BEAM DECELERATION IN THE OPERATION OF THE BEAM EXTRACTION WITH A PATIENT RESPIRATION

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Abstract

Synchronized beam extraction with a patient respiration is planned for the irradiation on the cancer such as liver and lung, which will move with respiration. For this purpose we have applied rf knock-out extraction, with which the quick start and stop of the beam extraction is easy and important in the synchronized beam extraction. In the operation of this gated extraction there is unextracted high energy beam, that cause the unnecessary activation of the synchrotron ring. To prevent this, we have made and tested the deceleration system down to the injection energy of 6 MeV/u.

1 INTRODUCTION

Radiation therapy with carbon ion has started at June 1994 in HIMAC[1]. Since then several new developments on the radiation therapy are started such as three dimensional (3D) irradiation[2], synchronized irradiation with respiration[3]. With the 3D irradiation. we can decrease the dose on the normal tissue around the cancer. This method is applicable for the cancer that will not move during irradiation period of about 100 seconds. When there is movement of the cancer volume such as the lung or the liver, the irradiation gate with respiration will be applied to decrease dose on the normal tissue.

The gate pulse of the irradiation is made from the movement of the patient body. In the gated period, the movement of the cancer volume is relatively small, and the beam is extracted only in this period. If this gate period does not exist in the flat-top, the accelerated beam can't be extracted. To prevent the increment of the radiation level and the activation of the devices in the ring, there are two ways. One is the beam abort system with the fast kicker magnet, with which the activation due to the unextracted beam can be localized on the scraper. Another way is the beam deceleration down to the low energy with which the activation is small enough. In the HIMAC synchrotron we have applied the latter method. The reasons of this choice are as follows:

- There is no highly activated place due to high energy beam dump.
- In our acceleration system the stable operation is possible without any beam feedback, that mean the capability of the stable deceleration with low intensity beam after partial beam extraction.
- There are few devices required additionally.

2 MODIFICATION OF THE ACCELERATION SYSTEM

The digital acceleration system[4] is working stably, and the fluctuation of the accelerated beam intensity is satisfactorily small without any beam feedback. During the beam extraction the rf voltage is continue with the constant rf frequency, which was adjusted to obtain high extraction efficiency. With the old system , the rf voltage was turned off at the end of the flat top period, and the pattern data were set to the initial values of the flat base.

With the new system, the rf voltage is not turned off, but the clock pulse is switched to the B^- clock (0.2 Gauss increment or decrement of the dipole magnetic field) again from the T-clock (50kHz). According the decrease of the dipole field, the rf system decelerate the beam down to the injection energy of 6MeV/u. To decelerate the beam with good efficiency after the operation of slow beam extraction, the beam orbit must be set back to the center that is suitable for deceleration. In the ramping period of the deceleration, the pattern of the same function can be used as ones in the acceleration region. To obtain these functions, we have replaced the pattern memory modules to new ones, and added the event signals for start and stop of the deceleration. The operation with deceration require 100% duty, and increase power consumption in many components in the high power system. Because the system has enough capability for the full duty with 6kV, which is the enough rf voltage for acceleration and deceleration in HIMAC synchrotron, we haven't changed anything the high power system for this duty operation.

3 NEW PATTERN MEMORY

To obtain deceleration function we have developed the new pattern memory (see figure 1), which has following features.

- The pattern memory consists of four regions for the flat base, the magnetic field ramping, the flat top, and the reset patterns. In the field ramping region, the pattern data are driven with the field increment (or decrement) signals of 0.2 Gauss step. In the other regions the clock signal of 50kHz can be used. With the event signal of the deceleration start, the address changed to the one that have the same output data as the value at the end of flat top region. To control the beam position at the deceleration start, the frequency can be adjusted at the end of the flat top.
- Every 64 data of the output pattern is stored in the pattern memory, and the real output data are calculated from these stored data with the DSP (Digital Signal Processor). With this DSP the maximum output rate of 105kHz can be achieved, and this speed is high enough for our digital acceleration system. The length of the stored data is 64k word, and this is long enough for the maximum flat top of 1.8 second. This contraction of the stored data has the advantage of short changing time with new data, and this quick change of the pattern is required in the therapy machine. For the future usage, there are memory banks of 16 to change the pattern data more quickly or to change operation pattern from pulse to pulse successively.

