MACHINE-MODE AWARE BEAM LOSS MONITORING*

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Abstract

Beam-loss level monitoring is a powerful diagnostic tool concerning accelerator health. Particles leave the vacuum pipe for various reasons, such as intrabeam scattering (Touschek effect), residual gas molecules, closed orbit distortions or mechanical obstacles (aperture restrictions, installation errors). These can be identified by appropriate measurements. The steady-state beam loss level varies throughout the machine and has to be measured and documented for further reference. Besides general radiation safety purposes, changes (especially increases) occurring after machine upgrades are of special interest. When simple monitoring of average beam loss fluctuations is insufficient, problem diagnostics should be further enhanced by correlating beam loss monitor (BLM) detector readout with events in the machine. For best flexibility, pulses should only be counted at certain conditions and during well defined time slots synchronized with the current machine operation cycle. In cooperation with Cosylab, such an advanced BLM acquisition system was developed for the Electron Stretcher Accelerator ELSA (University of Bonn, Germany), allowing various optimized acquisition modes.

INTRODUCTION

Beam loss rates which are too small to be detectable or even traceable with a beam current monitor can impose major limitations in accelerator operation procedures. In order to determine their origins, a more sophisticated detection scheme is needed.

For purposes such as the identification of areas with high radiation level (e.g. in order to set up radiation-sensitive equipment accordingly), the avoidance of installation errors, or minimization of material activation a spatially resolved beam loss detection is perfectly sufficient.

However, this is not the case for certain critical issues of accelerator operation at ELSA which do in addition require time resolved beam loss information in order to reveal correlations of beam loss events with the different phases of the acceleration cycle. These needs for time resolved beam loss monitoring on a less than 20 msec scale have initiated collaboration between ELSA and CosyLAB which lead to the developments described in the following chapters.

BEAM LOSS DETECTION REQUIREMENTS AT ELSA

The ELSA accelerator facility at the University of Bonn [1] consists of a 50 keV source of polarized electrons [2] and two thermionic electron guns, two injector LINACs, a booster synchrotron and the 3.5 GeV stretcher ring (Figure 1). Electron sources as well as the booster synchrotron are operated at 50 Hz repetition rate. In order to supply a nearly continuous beam to the external hadron physics experiments, several injections from the synchrotron are accumulated in the stretcher ring (at 1.2 GeV typ.), accelerated to the extraction energy (3.5 GeV max.) and then extracted slowly by means of resonance extraction, thus yielding a duty factor of >70%. For synchrotron radiation experiments, after accumulation and acceleration the beam (100 mA max.) is stored without extraction.

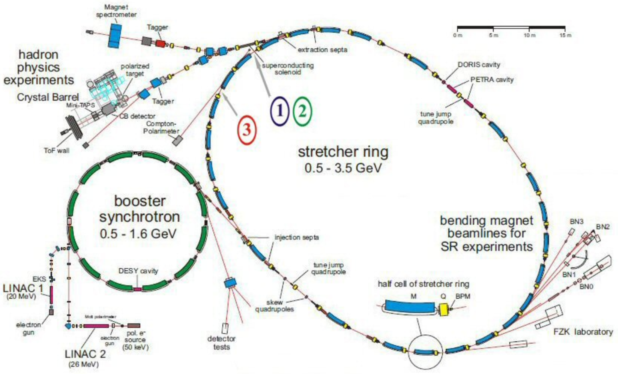

Figure 1: The ELSA accelerator facility.

All these procedures benefit substantially from precise beam loss diagnosis as will now be described in detail.

On the fast energy ramp (4 GeV/sec typ., 7.5 GeV/sec max.), a precise synchronization of the power supplies of the different magnet families is mandatory. Slight tracking errors can result in beam loss which, even if too small to be detected by a beam current monitor, is sufficient to compromise optimal accelerator performance.

Depending on its location, beam loss can cause an increase in radiation background in the external experiments which is highly undesirable and needs to be avoided.

