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# A BEAM SPILL CONTROL SYSTEM AT HIMAC

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## Abstract

A beam spill control system has been designed and installed in order to improve a spill structure of extracted beams from synchrotron at HIMAC. The system concept is to optimize a current setting pattern for correction quadrupole magnets (QDS), by utilizing an iterative control based on information of a spill structure from the beam ripple monitor.

## 1. Introduction

A high accuracy for the dose distribution is required in heavy ion therapy because of its sharp localization and high RBE (relative biological effectiveness). It is thus necessary to obtain a uniform dose with sharp boundary in the lateral direction, and to control precisely the total dose per patient. An irradiation system at HIMAC adopts a beam wobbling method along with a scatterer to obtain such uniformity within $\pm 2\%$ [1]. However, when a frequency of ripple in the extracted beam spill is close to the driving frequency of wobbling magnets (57Hz), the dose uniformity can be lost due to a beat phenomenon.

In a resonant slow extraction at HIMAC, a main ripple of beam spill is caused by a current ripple generated in the power supply of main focusing quadrupole magnets (QF), which is 100Hz. It is monitored with a thin scintillator at extraction beam line. A signal of harmonics synchronizing with the PLL (phase locked loop) was fed forward to the active filter of QF power supply, which was effective to reduce ripple [2]. This observation suggests a possibility of ripple reduction by quadrupole components. A beam spill control system has, therefore, been developed in order to reduce a beam ripple and to secure uniformity by shaping a spill envelope. A set of QDS, originally installed for tune-shifter, is utilized in the system. This paper reports a design consideration and preliminary experimental results concerning the beam spill control system.

## 2. Design Consideration

### *2-1. Framework*

As mentioned above, basic component of ripple reduction is harmonics of power supply driving frequency. Superpositioned harmonics forms starting point of QDS output current pattern. However, there must be other sources of ripple and also fluctuation in AC line, for example, affect actual ripple output. An adjustment is necessitated for current setting to reflect these effects. It means that our system should have a function of feed forward setting and feed back from ripple signal. Iterative control of current pattern by beam signal would provide long term operability against various fluctuation conditions.

### *2-2. Optimization Algorithm*

The important aspect of the system is an algorithm to optimize a current pattern for QDS automatically by utilizing the iterative control [3] based on information of a spill structure from the beam ripple monitor.

Assumptions on the algorithm is summarized as follows: (1) transfer function concerning the parameters of digital filter and a power supply are known; (2) the extracted beam spill is reproduced at each operation cycle of synchrotron while the beam intensity is fluctuating; (3) gain of the iterative control can be optimized in order to make the control system stable.

The optimization for the current pattern is carried out separately at low (for shaping a spill envelope) and high (for correcting a beam ripple) frequency regimes, as shown in fig.1. At a low frequency regime, an error between the spill signal after the low-pass filter and a current pattern is fed back to QDS after averaging. At high frequency regime, the spill signal after the band-pass filter with phase compensation is fed forward to QDS. Each filter is employed a FIR (finite impulse response) digital filter because of considering stable. The optimization is completed when a root mean square of the error between the spill signal and the pattern becomes smaller than a specified value. Parameters of filters at both frequency regimes as well as the feed-back and feed-forward gain are designed to be adjustable.

### *2-3. Structure of hardware*

A beam spill controller and QDS magnet power supply have been developed to realize the system algorithm. The system structure is shown in fig.2.

