DEVELOPMENT OF INTENSITY CONTROL SYSTEM WITH RF-KNOCKOUT EXTRACTION AT THE HIMAC SYNCHROTRON

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Abstract

We have developed a dynamic intensity control system toward scanning irradiation at the HIMAC synchrotron. In this system, for controlling the spill structure and intensities of the beams extracted from the synchrotron, the amplitude of the RF-knockout is controlled with the response of 10 kHz. Its amplitude modulation (AM) function is generated based on an analytical one-dimensional model of the RF-knockout slow-extraction. In this paper, we describe the system for controlling amplitude modulation including feed back and the experimental result.

INTRODUCTION

At HIMAC (Heavy Ion Medical Accelerator in Chiba) [1,2], the construction of additional treatment rooms was initiated from this April, while clinical trial has been in progress since 1994. One of these developments is a beam-scanning irradiation method [3,4], which brings a high irradiation accuracy, even for an irregular-shaped target. For the purpose of realizing precise irradiation by means of beam scanning, at HIMAC synchrotron, we have studied and improved the quality of the extracted beam by the RF-knockout slow-extraction method [5,6], which employs a transverse RF-field to diffuse particles. Since the flat spill (constant current) and the intensity control allow precise irradiation with a larger dynamic range of dose modulation, we have developed a scheme to control the spill structure and the beam intensity by the AM of the transverse RF-field for extraction. In order to obtain the AM function analytically, a one-dimensional simple model [7] was used in this scheme. By using this scheme, the intensity of extract beam was controlled dynamically. By cooperating with the feed back system, this technique allows us to control the beam current almost as planned. In this paper, intensity control system in RF-knockout extraction for the scanning irradiation is reported.

INTENSITY CONTROL SUSYEM

System Configuration

Brock diagram of the intensity control system is shown Fig. 1. The core of this system is an AM function controller. This controller employs the feed forward and feed back controls to realize the extracted intensity as requested. AM function is generated so as to deliver the requested intensity and beam extract gate from irradiation system. AM controller calculates and outputs the AM function based on the intensity requirement signal and beam gate signals, as input. A few of function generators generate the basic waveform, which is the combination of the frequency modulated sinusoidal wave. After the amplitude modulation by VCA (Voltage Controlled Amplifier) module, this basic waveform is amplified and fed to the RF-kicker in the ring. The extracted beam is monitored by an ion chamber, which is installed in the irradiation system. This signal of extracted beam current is used for feed back control in the AM controller.

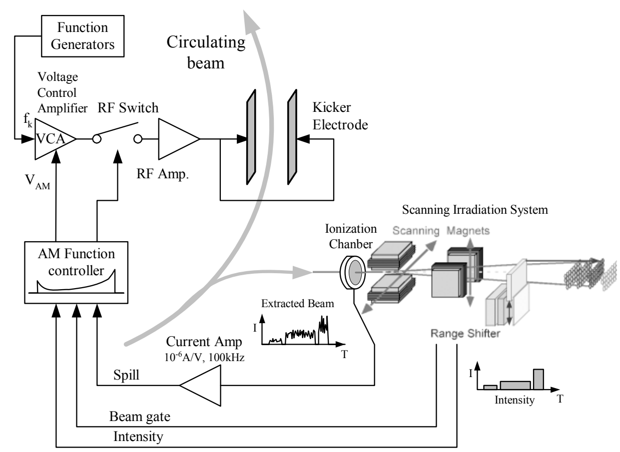

Figure 1: Block diagram of intensity control system.

Feed-Forward Control Based on 1-D Model of RF-Knockout Extraction

For the purpose of feed forward control, we employed a scheme to analytically optimize the AM function of a transverse RF-field [7]. In this scheme, a simple model of the extraction process, in which the radial distribution of particles in phase space under diffusion by RF-knockout is assumed to have the Rayleigh distribution, was used to optimizing the AM function. By solving the following simultaneous equation, as a result, we can obtain the AM function toward a constant number of extracted particles in each turn, as planned:

$$\begin{cases} N_0 \dfrac{d\sigma^2(n)}{dn} \cdot \dfrac{r_0^2}{\sigma^4(n)} \cdot \exp\left[-\dfrac{r_0^2}{\sigma^2(n)} \right] = \left(\dfrac{dN_{ext}}{dn} \right)_{plan} \\ d\sigma^2(n) = k\theta^2(n) \cdot dn \end{cases} \quad (1)$$

where σ is the standard deviation of the Rayleigh distribution in the horizontal phase-space, r_0 the boundary of the separatrix, n the number of turns, N_0 the circulating

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particle number, k a parameter relevant to the diffusion and θ the kick angle of the transverse RF-field

Feed Back Control

AM function for intensity control is obtained by means of the simple extraction model. However, the feed forward control has a practical limit due to the difference between the model and the actual beam and the fluctuation of the magnetic field and so on. Thus, we employ the feed back control as an additional control. The block diagram of the feed back control is shown in Fig. 2. In the feed back control, we use both the proportional and integral controls by using the difference between the beam current signal measured by the ion chamber in the irradiation system and the reference value.

