RECENT IMPROVEMENT OF SLOW-EXTRACTION AT HIMAC SYNCHROTRON

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Abstract

Concerning the beam scanning irradiation as an advanced irradiation technique in heavy ion cancer thrapy, recently, the development of the RF-knockout extraction has been progressed, because the RF-knockout extraction can achieve the quick response of beam on/off. In this paper, recent improvement of slow-extraction at HIMAC synchrotron is presented.

INTRODUCTION

Clinical trials of heavy ion therapy in HIMAC (Heavy Ion Medical Accelerator in Chiba) [1] started on June 1994, and treatments of more than 1800 patients were successfully completed by June 2004. On the other hand, as one of the objectives at the HIMAC, new technologies in heavy-ion therapy and related basic and applied research have been developed. At the HIMAC synchrotron, therefore, the RF-knockout slow-extraction method has been developed and utilized, not only for cancer therapy but also for physics and biological experiments. Concerning the beam scanning irradiation as an advanced irradiation technique, recently, the development of the RF-knockout extraction has been considerably progressed.

For the purpose of realizing the precise irradiation by means of the beam scanning, the studies of the irradiation [2-4] indicated requirements to a medical accelerator as follows; 1) fast beam cut-off, 2) time-structure control and 3) beam size control. By turning off both the transverse and longitudinal RF-fields, the cut-off time of 50 μs was realized [5-6]. On the other hand, the kHz order of spill ripple was significantly reduced by separate function method [7]. These results were already reported in last EPAC [8]. However, the global spill structure (10 Hz order) and the beam size had not yet been sufficiently controlled. Recently, thus, the development for controlling the global spill and the beam size has been carried out. The global spill structure is improved by optimization of amplitude modulation (AM) function based on analytical approach. Cooperating with the feedback system, the flat spill is easily obtained without gain control of the feedback during extraction. On the other hand, the effect of the longitudinal motion for the bunched beam extraction was studied to suppress the frequency component of the synchrotron oscillation. For controlling the beam size, further, the measurement method of the outgoing separatrix is proposed and verified. Based on this measurement, the transport optics of the extracted beam was readjusted. This technique allows us to control the beam size precisely as planned.

In this paper, recent improvement of slow-extraction at HIMAC synchrotron is reported.

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IMPROVEMENT OF TIME STRUCTURE

Global spill control

For the purpose of global spill control, we have proposed a scheme to optimize the AM function of the transverse RF-field [9]. In this scheme, a simple model of the extraction process, in which the radial distribution of particles with diffusion by the RF-knockout is assumed to be the Rayleigh distribution as shown in Fig. 1, was used to obtain a new AM function for a flat spill. Using this model, the global spill structure without AM was analyzed to determine the parameter relevant to the diffusion process by RF-knockout. As a result, we can obtain the new AM function to realize the flat spill.

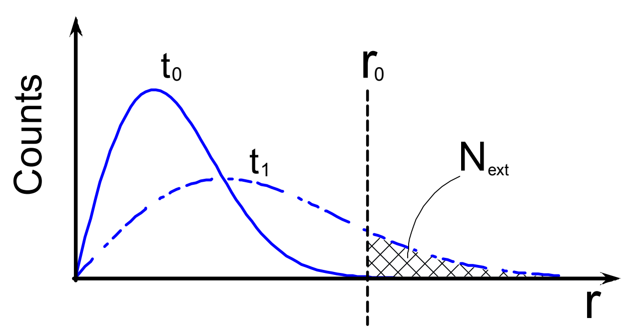

Fig. 1: Radial distribution in the normalized phase-space for considering the simple extraction model. r_0 represents the boundary of the separatrix.

By applying the new AM function obtained by this scheme, a flat spill within ±23% can be provided as shown in Fig. 2 (a). Cooperating with the feedback system, finally, a flat spill was provided to be less than ±5% in fluctuation, as shown in Fig. 2 (b), while a kHz order ripple was suppressed by the separate function method [7].