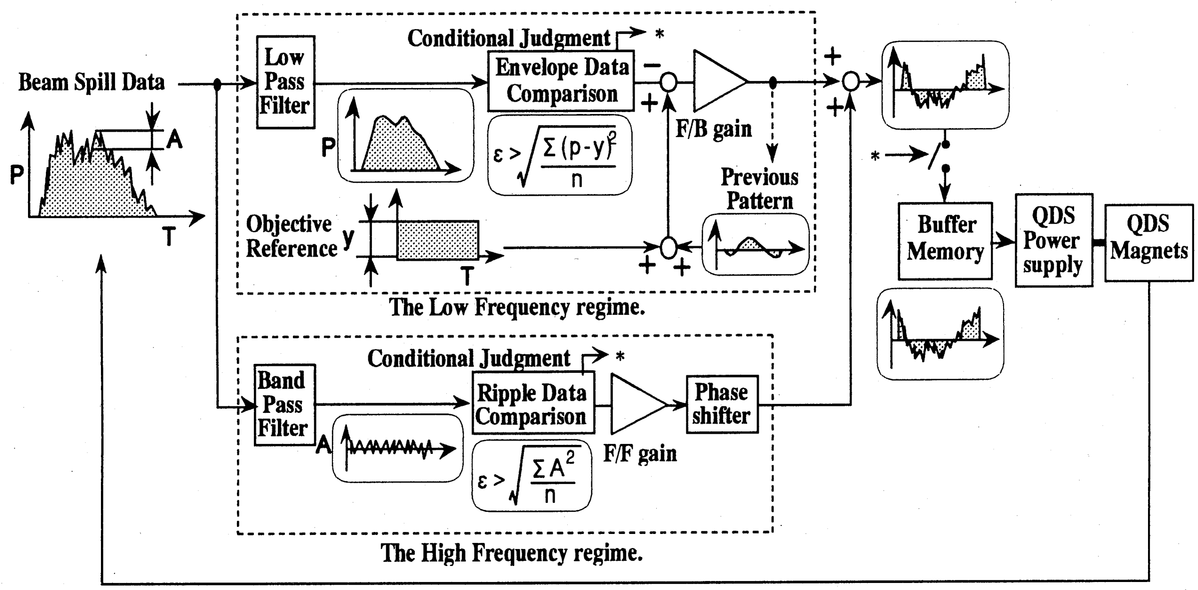



Fig. 1 Each algorithm enclosed by broken lines indicates the low and high frequency regimes.

QDS power supply is designed to have bipolar outputs, so that QF current pattern can be the same with or without the beam spill controller system. QDS power supply is operated according to the current patten that is produced based on the beam waveform.

In the control device of QDS system, VME computers are used to carry out the real-time control. VME computers consists of processors, memories and I/O's in the unit, which use a digital signal processor (DSP). CPU is MVME147S, which is used for the operating and file management, DSP is DSP8031 for filtering and other pattern control function, memory is HIMV210, A/D converter is DSP8112, D/A converter is DSP8124 and clock generator is DSP8240 for making sampling clock of 6kHz. The system realizes fast I/O handling by using a "mtt Link" bus independently. The system has been designed to be maintained by E.W.S., including file management [4]. The sampling cycle of beam waveform is 1200Hz. That of the current pattern to QDS power supply is 6kHz, which was chosen to reduce

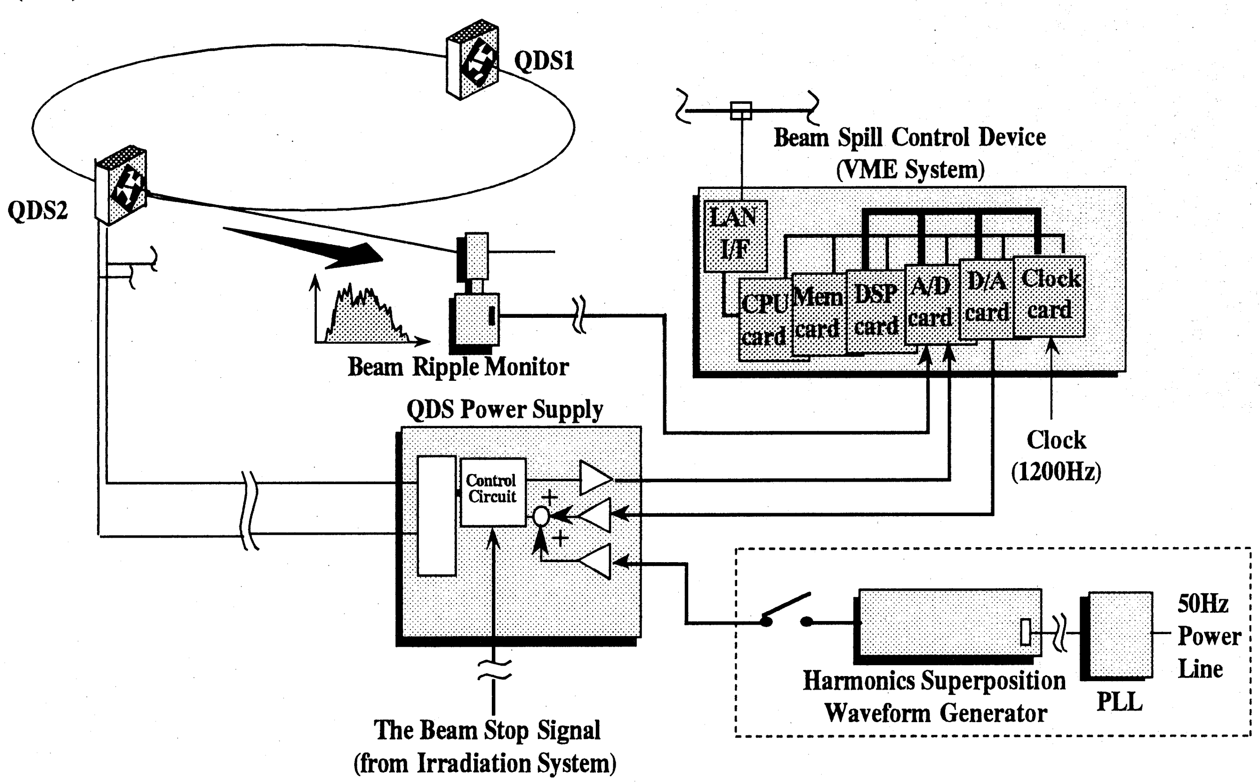



Fig. 2. Schematic diagram of spill control system and HSWG.

the peak voltage due to discrete signal.

