INSTALLATION AND TEST OF A BEAM LOSS MONITOR SYSTEM FOR THE S-DALINAC*

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Abstract

The superconducting Darmstadt electron linear accelerator S-DALINAC provides electrons with energies of up to 130 MeV with beam currents up to 60 μA. The delivered electron beam is used to carry out experiments in nuclear physics at small momentum transfer [1]. The recirculating scheme of the accelerator demands for extensive periods of beam adjustments through the operator when the energy needs to be changed. The existing beam diagnostics is composed of only of fluorescent screens and faraday cups. Both need to be activated temporary and interpreted by the operator. For the purpose of machine protection and in order to increase reliability and efficiency a tool for on-line measurements of beam losses down to electron energies of 1 MeV is desirable. Therefore a system of beam-loss monitors has been developed, installed, and tested. The system utilizes commercially available PIN-diodes and in-house developed data acquisition electronics. Integration into the S-DALINAC's control system is done via EPICS IOC. We will report on the setup of the beam-loss monitoring system and on its performance in initial tests.

INTRODUCTION

The superconducting Darmstadt electron linear accelerator (S-DALINAC) is a linear electron accelerator, which was built in the 1990s at TU Darmstadt. It contains two electron sources, a thermionic electron gun, providing a continuous electron beam, and the S-DALINAC polarized injector (SPIN) providing polarized electrons, which can be used alternatively to the thermionic gun [2]. The sources are followed by the chopper, which gives the electron beam the 3 GHz time structure used by the accelerating cavities, and the prebuncher section for compressing the electron bunch in time. The prebuncher section is followed by accelerating cavities, the injector LINAC, for acceleration up to 10 MeV. This LINAC can be used for production of Bremsstrahlung for nuclear resonance fluorescence experiments. Otherwise the electrons are further accelerated.
The beam is injected through a 180° arc the main LINAC, which consists of eight 20-cell superconducting niobium cavities, operated at 2 K. The cavities are hosted in pairs inside a bath cryostat, allowing single-pass acceleration of up to 40 MeV. Higher energies of up to 130 MeV can be reached by recirculating the beam twice. The accelerator is capable of electron beam currents of up to 20 μA, which are then used for high resolution electron scattering experiments.
If the beam is inadequately aligned inside the beam pipe, beam loss leads to emission of Bremsstrahlung and high energetic secondary particles, which are able to travel up to several meters through air and can damage control and measurement devices as well as endanger humans by activating accelerator components. They can also lead to an increase in temperature inside the superconducting cavities, resulting in a possible quench. Up to now a quench is detected through deviating behaviour of the RF control system, but there can be several reasons for this behaviour. To be able to react faster and avoid quenches the beam loss itself shall be detected. In addition an effective diagnostic tool for on-line monitoring of the beam alignment is desired, for a smoother and more time efficient adjustment, than by using only fluorescent screens and faraday cups. Both of these issues can be solved by installation of a beam loss monitoring (BLM) system. To obtain a comprehensive picture covering all critical structures, the installation concept shown in Fig. 1 is planned. A differentiation between important and less important, but potentially interesting, positions for beam loss monitors has been made.

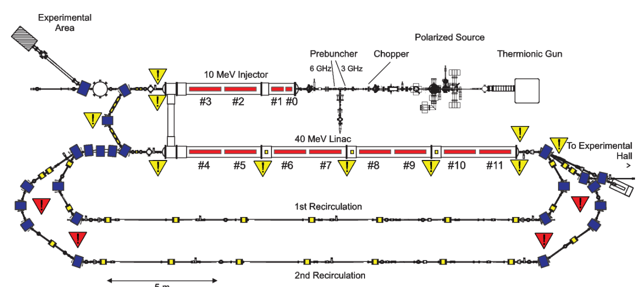

Figure 1: Floor plan of the S-DALINAC. Yellow triangles mark important locations for BLMs during beam optimization. Red triangles mark other potentially interesting positions for those monitors.