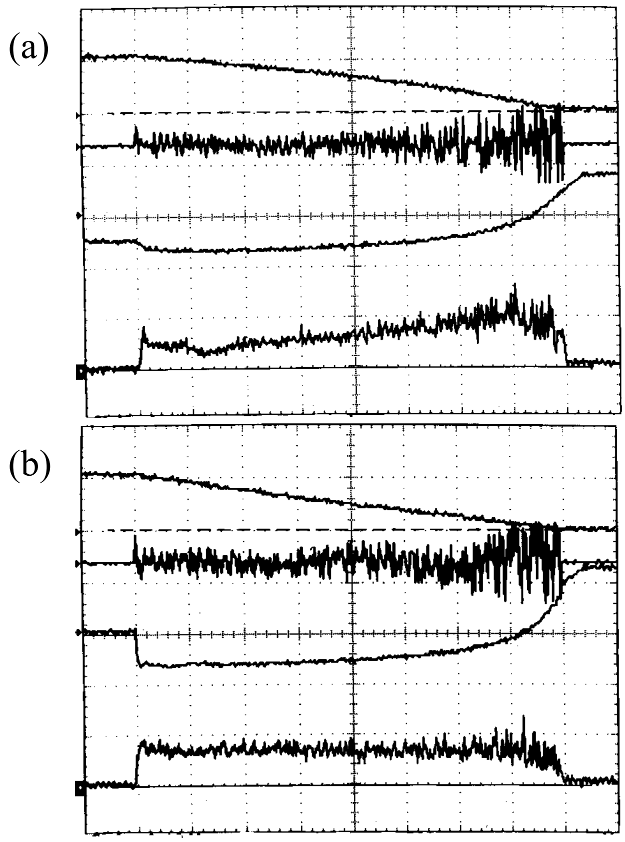

Fig. 2: (a) Spill structure by using new AM function obtained by analytical approach without feedback system, (b) with feedback system. From the bottom of each figure, the spill structure, the AM signal, the transverse RF-field, and the circulating beam intensity.

Contribution of synchrotron oscillation

Although the kHz order spill ripple is suppressed by means of the separate function method, the synchrotron oscillation frequency component could not be removed. For a further improvement of the extraction-beam quality, the contribution of the synchrotron oscillation to the spill ripple has been studied.

By using the simulation, it was found that the followings are essential for suppressing the spill ripple: 1) sufficient amplitude of the momentum oscillation and 2) uniform longitudinal phase distribution. They were verified through the experiment with the debunch-recapture process before extraction. The experimental results of ripple spectra are shown in Fig. 3. Although the off-centering beam in the RF bucket brings the frequency component of the synchrotron oscillation to the spill ripple, the recaptured beam can suppress the frequency component due to the synchrotron oscillation owing to their uniform distribution of the longitudinal phase and to their larger longitudinal emittance. On the other hand, it was found that the longitudinal phase-space distribution changes slightly during extraction, which causes a slight change in both the momentum distribution and the momentum-center of the extracted beam during extraction. However, such a small difference in the momentum distribution does not affect practical ion therapy, because the momentum spread is enlarged to obtain a spread-out Bragg-peak (SOBP).

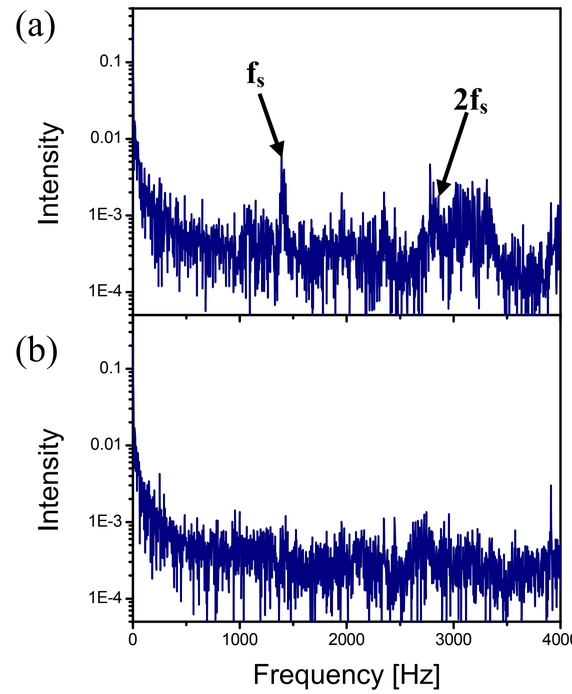

Fig. 3: Fourier spectrum of spill. (a) ordinary bunched beam, and (b) debunch-recaptured beam.

MATCHING TO TRANSPORT SYSTEM

In the RF-knockout extraction, to keep the emittance constant during the extraction is easier than the ordinary slow-extraction owing to the constant separatrix. However, the verification method of beam matching has not yet been developed. In order to estimate the optical characteristics of the extracted beam, thus, a simple method [10] to measure the outgoing separatrix using two tantalum rods has been proposed and verified.

By measuring the extracted beam intensity with inserting two rods into the ring, the intensity difference for different position of second rod can be observed for each position of rod1. As a result, one of the outgoing separatrix for the extraction can be measured. As shown in Fig. 4, the result of the measurement is in good agreement with the simulation result by the particle tracking code [5] for the RF-knockout extraction. Since there is the electrostatic deflector (ESD), the particles into 77~90mm will be extracted. As a result, we can determine the twiss parameters of the extracted beam at the entrance of the ESD. This result suggested the mismatching of the dispersion and twiss parameters from the original design value.

