A FEEDBACK SYSTEM TO IMPROVE THE SPILL STRUCTURE OF A SYNCHROTRON

U. Blell, GSI Darmstadt, Germany

Abstract

Both the high energy experimental program and especially the GSI Therapy project require a uniform intensity distribution of the slowly extracted ion beam from the synchrotron SIS.

At GSI a feedback system has been tested to improve both the coarse and the fine time structure of the spill.

1. INTRODUCTION

The resonance extraction of particals always shows some fluctuations. The fluctuations can be split into *non-coherent contributions* like energy fluctuations of the particals, noise in the magnet power supply systems and their regulators, and into *coherent contributions* like power supply ripple on harmonics of the main power system and harmonics of regulator system clock frequencies.

Upgrading the present resonance extraction system at the heavy ion synchrotron SIS to a closed loop extraction feedback system promises to improve the time structure of the extracted particle flux. To verify the principle of such a control schema, first experiments were done during several runs [1, 2]. A rather simplified model of a extraction setup is sketched in Fig. 1 [3].

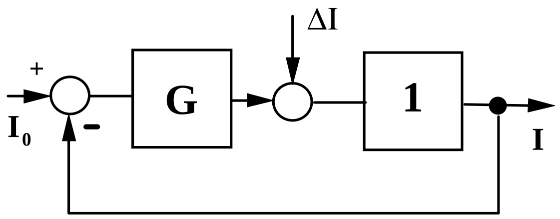

Figure 1: Simplified feedback control system.

In this figure $\mathbf{I_0}$ denotes the DC reference input corresponding to the wanted spill rate, G is the total loop gain, ΔI represents an external perturbation from current ripple on magnet power supplies and **I** is the detected spill signal. **1** is a simplified expression for the system to be controlled. From this, **I** follows the relation

$$\mathbf{I} = \mathbf{I_0}\frac{\mathbf{G}}{\mathbf{G+1}} + \Delta\mathbf{I}\frac{\mathbf{1}}{\mathbf{G+1}}. \qquad (1)$$

As a general effect of a feedback system, an increase of the loop gain leads to an approach of the extracted particle distribution to the reference value and to a reduction of the influence on external perturbations. In order to maintain system stability, **G** as a funktion of frequency has to be limited to certain values which depend on the phase response of the open loop. Therefore, the implementation of a successful feedback spill control system requires the development of a suitable controller unit which maximizes system bandwidth and loop gain as well.

2. SPILL CONTROL SYSTEM

Fig. 2 shows the schematic diagram of the feedback system for the slow resonance extraction. The system to be controlled consist of the power supply of the fast quadrupol magnets, the physics of slow resonance extraction, ionization chamber as detector and a current digitizer to transform the number of particals into a voltage information.

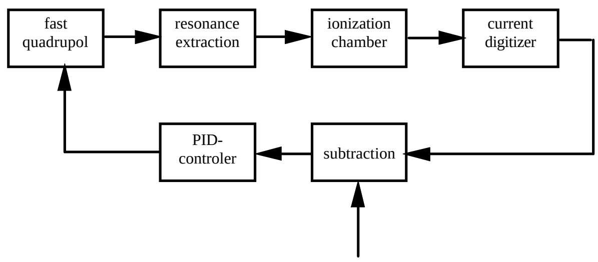

Figure 2: Schematic diagram of the feedback control system

The phase and magnitude of the transfer function of the system to be controlled has been measured from DC to 1 kHz [4].

At SIS we obtained a delay of roughly 90 - 160 μs between the excitation of the fast quadrupole and the observed signal from the ionization chamber. This value is equivalent to about 100 revolutions of the particals, which roughly corresponds to values calculated with theoretical simulation programs. The dead time of the system mainly consists of the physics of slow resonance extraction and the time constant of ionization chamber. For the dead time the cable delay is neglectable. The delay sets an naturel upper limit for the feedback bandwidth of the spill controler.

The feedback controller is a universal analog PID-controller, in which the gain (P), integration (I) and differential (D) part can be adjusted seperately.

The reference signal is a rectangle with variabel flat top (extraction time) and constant rise- and falltime of 20 ms. The height of the rectangle corresponds to the intensity.