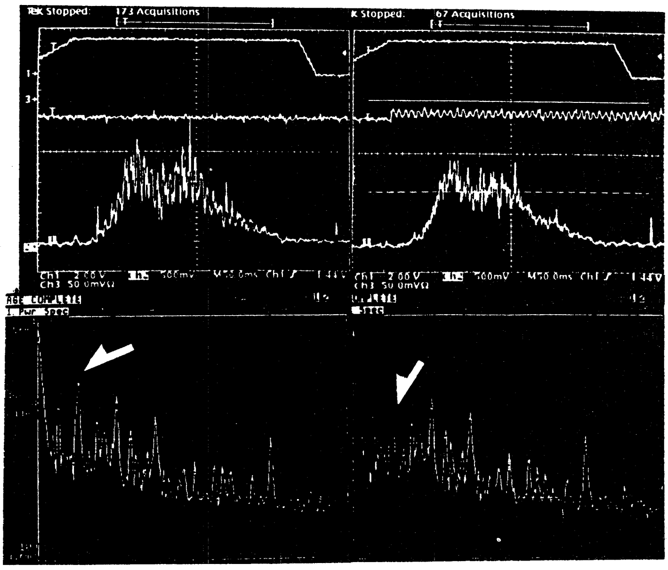
In addition, QDS magnets and power supply are used to determine the total dose for treatment. They can directly move a horizontal tune from the resonance. When the "beam stop" signal comes from the irradiation system, forcing in QDS power supply without software handling directly realizes stopping of a beam extraction faster than few ms.

## 3. Experimental result and discussions

### *3-1. HSWG with feed forward*

The experiment was carried out first by using only the "Harmonics Superposition Waveform Generator" called "Ripplebasher" [5] for the feed forward to QDS power supply. It is shown in the part enclosed by broken lines in fig. 2.

Fig.3 shows beam spills and their FFT analysis in the operation with and without HSWG, under the condition of $3\times10^{8}$pps $C^{6+}$ beam with an energy of 350MeV/u. The amplitude and phase of HSWG were adjusted to reduce the frequency component of 100Hz at the beam ripple, respectively. The effect for ripple reduction was -14dB at 100Hz.




(a) (b)

Fig.3 Comparison between without (a) and with HSWG (b). beam spills and their FFT analysis are shown in the upper and lower photographs. Arrows points out a component of 100Hz.

Harmonics of 50Hz component in the case of synchronizing with the PLL was decreased by some degree compared with that in the asynchronizing case.

### *3-2. Computing system with VME*

Encouraged by the experimental result of HSWG, the beam spill control system was tested where HSWG was removed from the system. The upper and lower limit of the band-pass filter were set to 150Hz and 100Hz. The dimensions of FIR filter are 81. The relation between the gain of the beam control system and the 100Hz component at the beam spill is shown in fig.4.

An effect in correcting the beam ripple of 100Hz has been undoubtedly recognized. However, it has not yet been satisfactory. Possible explanations are as follows: (1) the parameters of the band-pass filter seem to be inappropriate; (2) time delay due to the power supply and the load must be taken account; (3) the sampling cycle of the beam waveform seems to be too low. Next experiments will be carried out to shape the spill envelope at the low frequency.

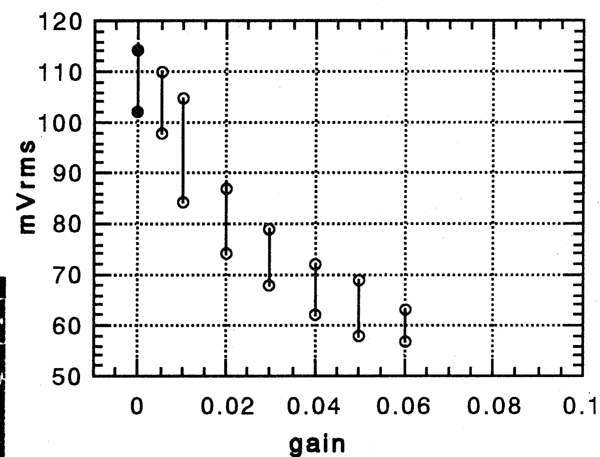



Fig. 4. Relation between the beam ripple of 100Hz and F/F gain (high frequency regime). Points at gain 0 (●) represent the ripple before the correction, while the others (○) show correction effect the system.

## Acknowledgment

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