Secondary-Beam Tuning System at HIMAC

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Abstract

A secondary-beam course have been constructed at HIMAC. The ^{11}C beam analyzed with the newly developed beam course showed satisfying quality; a production rate and a purity are 0.2% and 97%, respectively. A computer control system was designed so as to realize automatic beam-tuning; i.e. processes, such as calculation and setting of the device parameters, data acquisition and analyses for particle identification, and optimization of device parameters, are executed without intervention of operators. In a preliminary test operation, automatic tuning of ^{11}C beam was performed within 40 min. The reproducibility of the beam quality was very well.

1 Introduction

Clinical trials of cancer treatment by using high-energy heavy-ion beams have been practiced since June 1994 at HIMAC (Heavy Ion Medical Accelerator in Chiba) [1]. Heavy-ion beams have the following advantages: (1) good dose localization due to the Bragg-peak, and (2) large values of relative biological effectiveness. In the cancer treatment, it is important to determine residual ranges of irradiating ions with high accuracy. At present, the range is calculated based on the CT values obtained by X-ray CTs [2], and the errors involved are not negligible in some cases. A more precise method for the range measurement is required in order to take full advantage of the heavy-ion beams. Radioactive isotope beams (RI beams) are expected to be an excellent tool for the range measurements. One can estimate a position where a beam stops with high accuracy by detecting annihilation gamma rays. Other application includes confirmation of irradiated targets by employing the positron emission tomography [3]. Thus, a secondary-beam course to select mainly the positron emitters has been constructed at HIMAC [4,5]. In this report, we describe an outline of the control system and some preliminary results obtained in the beam tests.

2 Secondary-beam course at HIMAC

High-energy secondary beams can be produced by the projectile-fragmentation method. A layout of the secondary-beam course at HIMAC is shown in Fig. 1. The beam course, named as SB1, is a spectrometer comprising a pair of bending magnets, eleven quadruple magnets, a production target and an energy degrader [4]. The principle to separate ions with specific mass A and charge Z is as follows. (1) Fragments are produced in the target at the focusing point F0. (2) Particles with a given A/Z value are selected at the dispersive focusing point F1 after the first bending magnet (BM1). (3) Particles separated at F1 lose their energy in the energy degrader by an amount determined mainly by their Z values and the degrader thickness. (4) Particles with desired A and Z are focused at the doubly-achromatic focusing point F2 with the second bending magnet (BM2).

Particles are identified by a ΔE counter at F2 and Time-of-Flight (TOF) counters at F1 and F2. The TOF counters also work as intensity monitors in the beam tuning.

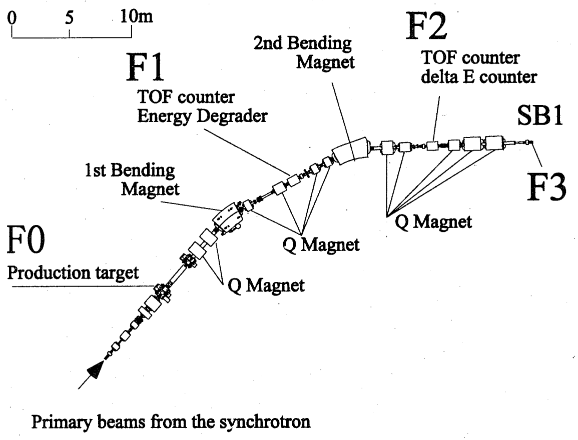

Fig. 1 A layout of the secondary-beam course at HIMAC.

3 Tuning system of secondary-beam

3.1 Requirements to the control system.

Beam courses for medical use are required to fulfill the characteristics of high reproducibility of beam quality and easy operation. The beam quality includes energy, intensity, size, and purity of the secondary beams. The easy operation is indispensable so that operators without special knowledge about reaction products can operate the beam course as a routine work. Furthermore, the tuning time should be as short as possible to increase available beam time for users. A new control system (SB control system) was designed and constructed, in addition to the existing control system, to satisfy above requirements.

The SB control system was designed to possess the following functions: (1) calculating and setting the device parameters (magnets, slits, and so on), (2) monitoring those devices during the operation, (3) acquiring and analyzing data concerning with the primary beams and secondary beams, and (4) automatically adjusting the device parameter to optimum values. The last item, i.e., automatic beam-tuning, is strongly desired for the easy operation.

3.2 The SB control system and existing system

The SB control system comprises two computers: SB-GCU (Secondary Beam Group Control Unit), and SB-DAU (Secondary Beam Data Acquisition Unit). These computers are connected with an existing main computer of HEBT-SCU (High Energy Beam Transport System Control Unit) through a network as shown in Fig. 2.