DETECTORS

Radiation detectors based on semiconductor diodes feature several advantages: High energy resolution capability, easy handling, directional sensitivity and a low price. Radiation detector systems based on semiconductors are also widely used and well known in their behaviour [3]. The schematic working principle of such a detector is depicted in Fig. 2.
These detectors can be manufactured in small dimensions, which allows mounting at places difficult to access, at gen-

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erally only limited space around the beam pipe. An example is presented in Fig. 3, where two beam loss monitors are mounted near the beam pipe. In spite of the narrow space between the injector cryostat on the left and a flange on the right, semiconductor detectors are small enough to be mounted. This kind of detector also has very little weight, so that it can be attached to nearly any structure without the need for elaborate attachments. Another advantage of its dimension and weight is the capability of fast relocation, giving high flexibility for temporary monitoring of positions. They can be mounted at different positions for optimization of the beam position quickly. Another reason

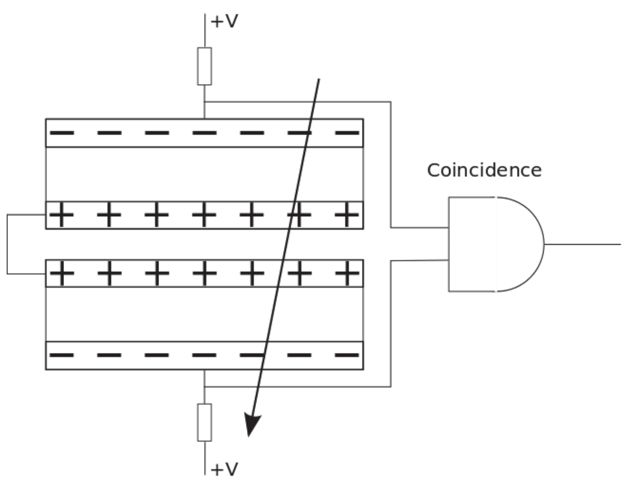

Figure 2: Operating principle of semiconductor beam loss monitors based on diodes.

for using semiconductor detectors are high radiation doses inside the accelerator hall, so that the beam loss monitors have to be reasonable radiation-hard. The biggest part of the radiation inside the accelerator hall are low energy photons.

Due to this condition, efficient background suppression is necessary. The beam loss monitors used at the S-DALINAC are of the Bergoz "BLM" semiconductor diode detector type. This type provides detection efficiencies of more than 30% for minimum ionizing particles (MIPs), count rates up to 10 MHz [4], commercially available and well tested [5]. The signal for a pulse is triggered by coincidence of two separate PIN-photodiodes inside a time frame of several nanoseconds, which ensures that only charged ionizing particles trigger signals. Most photons will be Compton scattered and absorbed inside one diode, causing no coincidence. As a result the coincidence circuit filters the dark current of the single diodes and events from photons, reducing the background of the measurement. If the beam hits the vacuum tube, charged particles from secondary emission and high energy Bremsstrahlung photons, capable of pair production, will be produced. This allows reliable detection of a beam loss with effective low energy photon background suppression.

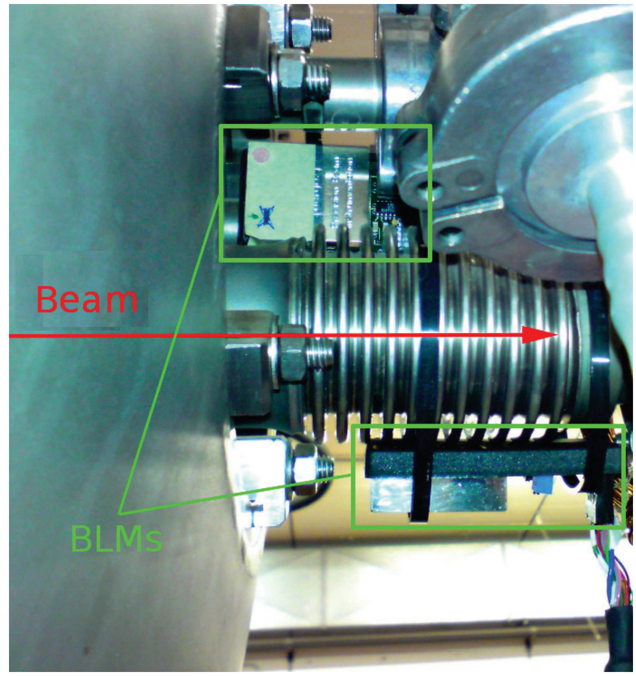

Figure 3: Beam loss monitors mounted directly onto the beam pipe in a narrow spot behind the injector cryostat.

INITIAL TEST AT THE S-DALINAC

Initial tests using beam loss monitors of the Bergoz model were done after a maintenance phase during 2011. As no experiences concerning these monitors existed, two monitors and appropriate readout electronics were used to observe the performance at the S-DALINAC. The threshold for particle detection is around 1 MeV [6], limiting possible positions for beam loss detection to the beam pipe behind the injector cryostat, as the beam energy in front of the injector cryostat is 250 keV at maximum.

