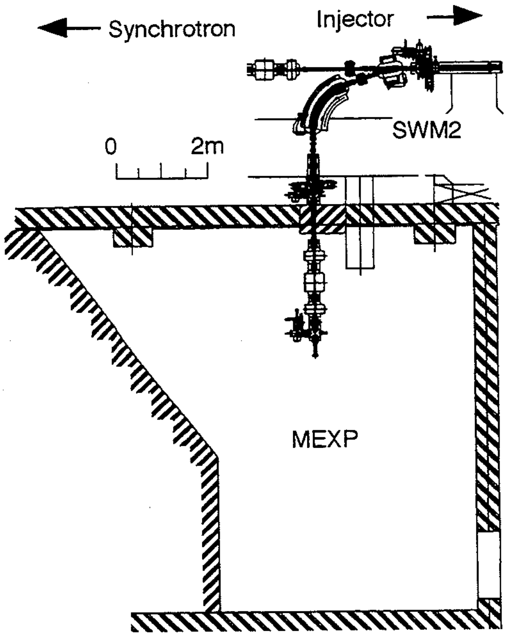

Fig. 2. Layout of the MEXP course.

Clinical Study

The clinical studies presently employ C beams with energies of 290, 350, and 400 MeV/u. Beams of C^{4+} supplied by the ECR ion source are accelerated by the injector up to 6 MeV/u, and pass through the C stripper foil to be fully stripped. About 250 μA of C^{6+} beams are provided to the synchrotron.

Precise positioning of the patients takes from 20 to 30 minutes, while beam irradiation continues for 2 minutes or less in typical cases. Irradiation corrected for respiration motion began in May, 1996. The treatment sites include the brain, head and neck, lung, liver, prostate, and uterus.

Basic Research

There are four experiment rooms: medium energy, physics and general, biology, and RI beam irradiation rooms. (The last one is not completed.) Experiments involving basic research include wide areas: physics, chemistry, engineering, and biology. In 1996, nearly 100 proposals were accepted, half of which were related to biology. The C beam is most commonly used in basic research, because the biology researchers are now concentrating their attention mostly on C beams. Experiments other than biology employ other kinds of beams, such as He, Ne, Si, and Ar. Seven proposals have been made which would use injector beams of He, C, Ne, and Ar. About 300 researchers inside and outside the institute participate in those researches. The beam time assigned for basic research in FY 1995 was 2200 hours in total.

Time-Sharing-Acceleration Mode

The two rings of the synchrotron can be operated independently, and injection beams into the rings are deflected by a pulse-operated switching magnet (SWM1). Using the associate of MEXP, it is possible even now that three user groups share the beam time (two beams from the synchrotron and one from the injector), if all groups utilize the same ion species. Since the condition is, however, not always satisfied, a system for a time-sharing-acceleration mode (TSA) was designed. Using TSA, it is possible to deliver different ion species to three user groups.

Our design policy is that all ions should be accelerated under the optimum condition, even in the case that beams with very different q/A values are accelerated simultaneously. Therefore, the excitation of the RF level and Q-magnets is changed on a pulse-to-pulse basis, as shown in Fig. 3.

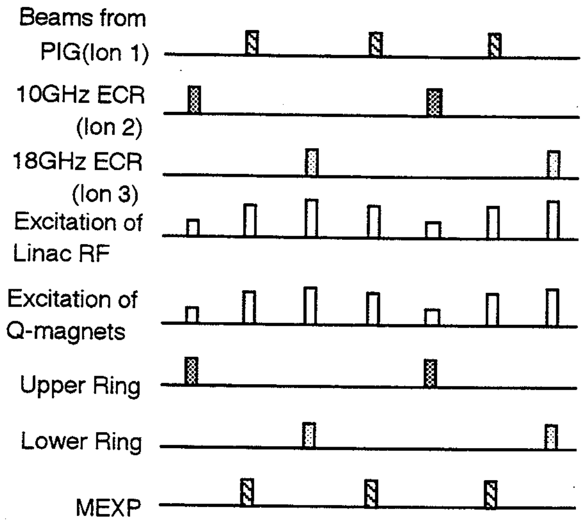

Fig. 3. Beam-pulse relation in the TSA system.

