Status Report of the HIMAC Control System
--Reliable beam supply for cancer radiotherapy with carbon beam--

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Abstract

HIMAC has been in operation for nearly two years. During this period, the accelerator complex was commissioned, clinical trial started June 1994, and more than fifty patients treated with a 290 - 400 MeV/u carbon beam, which has been delivered on schedule and with greater than 99% reliability.

Introduction

HIMAC, the Heavy Ion Medical Accelerator, in Chiba was commissioned during November 1993 and February 1994[1]. After the pre-clinical physics and biology experiments, a clinical trial of ion beam therapy started in June 1994, when a 290 MeV/u carbon beam was delivered against tumors. Since October '94, accelerator operation has been extended from 12 hour/sday to 24 hours/day, Monday through Saturday, and basic research experiments in biology and physics have been carried out during night and week-end shifts. Various beams have been supplied for experiments, ranging from He to Ar.

In the first year of operation 55 patients were treated, and preliminary results show the effectiveness of ion beams. This paper presents operational experience of the HIMAC accelerator complex during this period.

Control system of HIMAC

The control system of HIMAC comprises a supervising computer and three "sub-system" controls: Injector[2], Synchrotron[3], and High Energy Beam Transport system[4]. The irradiation control, including beam shaping and dosimetric functions for clinical trials, is carried out at a therapy control area.

The design principle of the control system, concerning operational aspects, is such that: 1) all the equipment is controlled at a "sub-system" console, 2) the operational procedures or sequences are unified to touch panel operations and rotary dials and are common to all subsystems, and 3) parameters such as current settings of magnets are saved as files and can be reloaded. The design was to assure operators easy access to control of the machine. This principle was followed for themost part, but response time, for example, differs somewhat due to different platforms and system constructions among sub-systems.

The injector control system was designed and built earlier than the other subsystems, and has been used for longer time. The CPU for System Control Unit and Group Control Units were upgraded during a scheduled maintenance period in March 1995, and improved system performance substantially. Typically, loading time for the entire injector system from cold start is reduced to 5 minutes from 40 minutes. Application enhancement for various operational needs is also being made; details will be described elsewhere.[5]

Synchrotron controls perform timing control for the overall system and control of repetitive patterns of magnets and rf. As for tracking of main dipole and QF/QD magnets, although we had prepared a tool to form the current waveform from the desired values of magnetic field, it was found that simple scaling of the current pattern between dipole and QF/QD would suffice for daily operation, provided that an iterative adjustment for the driving voltage waveform was carried out. However, more studies are needed to understand the system.[6]

High Energy Beam Transport control has to deal with requests from Irradiation Control for beam control and switching. Since HIMAC comprises two synchrotron rings and four treatment beam ports, as well as two physics ports and a biology port, HEBT control must be capable of exciting proper switching magnets and de-exciting unnecessary ones. Using an operation parameter file that has descriptions of source ring(s) and destination port(s), it can set up the HEBT system for the requested delivery.

The overall controls were designed so that one can set up each subsystem from the supervisor system using a system standard file, while at present daily operation is carried out from each subsystem.

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Operations Framework

Daily operations of the machine are carried out by the crew of operators who belong to a company established for accelerator operation, maintenance and development by manufacturing firms. The operators' prior experience on accelerators varies from null, some even without a college physics degree, to years at other facilities. The man-machine interface of the control system provides tools for operators. Twenty-four hour operation started in October 94, with two shifts of six operators.

The weekly operational schedule is as follows: Monday 9 a.m. to 3 p.m. for preventive maintenance, then the cold start of machine, from 7 p.m. delivering beam to experiments until Tuesday 7 a.m. After tuning the machine for treatment beam, 9 a.m. to 7 p.m. are exclusively for medical treatment and relevant dosimetry. Again with re-tuning, beam is delivered to other experiments until 7 a.m. next day. From Friday evening the time is for experiments usually until Saturday 8 p.m. and sometimes until Sunday morning.

Beam Delivery

In March 1994, we accelerated carbon beam to 290 MeV/u, which has a most reasonable characteristic for initial clinical trial, in both rings. Typical intensity for treatment is 3×10^8 particles per second. In clinical irradiation, beam is used after baing modulated by wobbler magnets and scatterers to cover the tumor volume with uniform intensity for treatment. The patient must be immobilized in a pre-determined position so that beam irradiates cancerous parts without damaging healthy organs and tissue. It usually takes 20 - 40 minutes to position the target in a patient, then irradiation needs less than 5 minutes, which takes place typically 18 times per patient. This means that stable and reproducible beam delivery is necessary during a day and also for an extended period of several months. HIMAC has been up to this demand since the first clinical trial. Exceptions are one call-off for the day due to rf trouble in the linac and a few re-schedulings within the day due to various minor troubles such as malfunction of waterflow monitors.

We also accelerated Ne, Si, and Ar up to 600, 800, and 650 MeV/u, respectively. In accelerating these ions the synchrotron main magnets are expected to show field saturation; nevertheless, we could accelerate them within a couple of hours thanks to the existing excitation pattern and scaling function of the control system. Notably, for beams with charge-to-mass ratio of 1/2, parameters can be essentially common as long as the acceleration energy is the same.

Since May 1995 clinical trials have been carried out also with 350 MeV/u for vertical irradiation and 400 MeV/u for horizontal ports, in addition to 290 MeV/u. This represents another challenge in operation: We have to deliver beam of two different energies within an hour or less, and they must both be stable and reproducible. It has been met after establishing parameter files and simulating the situation.

Still another requirement is that beam must be delivered to different irradiation ports without adjusting beam position, etc. at the final irradiation point. This has also been examined and is ready for actual practice.

Most of the tuning effort is to adjust ion source parameters and transport to linacs in the case of the injector system, injection angle, position and timing for synchrotron rings, and centering the extracted beam for both synchrotron and HEBT systems. By analyzing these activities, necessary tuning time for treatment beams is reduced and stability and reproducibility of the beam are also improved.

Development Activities

For improving irradiation characteristics further, several efforts are being made. One is to gate beam extraction by signals from the patient's respiratory motion. This can be realized by applying transverse electric fields to the beam at the flat top.[7] The respiration motion sensor and interlock system is scheduled to begin operation in summer 1996.

A VME module for dynamic switching of the excitation pattern is also under development, and is reported in this conference.[8]

In the injector, it is planned to expand pulse operation to the entire system in order to accelerate different ion species for respective rings in a pulse-by-pulse mode. This will also enable more independent use of the 'medium energy' beam port, which utilizes the 6 MeV/u output beam from the linac. An 18 GHz ECR ion source is also under development for heavier ions such as Fe.

Major effort is also now expended to design and to construct Secondary Beam irradiation ports. With use of positron emiters beam such as ^{11}C, one can expect to monitor the beam irradiation volume by PET technology. It will also provide for experimental research in physics and biology.

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