After the identification of the system to be controlled it was possible to do some theoretical calculations with a network simulation program. According to these simulations the maximum bandwidth of the whole feedback system is about 3 kHz. That means it is not possible to reduce the spill fluctuation of the extracted beam with a mikro structur less than 330 μs.

3. EXPERIMENTAL RESULTS

A spill signal of the conventional slow extraction process is shown in Fig. 3 ($^{197}\mathbf{Au}^{65+}$ - beam at 167 MeV/u, detected by a scintillator) [5].

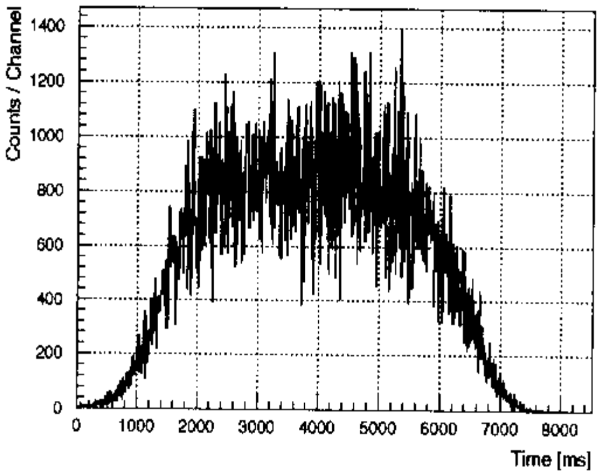

Figure 3: Slow resonance extraction without feedback.

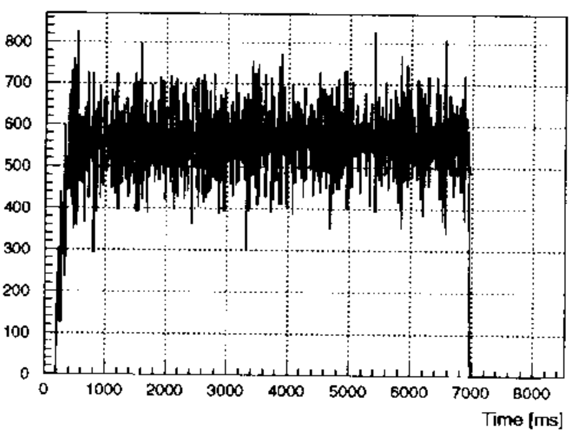

Figure 4: Slow extraction with closed feedback loop.

The resonant extraction is done by ramping two fast quadrupole magnets in a predefined manner, which will smoothly drive the beam into a 1/3 - order horizontel resonance. In case of closed loop spill control extraction (Fig. 4) the spill signal was subtracted from a rectangle reference signal, amplified and fed back to the power supply of the two fast quadrupoles. As expected the average spill rate follows quite well the reference signal.

With a special adjustment at the controller the feedback system shows a characteristic self-oscillation. This special adjustment is unnormal for a feedback system. The PID- controler works with a high gain loop, so the beam will steer very fast into resonance. The controler regulate immeddiately against and the slow extraction is stoped for a short time. The controller is active again and the feedback system oscillates. Fig. 5 shows the spill with open loop, the micro structure of the bursts is irregular both in amplitude and time. In the case of closed loop (Fig. 6) the micro stucture shows the characteristic self-oscillation with an improved amplitude uniformity.

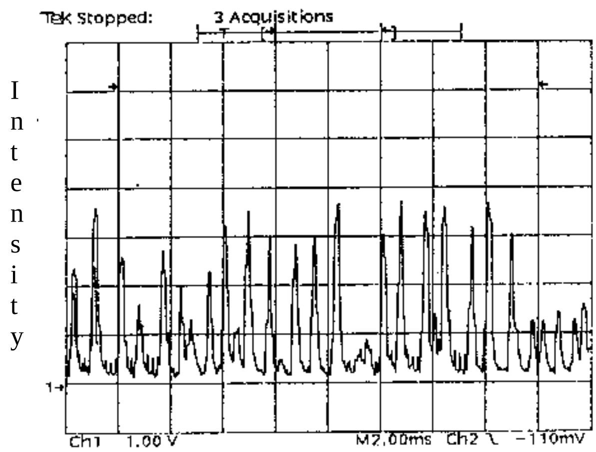

Figure 5: Spill micro structure with open loop.