For the continuous beam extraction from the stretcher ring the horizontal betatron tune is shifted increasingly close to a third integer optical resonance by appropriate machine optics modifications. Thus, every turn a fraction of the beam leaves the stable phase space region and en-

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*Work supported by DFG within SFB/TR 16.
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ters the external beam line at the extraction magnet. Optimization of both, the extraction efficiency (minimizing beam loss at the septum magnet blade) and the extracted beam's emittance as well as investigation concerning location and mechanism of beam losses require adequate diagnostics.

The hadron physics program performed at ELSA is mainly focused on double polarization experiments utilizing tagged photons (linearly and circularly polarized) and a polarized frozen spin target [3].

Since photoemission cathodes are limited to much smaller beam currents than are thermionic guns, the polarized beam at ELSA requires optimization of the transfer efficiency especially at injection into the stretcher ring in order to maximize beam current and duty factor at the external experiments.

During the fast energy ramp, a sophisticated scheme for the correction of depolarizing resonances is mandatory: at ELSA, betatron tune jumps are applied for compensation of intrinsic resonances and harmonic closed orbit corrections for compensation of imperfection resonances [4]. Depending on ramping speed, these resonances occur every 20..50 msec during acceleration. For their compensation, rapidly changing manipulations of the closed orbit as well as of the sensitive betatron tunes have to be applied. In order to utilize the full beam-optical machine acceptance at all these instances, spatial as well as time resolved information on beam loss rates on a 20 msec scale is required for optimized machine control.

MICROIOC-BLM

microIOC-BLM [5] is a turnkey solution for monitoring beam loss in particle accelerators. It gives spatial as well as time resolved (1 ms) information of beam loss. Readings are obtained in real time, thus making the system ideal for optimizing machine parameters. Since the system is highly portable, it can be used also to pinpoint loss locations and help with commissioning new devices.

The microIOC-BLM consists of the following components:

- Bergoz BLM detectors where the signal pulse is generated.
- Beam loss Signal Conditioning (BSC) units used for counting and processing pulses from the BLM detectors.
- microIOC-CosyIcon [6] used as a central unit to control and give power to BSC units and to interface with the accelerator control system.

To accommodate all possible applications allowed by the sensor, a flexible data acquisition system was developed.

Let us define a time-slot count (TSC) as the number of BLM pulses accumulated over a certain time slot. The time slot can be defined either by a Gate/Trigger signal or by elapsed time. At the end of each time slot the TSC is stored into the memory buffer. For any measurement, it needs to be selected how and when to capture TSC (TSC capture mode) and how to store TSC into the memory (TSC store mode).

Figure 2: BSC modules connected in a daisy chain and connected to a microIOC-CosyIcon as the central processing unit. To each BSC two Bergoz detectors can be connected (not shown).

TSC Capture Mode

There are four different ways to capture TSC:

- **Time-based operation** – time-slot for the TSC acquisition is defined by the elapsed time. The time-slots are of equal duration and the advancement to the next time-slot is made after the time of the slot has elapsed (Figure 3).

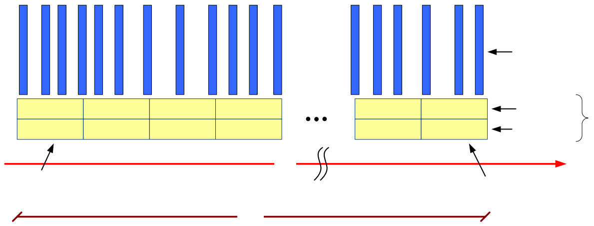

Figure 3: Time-based operation.

- **Gate-based operation** – time-slot for the TSC acquisition is defined by external gate signal. The time-slot starts at the rising edge of a gate-signal and ends at the falling edge. The BLM pulses are counted only while the gate signal is active (Figure 4).

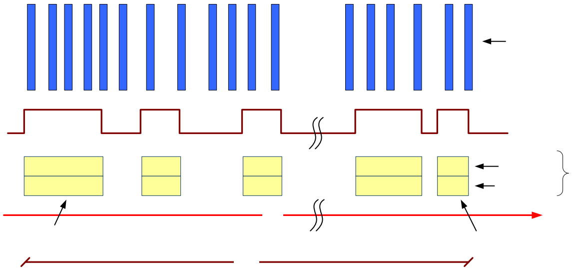

Figure 4: Gate-based operation.