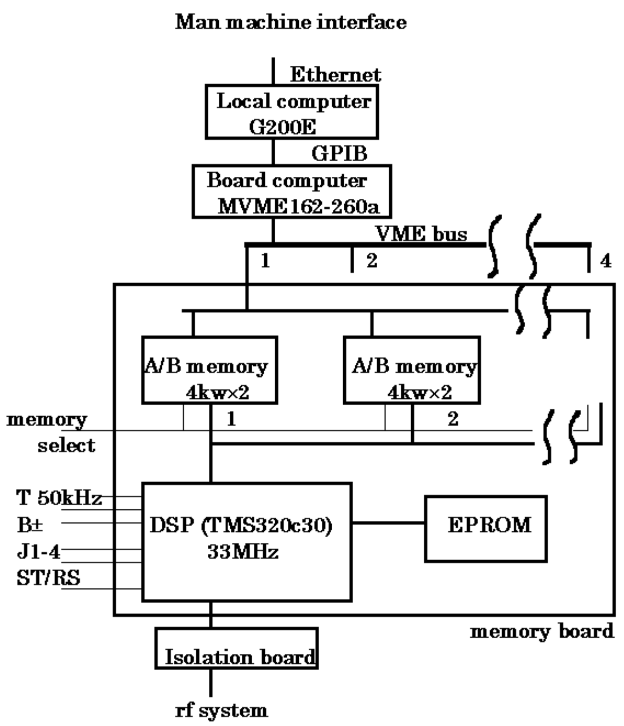

Figure 1. The new pattern memory with the interface computers.

4 BEAM TEST

In the beam test, the operation pattern of 400MeV/u has been used, which is used in the current carbon therapy in the HIMAC. In the operation of the acceleration system, the constant voltage of 4kV has been applied. And this voltage is lowest value in the beam acceleration, with which we have no clear deterioration in the beam intensity than the case with 6kV. In the beam experiment we have not used the beam feedback of the phase and position.

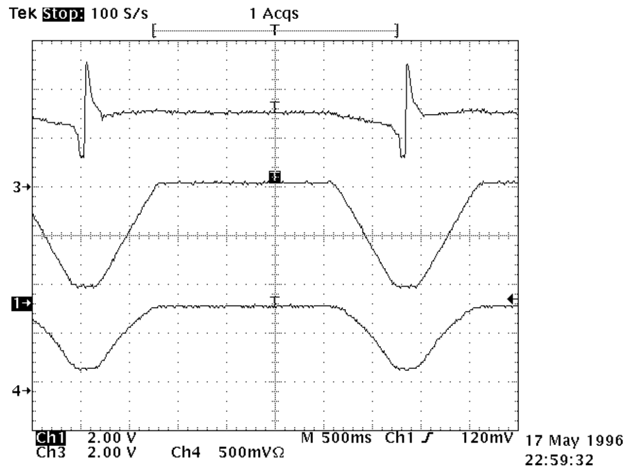

Figure 2. The beam signal with the deceleration (upper signal). The middle and lower signals are the current of the magnet and the acceleration frequency, respectively. Horizontal scale is 0.5sec/div.

Adjustment parameters for the deceleration are only the fine gain of the B^{-}clock and the beam position at the start time of the deceleration. In Figure 2 the beam signal of the electrostatic pick-up monitor (amplitude of the fundamental acceleration frequency) is shown together with the current pattern of the dipole magnet and the frequency. Except for the low energy beam loss just after the capture and at the end of the deceleration, the beam loss is small.

In Figure 3 the beam intensity signal (DCCT output signal divided with acceleration frequency) is shown together with the current pattern of the dipole magnet. In this case we haven't applied the knock-out rf power. The deceleration efficiency to the injection energy from the top energy was 71%. The efficiency was 85% until the large loss occurred just above the injection energy, where the ramping speed was varying. The Figure 4 show the case of the deceleration after the partial extraction. Even though the emittance growth with the knockout rf field to extract the beam exists, the beam loss was small at the high energy.

To see the effect of the deceleration, we have measured the radiation level with the gamma and the neutron monitors in the following three cases. In the first case we have knocked out the full beam from the ring for extraction with the extraction efficiency of 83%. In the second case half the beam was knocked out to extract, and in the third case there is no knock-out rf power.

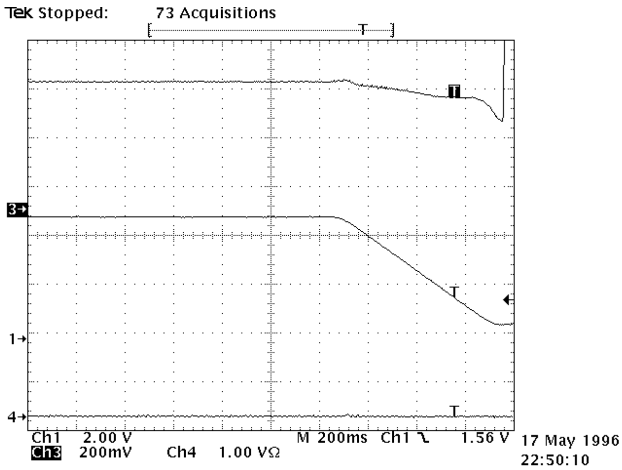

Figure 3. DCCT signal (upper) with current pattern (lower) at the deceleration. Horizontal scale is 0.2 sec/div..