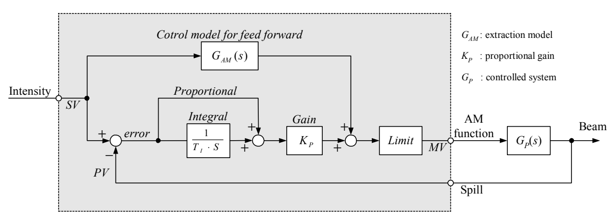

Figure 2: Block diagram of the feed back control.

Hardware

Circuit diagram of the AM controller is shown in Fig. 3. The configuration is simple because of a single chip microcomputer (Renesas Technology Corp., H8/3052) having some features; 512KB flash ROM, A/D converter, digital I/O and timer. Thus, we only need to employ a scale/ buffer amp for analog I/O. Figure 4 shows a photograph of the AM controller.

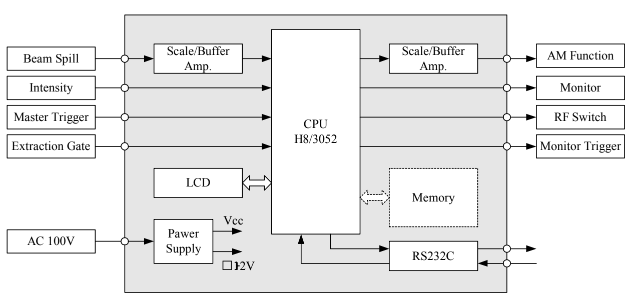

Figure 3: Block diagram of AM controller.

Software

In order to increase the processing speed, the software is coded by assembler. The total size of the program is to be around 400KB. Almost part of this program is used for data, and the main program code is only 1KB. The interrupt processing, which are output of AM function and digital I/O, is in synchronizing with 100μs timer. Other processing is the readout process of the current signal and the intensity request signal, the calculation of AM function and the feed back control. It is necessary to complete these processing within timer cycle of 100μs.

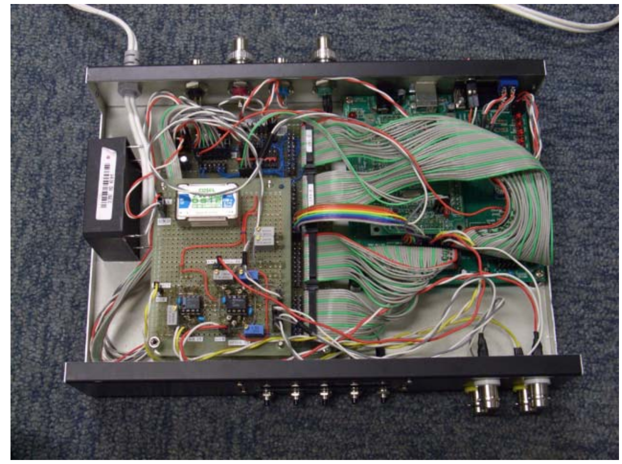

Figure 4: Photograph of AM controller.

Due to the processing power, it is difficult to calculate the AM function directly by using Eq. (1). Thus, we develop new algorithm to minimize the number of processing step. In this algorithm, it is necessary to firstly prepare several AM functions, which are calculated for different flat intensities. By using these functions, we can calculate AM function dynamically as followings. When the extraction duration is T_m, the extracted number of particles can be calculated to be $N_m=I_m \cdot T_m$ while the current I_m was kept to be constant. Secondly, it is assumed that the request current changes from I_0 to I_1. In the analytical model, the particle distribution corresponds to the extracted number of particles. Considering two different extraction (I_0 and I_1) cases, thus, the extraction duration for same particle distribution can be written as $I_0 \cdot T_0 = I_1 \cdot T_1$. By using this relation and data table of 2 dimensional array $P_{AM}(I_m, N_{ext}/I_m)$ for pre-calculated AM functions, we can change the extraction intensity. In our case, we prepare 16 functions, and record them on the ROM. Figure 5 shows table of the 2D AM functions array P_{AM}.