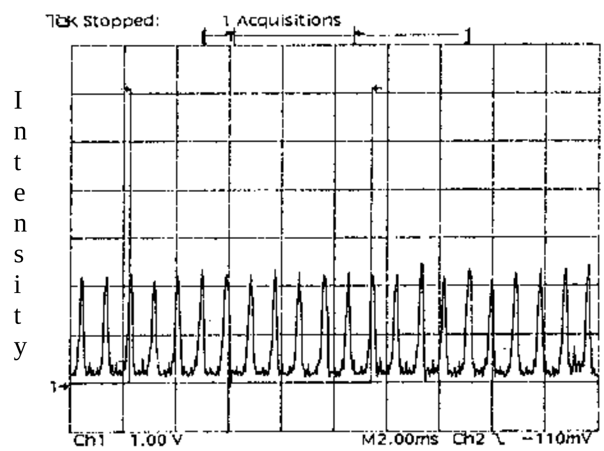

Figure 6: Spill self-oscillation with closed loop

The period of the oscillation is in the theoretical limit twice the dead time of the feedback sytem. In real cases the PID-controller extends the period.

The stochastic structure of the spill is reduced in the controlled extracted bursts. This is the reason for the improved intensity distribution of the spill. The definition of the spillquality is the ratio of maximum to mean value within any time window during the slow extraction. This value is in the best case one, higher values means a worse spillquality. The best value for the spillquality with a self-oscillation (Fig. 6) is two.

In Fig. 7 the spillquality with open and closed loop is shown as a function of the time integration intervall (C^{6+}-beam at 300 MeV/u, detected by a ionization chamber) [6].

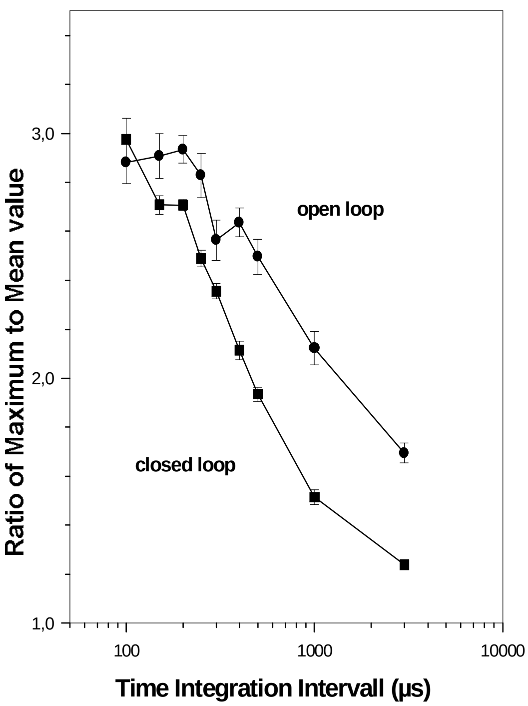

Figure 7: Spillanalysis with open and closed loop

An additional diagnostic hardware provides a spill time integration with an adjustable time intervall. With a short integration time we see the micro structure of the spill intensity and a long integration time shows the macro structure.

Wheras the spill coarse time structure can easily be improved by a feedback system, for SIS the micro structure can only be reduced for time intervals above 200 μs [7].

REFERENCES

[1] J. Pinkow, GSI Arbeitsnotiz Nr. SIS18074.BEX, private comunication, Darmstadt 1994

[2] J. Pinkow, GSI Arbeitsnotiz Nr. SIS08114.BEX, private comunication, Darmstadt 1994

[3] H. Sato et al., Proc. of the 9th Sym. on Acc. Sci. and Tech., 1993, Tsukaba, Japan, pp. 208

[4] P. Moritz, GSI AIP Confererence Proceedings 333, 1994, Vancouver, Canada, pp. 294-299

[5] J. Pinkow, H. Eickhoff, P. Moritz, GSI Scientific Report, 1994, pp.238, Darmstadt 1994

[6] U. Blell, GSI Arbeitsnotiz Nr SIS19036.IEX, private comunication, Darmstadt1996

[7] U. Blell, GSI Arbeitsnotiz Nr SIS24056.IEX, private comunication, Darmstadt1996