HEBT-SCU is a main part of the existing control system of High Energy Beam Transport System. Beam transport devices, such as the magnets, slits, targets, and the degrader, are connected to HEBT-SCU. Thus, HEBT-SCU sets device parameters after receiving those values from SB-GCU, and monitors the device status during the operation.

The SB control system was designed to be independent from the existing system so that the former can be debugged and modified without disturbing the latter.

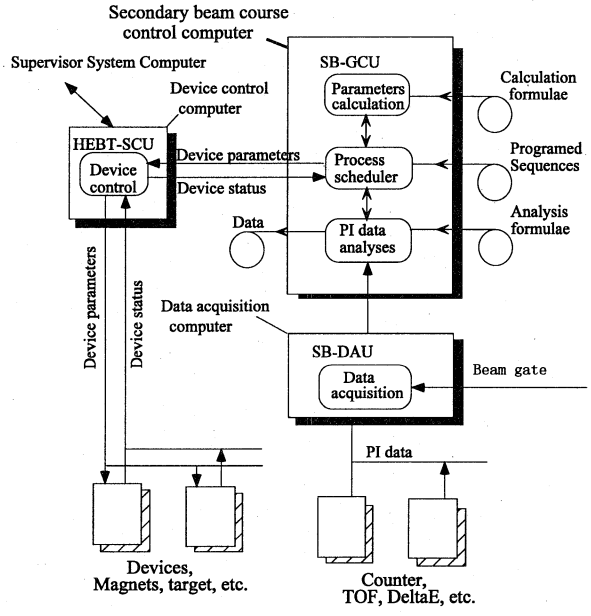

Fig. 2 Outline of the SB control system.

3.3 SB control system

Secondary Beam Data Acquisition Unit

SB-DAU is a front-end processor using the VME bus (Eagle162LX), and is devoted to data acquisition of particle-identification (PI) data. Detectors, TOF counters and a ΔE counter, and modules for PI data are controlled by SB-DAU. The ΔE counter is a silicon detector with a size of 48×48 mm and a thickness of 325μm. Analog signals from the ΔE counter is fed to an amplifier and is digitized by an ADC (mtt DSP 8112). The TOF counter is a plastic scintillater with a size of 50×120 mm and a thickness of 0.5mm. A couple of photomultiplier tubes is connected at the both sides of the TOF counter. Mean values of two signals are adopted as timing signals to avoid the position dependence. Start and stop signals are fed to a TAC digitized data together with ΔE data are stored in the memory module (mtt DSP 8031) and are transferred to SB-GCU through LAN during beam-off intervals. Conversion and storage takes about 20 μs for each event, and the memory module can store the data up to 10000 event per spill.

Secondary Beam Group Control Unit

SB-GCU plays the leading role in the SB control system except for the acquisition of the PI data. All the data, such as parameter sets and observed data, are stored in SB-GCU. Moreover, SB-GCU works as a man-machine interface in a development stage, i.e. analysis formulae and programmed sequences are set or corrected on the console of SB-GCU. Device parameters calculated by SB-GCU are sent to HEBT-SCU. Information of device status is sent back from HEBT-SCU in the opposite direction.

As stated above, three computers exchange a lot of data and information. In order to avoid congestion of the network, the data transfers are carried out during beam-off intervals. Figure 3 shows timing of the data transfer. Beam-off triggers initiate the transfer of the device parameters and the PI data. Change of device parameters occurs only in the beam-off intervals.

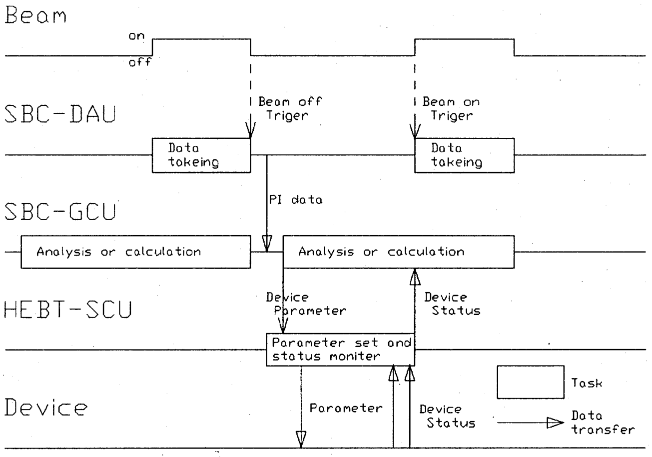

Fig. 3 Time chart of the data and parameter transfer

4 Procedures of automatic beam-tuning.

Automatic beam-tuning procedure consists of two phases: (1) tuning to the primary beam for calibrating magnet strength and PI signal, and (2) searching for optimized set of parameters for secondary beam of interest as defined by Bρ value and an area in A/Z plane. Optimization is done by maximizing the relative yield of defined secondary beam over total yield.