The optical parameters of the transport line were redesigned to match the optical function with the extracted beam. Finally, it was experimentally verified that the optics of the slowly extracted beam matches with the transport system. The measured beam profile and dispersion function is in good agreement with the simulation at each monitor in the transport line. The typical result of the beam profile is shown in Fig. 5. Further, it was verified that the HIMAC transport system can deliver the beam having wide momentum spread ($2\sigma = \pm 0.4\%$) owing to minimized dispersion function. The extraction and transport efficiency of more than 95% and the beam size were kept even for such wide momentum spread beam. This result is essentially important in the fast beam switching [6], in which the longitudinal emittance inevitably increases during the extraction due to turning on/off the RF many times.

On the other hand, the technique of the outgoing separatrix measurement can be applied to diagnose the ordinary slow-extraction for optimization of the extraction.

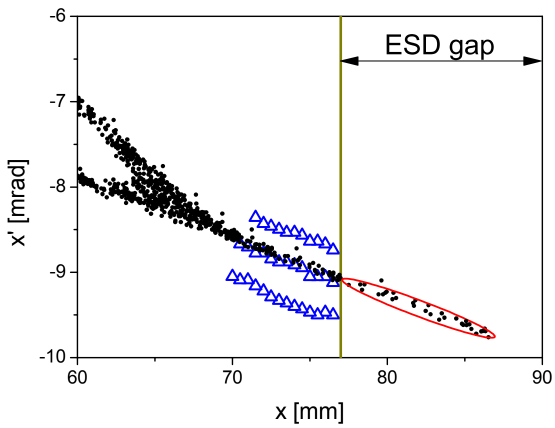

Fig. 4: Triangles represent outgoing separatrix for each momentum of –0.3%, 0.0% and 0.3% from the bottom, as a result of the experiment. Closed circles are simulation result of the separatrix. The area enclosed by line shows extracted beam.

SUMMARY

For the purpose of realizing the precise irradiation by means of the beam scanning, recently, the development of the RF-knockout extraction for controlling the global spill and the beam size has been carried out. The global spill structure is improved by new AM function obtained through analytical approach and the feedback system. For controlling the beam size, on the other hand, the measurement method of the outgoing separatrix was proposed and verified. Based on this measurement, the transport optics of the extracted beam was readjusted. This technique allows us to control the beam size precisely as planned. Further, these techniques can be applied to the ordinary slow-extraction toward the improvement of the extracted beam quality.

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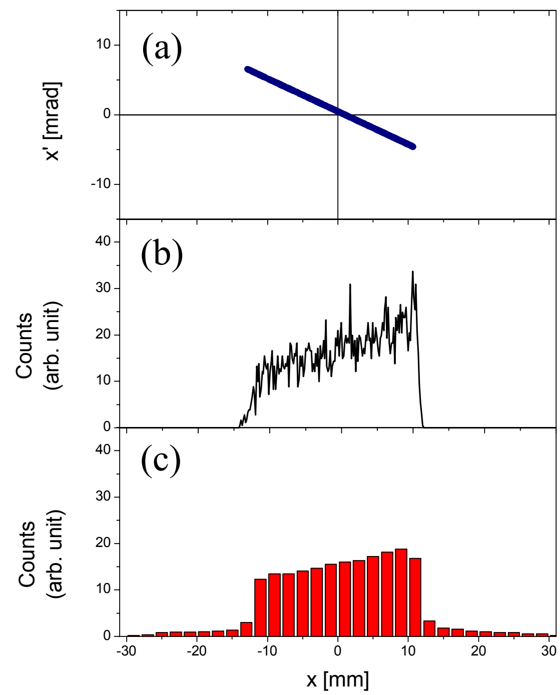

Fig.5: Comparison of the horizontal beam profile between the simulation and the experiment. (a) Phase-space distribution estimated by simulation, (b) profile estimated by the simulation and (c) the measured profile.

REFERENCES

[1] E. Takada et al, Proc. 3rd APAC, in press.
[2] T.R. Renner et al, Proc. 1st Symp. on Hadrontherapy, (1993) 453.
[3] Th. Haberer et al, Nucl. Instr. and Meth. A 330 (1993) 296.
[4] E. Urakabe et al, Jpn. J. Appl. Phys. 40 (2001) 2540.
[5] T. Furukawa et al, Nucl. Instr. and Meth. A 489 (2002) 59.
[6] T. Furukawa et al, Nucl. Instr. and Meth. A 503 (2003) 485.
[7] K. Noda et al, Nucl. Instr. and Meth. A 492 (2002) 253.
[8] T. Furukawa et al, Proc. 8th EPAC, (2002) 2739.
[9] T. Furukawa et al, Nucl. Instr. and Meth. A 515 (2003) 853.
[10] T. Furukawa et al, Nucl. Instr. and Meth. A 522 (2004) 196.