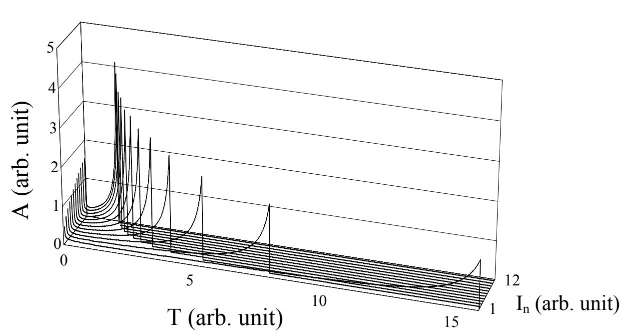

Figure 5: Table of the 2 dimensional array P_{AM} for pre-calculated AM functions.

EXPERIMENTAL RESULT

In order to verify the feasibility of the system, the experiment was carried out at the HIMAC synchrotron and its transport system by using carbon beam with the energy of 400 MeV/u. The beam spill, which is used for feed back control, was measured by using an ionization chamber in the beam transport line and current amplifier. Figure 6 (a) shows typical result of the flat spill structure. In this case, the standard deviation of the spill ripple was to be ±10% including 50kHz frequency component at maximum. Concerning scanning irradiation, the magnet has no response up to kHz. By using low pass filter up to 100Hz, therefore, the standard deviation of the ripple is measured to be ±4%. Further, the dynamic intensity control is tested by using the external input of the requested beam current. These results were typically shown in Fig. 6 (b) and (c). It is clearly observed the well controlled spill structure. Further, we employ this system for study of scanning irradiation, recently. It was verified that this system makes it possible to reduce unwanted dose and the total irradiation time.

SUMMARY

For the purpose of realizing the precise irradiation by means of the beam scanning irradiation, the development of the intensity control system with RF-knockout extraction for controlling the beam intensity has been carried out. The extracted beam intensity is well controlled by AM function obtained through feed forward control of analytical approach and the feed back control, which employs both the proportional and integral controls. This system is quite useful in the scanning irradiation to reduce the unwanted dose.

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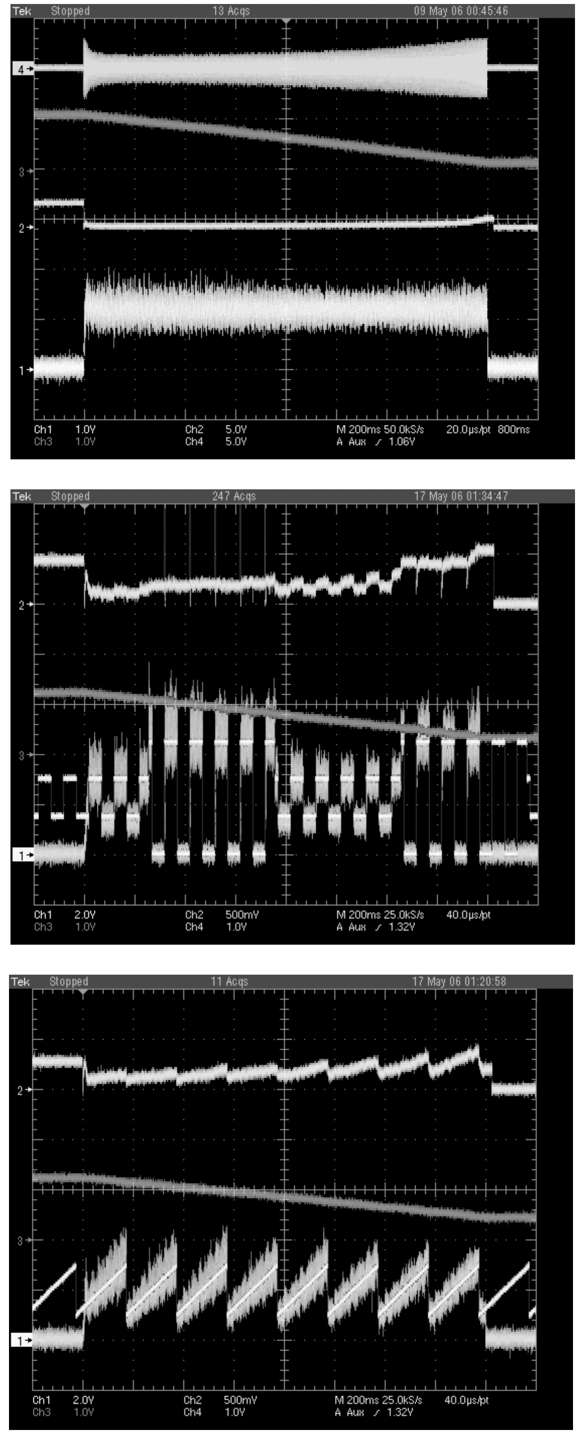

Figure 6: Typical result of intensity control experiment: (a) flat spill control. From the bottom to the top: spill, AM signal, circulating beam current and transverse RF-field. (b) 3 step intensity control and (c) triangle intensity control. From the bottom to the top: spill, circulating beam current and feed back signal.