The following procedures are employed in the automatic beam-tuning. Firstly, beam-transport parameters for the primary beam are calculated and the devices are set to those values. Then, (1) the field strengths of BM1 and quadrupole magnets placed upstream from the F1 are optimized so as to give the maximum intensity of the TOF counter at F1. (2) The field strength of BM2 is adjusted by the same way as the case of BM1. Second procedure is important to estimate the energy loss through the degrader. The currents of the quadrupole magnets are changed with the same ratios as those of the bending magnets during the optimization procedure. (3) The PI data of the primary-beam particles are analyzed and mapped on an A-Z plane. Based on those data, an area where the secondary-beam particles would occupy is estimated.

Secondly, parameters for the secondary beam, are calculated from the optimized parameters described above. (4) A production rate and purity of the secondary beam can be estimated from the PI data, assuming that the events inside the predetermined area are desired secondary-beam particles. (5) The devices, such as bending magnets, quadrupole magnets, and slits, are adjusted to maximize the purity of the secondary-beam particles.

5 Results of the beam test using ^{12}C beams

An example of the particle-identification data is shown in Fig. 4. The primary beam was ^{12}C with energy of 400 MeV/u. A beryllium target with a thickness of about 51-mm was used. An aluminum degrader was with a wedge angle of 0.689 deg and a thickness at center of about 7 mm. The relation between A/Z and Z is plotted in the two-dimensional spectrum (top) and TOF and ΔE data are displayed (middle and bottom). In order to demonstrate excellent separation between the adjacent particles, the data of Fig. 4 were collected in the relatively poor condition for ^{11}C production (the degrader was removed). If all the devices were set in the optimum condition for production of ^{11}C, the production rate and the purity were 0.2% and 97%, respectively. The results were quite satisfactory.

A process of the automatic beam-tuning was also tested using the same primary beam and target. The magnetic rigidity of the bending magnets were searched within a range of ±0.3 % by a step of 0.05 %, and the slits width at F1 and F2 were adjusted. The currents of the quadrupole magnets were varied by the same ratios as those of the bending magnets. Starting from the calculated parameters, the system could find the condition for production of the ^{11}C beam of the mentioned purity and rate in about 40 min. It was also tried to produce a new secondary beam, ^{8}B. Using the similar procedures to the ^{11}C case, the system could adjust the devices for production of the ^{8}B beam successfully in 40 min.

The performance of the beam course and the control system so far has been very satisfying. Test operation employing the beams other than ^{12}C is in progress.

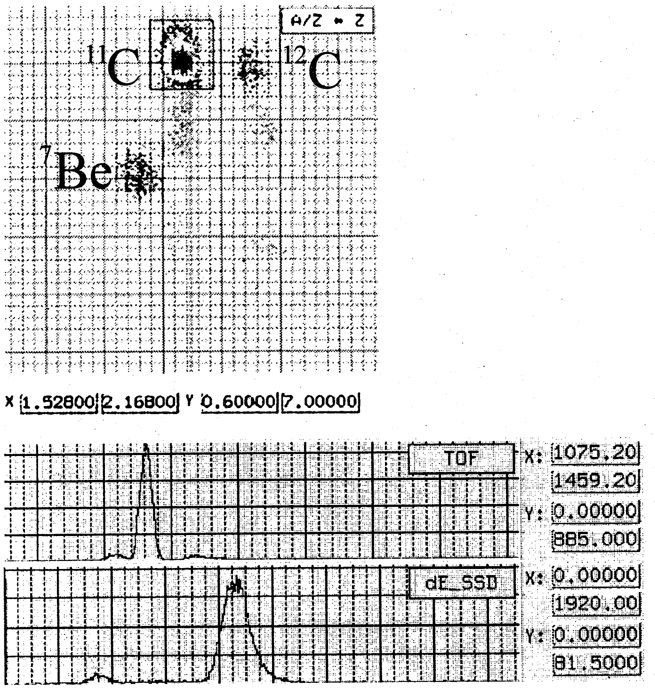

Fig. 4 Particle identification data (top) and TOF and ΔE data (bottom) in the beam using the ^{12}C beams.

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