The installation comprises several steps: (1) Installing the third ion source. The new ion source was chosen to be an 18-GHz ECR ion source, so that heavier ions, such as Fe, which are strongly desired by many users, would be available [3]. The new ion source and their power supplies have already been installed. The new ion source was placed on an elevated deck 2.5 m high, as shown in Fig. 4., and the beam is extracted downward. Conditioning of the ion source started in June, 1996, and will continue until March, 1997.

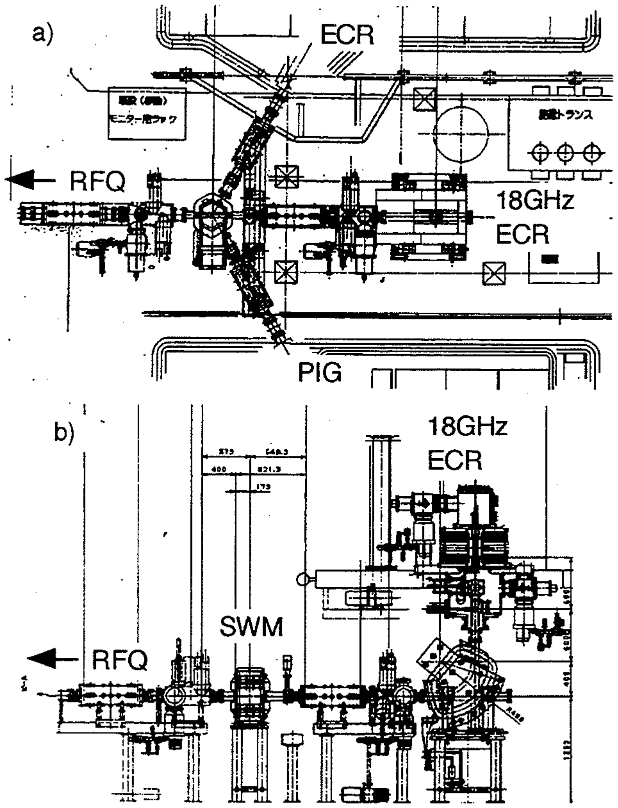

Fig. 4. Floor plan (a) and a sectional plan (b) of the new 18-GHz ECR ion source.

(2) All of the DC-operated magnets were replaced by pulse-operated magnets. They include a switching magnet downstream of the ion sources, which distributes the beams from the three ion sources to the RFQ linac. The bending magnets and quadrupole magnets in the transport line were also replaced by pulse-operated ones. The replacement of those magnets and the installation of power sources are near completion.

The following steps are scheduled for 1996 or 1997. (3) Non-destructive-type current monitors will be installed in the transport line, since the measurement of a beam should not affect any other beams. The presently used profile monitors will be used in the TSA mode, although they are multi-wire and destructive types, since no alternatives are available at present. The controllers of the profile monitors will be replaced by new ones, and profiles of three beams can be observed, independently.

(4) The control of the entire system, especially the man-machine interface, was the most controversial issue. The present control system in HIMAC employs four touch panel CRTs as input and display devices. In principle, the TSA system employs the same hardware. The CRTs are assigned to the selected ions, exclusively, and it seems for operators that there exist three independent accelerators.

The scheduling of hardware/software replacements and conditioning of the new system is the biggest difficulty. A long halt of the beam supply must be avoided in order to insure a treatment time as long as possible. Six weeks around the summer and spring are the only periods reserved for accelerator-related work. The steps described above are divided into a few sub-steps and processed during these periods. The devices and programs are tested at the factories as much as possible before installation.

The first phase of the TSA, which supplies the different beams to the MEXP and synchrotron users, is scheduled to begin in March, 1997. The second phase, which will deliver different ion species to three groups, will begin in March, 1998.

Acknowledgments

We are very thankful to the operation crew of AEC. The members of the synchrotron division of the accelerator group have provided many helpful suggestions. Sumitomo Heavy Industries is appreciated for its skillful design of the devices in the injector.

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