For the test, a detector was mounted right behind the injector cryostat (mechanically similiar to the position shown in Fig. 3), directly at the beam pipe. This allowed observation of losses inside the cryostat. The beam loss monitors can be utilized even during initial set up of the beam when it does not yet traverse the whole injector by optimizing on their count rates.

Electric charge effects inside front parts of the injector have been detected using these monitors. A periodic loss of the beam, implicating a deviation of the beam towards the beam pipe resulted in a prompt rise in the count rates of the monitors (see Fig. 4). Therefore initial tests have been promising for further operation of semiconductor diode based beam loss monitors at the S-DALINAC.

DESIRED SETUP AND CALIBRATION

Desired Setup

The bare beam loss monitors deliver TTL signals, indicating single events through voltage pulses. Therefore a separate data acquisition is mandatory. Since the whole

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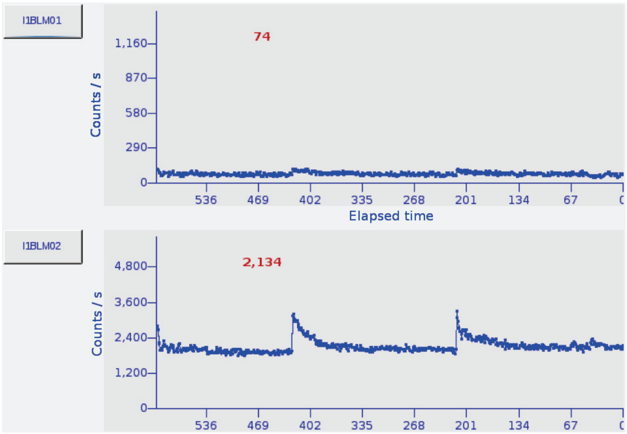

Figure 4: Electric charging effects can be observed directly through rising count rates of the beam loss monitors. The upper graph corresponds to a BLM located 0.5 m off the beam pipe, the lower one corresponds to a BLM attached directly to the vacuum chamber.

accelerator control system of the S-DALINAC is currently migrated to EPICS as a consequence of the commissioning of the new low-level rf control system [7], the data acquisition has to be compatible. Several commercially available systems exists, but due to the limited requirements most of them are too extensive. The solution was to integrate all BLMs into a modular multipurpose measurement system, which has been developed in-house.

Appropriate modules for counting pulses and adapter boards providing the necessary supply voltage have also been developed. The modules are capable to count rates up to 10 MHz and support additional features needed for calibration among other things.

Calibration

To ensure comparability between the individual beam loss monitors, their count rates have been measured against a 60 MBq ^{60}Co source under defined conditions using the same hardware, which will be installed for on-line beam measurements. The results of this measurements are summarized in Table 1. Count rates of single diodes without coincidence were similar. Besides absolute and background count rates, also the ratio of background substracted count rates of monitor i against the one of monitor 1 is given by

$$\frac{C'_{0,1}}{C'_{0,i}} = \frac{C_{0,1} - C_{B,1}}{C_{0,i} - C_{B,i}}.$$

Table 1: Properties of BLMs. Counts per $^{10}/_{7}$ s

No.	Counts without source $C_{B,i}$	Counts with source $C_{0,i}$	Counts BLM 1/ Counts BLM n
1	2.85	73.57	1
2	4.69	75.86	0.994
3	1.89	67.46	1.079
4	2.19	72.78	1.002
5	1.78	68.77	1.056
6	1.93	67.24	1.082
7	1.99	43.68	1.696
8	1.25	40.56	1.799

Knowing these ratios, it is possible to mount multiple beam loss monitors around the beam pipe, so that the direction of deviation of the beam from the ideal orbit can be detected. Once a displacement is measured using a monitor i with a count rate C_i, it can be normalized to the count rate of monitor 1:

$$N_i = C_i \cdot \frac{C'_{0,1}}{C'_{0,i}}$$

where N_i is the normalized count rate. Assuming a constant effectivness of the detectors, which does not depend on the intensity, and no saturation effects for high count rates, the direction of displacement could be efficiently detected.

SUMMARY

Beam loss monitors will be an effective and non-destructive tool at the S-DALINAC either for beam trajectory change measurement of different moments in time or for on-line determination of beam trajectory displacement. By comparison of monitored count rates different parameters can be optimized in a convenient way. This includes rf phases of chopper, bunchers and cavities as well as magnet currents.

ACKNOWLEDGEMENTS

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