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SOFTWARE DEFINED RADIO BASED FEEDBACK SYSTEM FOR TRANSVERSE BEAM EXCITATION*

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Abstract

Controlling stored beams in particle accelerators requires specially designed RF signals, such as needed for spill control via transverse excitation. The software-defined radio (SDR) technology is adopted as a low cost, yet highly flexible setup to generate such signals in the kHz to MHz regime. A feedback system is build using a combination of digital signal processing with GNU Radio and RF Network-on-Chip (RFNoC) on a Universal Software Radio Peripheral (USRP). The system enables digitization of signals from particle detectors and direct tuning of the produced RF waveforms via a feedback controller – implemented on a single device. To allow for triggered operation and to reduce the loop delay to a few ms, custom OOT and RFNoC blocks have been implemented. This contribution reports on the implementation and first test results with beam of the developed spill control system.

INTRODUCTION

Radio Frequency Knock Out (RF-KO) extraction [1] is a standard method used to extract stored particle beams from synchrotrons through transverse excitation, providing spills of particles for experiments and medical therapy. It uses a beam optics near a third order resonance driven by sextupole fields [2]. The non-linear amplitude and phase detuning effects create a separatrix in phase space [3]. Transverse electromagnetic RF fields are applied to increase the betatron amplitude of particles in a controlled manner. This process, referred to as excitation, drives the particles into the separatrix. As a result, the motion becomes unbound, and the particles can be extracted at a septum.

The excitation system consists of an RF signal generator, RF amplifiers, and a *stripline kicker* inside which the RF fields act on the beam. Here, the signal generator is the central element by which the extraction process, and thus the spill, can be controlled.

The primary goal is to maintain a constant spill rate, that is, to extract an equal number of particles per unit time. To reach this goal, two complementary strategies exist: On timescales above about 50 ms, the signal amplitude is controlled by a complex function or a feedback system based on measured spill rates [4]. On smaller timescales not accessible by the feedback system, the signal waveform is optimized to reduce statistical fluctuations [5].

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SOFTWARE-DEFINED RADIOS

Software-defined radio (SDR) is an RF transceiver technology where signal processing is implemented in software on computer processors (CPUs) and/or field-programmable gate arrays (FPGAs). It is widely used in radio communication systems, but has potential applications in many fields. An SDR typically consists of a frontend with ADCs and DACs, and a backend performing the digital signal processing (DSP). Here, a Universal Software Radio Peripheral (USRP) is used as off-the-shelf frontend to generate the RF signals. For implementation of the DSP chain, the open source framework GNU Radio [6] is used in combination with the RF Network-on-Chip (RFNoC) technology [7], which enable a flexible, graphical design of signal processing flow graphs by combining predefined and custom blocks. With SDRs being adopted by an increasing number of users in the accelerator community [8–10], collaboration and sharing of algorithms between institutes is easily possible [11].

IMPLEMENTATION

The excitation, feedback and spill control system builds on the development of a beam excitation system with applications in beam diagnostics [12]. The device does not only generate the excitation signals required for RF-KO extraction, but also processes the signals of a spill detector monitoring the extraction process. A feedback controller adjusts the excitation signal amplitude in order to maintain a constant spill rate on the detector. Statistical fluctuations on timescales below about 50 ms down to 10 µs – which are not accessible by spill feedback systems – are reduced by an automatic optimization of the used excitation signal waveforms. The implementation and realization of the system is described in detail in Refs. [11, 13].

COMMISSIONING

The spill control and feedback system was commissioned at the Cooler Synchrotron (COSY) accelerator in Jülich. For spill detection, a Low Gain Avalanche Detector (LGAD) developed by Ref. [14] for the High Acceptance Di-Electron Spectrometer (HADES) was used, which was being tested by the HADES LGAD group at COSY at the time.

Figure 1 shows a 20 s spill recorded with the developed system. Excitation with a constant signal level shows – as expected for this kind of slow extraction – a significant drift of the achieved spill rate over the course of the extraction. The feedback system, if switched on, is able to adjust the excitation level such as to maintain a constant spill rate on the detector. More details are available in Refs. [11, 13].

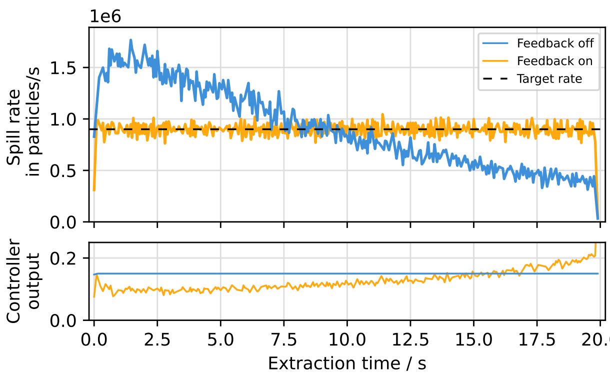

Figure 1: Measured spill rate and controller output with and without active feedback. Plot resolution: 50 ms.

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