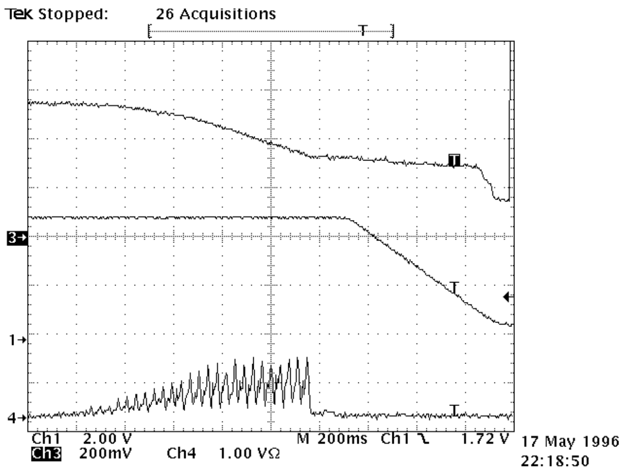

Figure 4. DCCT signal (upper) and current pattern (middle) with the partially extracted beam signal(lower).

The monitor locations are shown in Figure 4, and the measured values are shown in table 1. In all cases the beam intensity in the ring was 5.9×10^9 particles. This shows the clear effect of the deceleration in the third case and also in the second case. In these cases the radiation levels are low around extraction devices. At the injection point the level became higher with the deceleration. This is due to beam loss of the decelerated beam with fast bump orbit of the multi-turn injection, but the absolute radiation level are low enough in all cases. These results show the effectiveness of the beam deceleration to suppress the radiation level and the activation, and this deceleration system will be used in daily operation.

Table 1

Radiation level with the operation of deceleration

	extract	partial extract	no extract
n1(μSv/h)	2.5	1.2	0.55
r2(μSv/h)	0.29	0.28	0.09
r3(μSv/h)	0.65	0.62	1.6
r4(μSv/h)	50	42	31
r5(μSv/h)	40	33	2.7

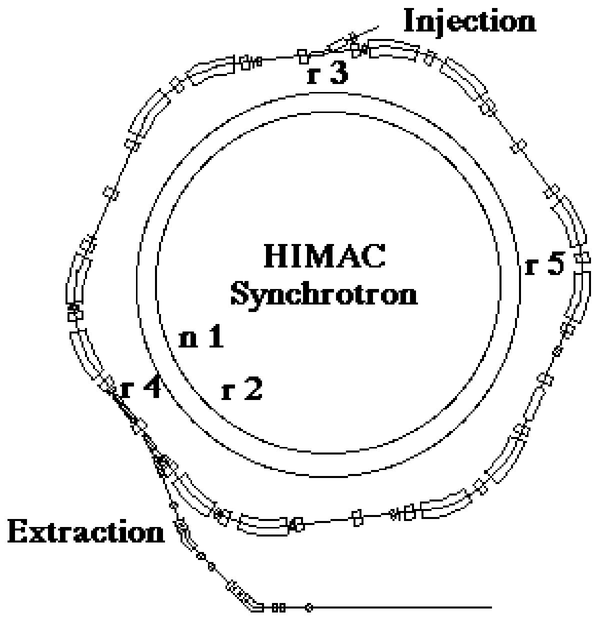

Figure 4. Layout of the HIMAC synchrotron and the monitors of the radiation level.

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REFERENCES

[1] S.Yamada, et al "Commissioning and performance of the HIMAC medical accelerator" PAC, 1995, to be published.

[2] Futami, et al., "Development of 3-dimensional irradiation System for Heavy-ion Radiation Therapy" Proc. Of 10^{th} symp Acc. Sci. and Tech., 442-444, 1995.

[3] K.Noda, et al., "A Treatment Beam Control System for Irradiation Gated by Respiration of a patient" Proc. Of 10^{th} symp Acc. Sci. and Tech., 439-441, 1995.

[4] M.Kanazawa, et al., "The RF System of the HIMAC Synchrotron", EPAC, 1179, 1992. M.Kanazawa, et al., "Beam Acceleration with the Digital Beam Feedback in HIMAC Synchrotron", EPAC 1972, 1994.