- **Trigger-based operation** – time-slot for the TSC acquisition is defined by external gate signal. The time-slot starts at the rising edge of a gate-signal and ends when the subsequent time-slot becomes active. In contrast to gate-based operation, the BLM pulses are always counted.

- **Triggered time-based operation** – the only difference to time-based operation is that the measurement is started after the rising edge of a gate signal is detected.

TSC Store Mode

There are four different ways how to store TSC into memory:

- **Single-cycle mode** – TSC are being continuously written into memory-buffer one after another until memory-buffer depth is filled.
- **Round-cycle mode** – TSC are being continuously written into memory-buffer one after another. When the end of the memory buffer is reached, writing starts from the beginning, overwriting previously written TSC.
- **Integral SW-cycle mode** – TSC are being continuously written into memory-buffer one after another. When the end of the memory buffer is reached, writing starts from the beginning. In contrast to round-cycle mode, TSC are not overwritten, but added to previous values. The number of cycles can be selected.
- **Integral HW-cycle mode** – like Integral SW-cycle mode, but rising edge of gate-signal transition is required to start writing from the beginning of the buffer. The number of cycles can be selected.

TEST MEASURMENTS AT ELSA

First test measurements of the new system have been performed at ELSA with a test setup consisting of three BLM sensors positioned close behind as well as further away from the extraction magnet (Figure 5). For test purposes, one sensor was placed on top of the beam pipe, the others on its inner radial side. Beam energy was 3.2 GeV and the maximum beam current 7 mA. Data acquisition was software triggered in time-based integral-cycle mode over a period of 7 sec (350 time slots of 20 msec each), covering a typical ELSA cycle as described above. The result presented in Figure 5 shows summation over 100 cycles.

The data indicates precisely where and when beam loss occurs and clearly reveals several effects that can now be studied in detail. Beam loss rates during the various cycle phases are clearly visible, as is the increased beam loss at the extraction magnet. The data also shows that during the extraction phase (E) the correlation between decrease in beam loss rate and decrease in beam current is linear at BLM positions 1 and 2 while there seems to be a slightly different behavior at BLM position 3.

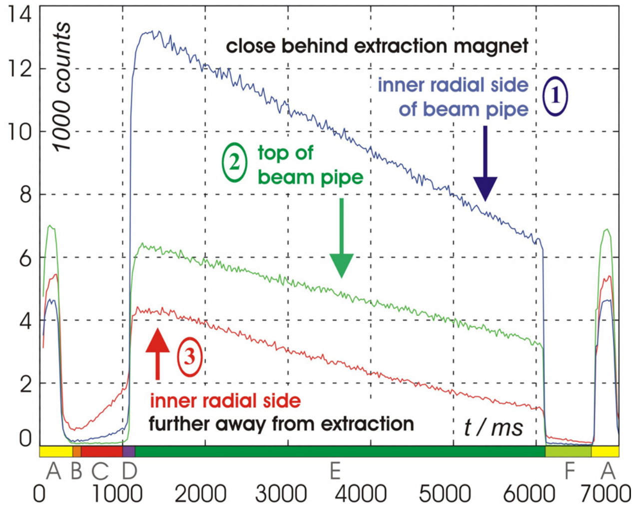

Figure 5: First measurements with the BLM system test setup at ELSA. Cycle phases are: injection (A),damping (B), fast energy ramp (C), extraction preparation (D), slow resonance extraction (E), ramp down (F).

CONCLUSIONS

The newly developed beam loss detection system with improved read-out scheme is a powerful tool for quality assurance in accelerator operation and maintenance after hardware changes as well as during standard operation. It provides in-situ detection and enables investigation of problems related to aperture limitations, steering errors and component malfunctions by a precise measurement of beam loss rates - both, spatially and time resolved. It thus allows for the optimization of accelerator components as well as operating procedures even in critical operation modes essential for the acceleration of a polarized electron beam for double polarization experiments at ELSA.

First measurements confirm the functional efficiency of software triggered readout scheme, tests of the hardware gated modes will follow soon.

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