INCREASING THE STABILITY OF THE ELECTRON BEAM OF THE S-DALINAC*

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Abstract

The S-DALINAC is a superconducting recirculating electron accelerator with a final energy of 130 MeV. It operates in cw at 3 GHz. It accelerates beams of either unpolarized or polarized electrons and is used as a source for nuclear- and astrophysical experiments at the university of Darmstadt since 1987. We will report on two future upgrade plans for increasing the operation stability of the accelerator: A high energy scraper system for collimating the beam before it is delivered to the experiments and a rf feedback system to fix the rf phase of the beam leaving the injector linac by measurements on a rf monitor.

INTRODUCTION

Since 1987 the Superconducting DArmstadt LINear Accelerator (S-DALINAC) is operating as a source for nuclear- and astrophysical experiments at the university of Darmstadt [1]. It produces beams of either unpolarized or polarized electrons [2] and accelerates them to energies of 1 up to 130 MeV with beam currents from several pA up to 60 μA. The layout of the S-DALINAC is shown in Fig. 1.

Acceleration in the injector and main linac is done by superconducting elliptical cavities with a quality factor of $Q_0 \approx 10^9$. The operation frequency is 3 GHz while the maximum accelerating gradient of each cavity accounts for 5 MV/m. As the main linac consists of 8 standard 20-cell cavities it can provide an energy gain of 40 MeV. By recirculating the beam two times the maximum energy of 130 MeV can be achieved. In the adjacent experimental hall this beam can be used for different experiments such as electron scattering in two electron spectrometers or experiments with tagged photons. For these experiments an energy spread (rms) of $1 \cdot 10^{-4}$ as well as a very low γ-ray background are required.

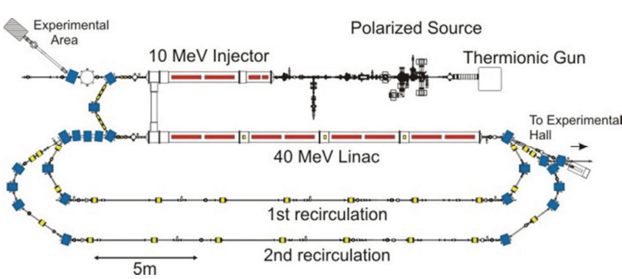

Figure 1: Floor plan of the S-DALINAC.

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HIGH ENERGY SCRAPER SYSTEM

If not optimized electron accelerators usually generate γ-ray background from bremsstrahlung processes on beam-line components which often prevents sensitive detection of photons from the reactions. The background is produced by beam losses coming from some beam halo which is generated during acceleration and reinjection of the recirculated beam. In order to enable proposed (e,e'γ)–experiments in the future this halo needs to be removed from the beam. In addition the low energy photon tagger NEPTUN [3] needs beam energies up to 40 MeV only, which means that the accelerator is operated in a single pass mode then. So the NEPTUN tagger doesn't profit from the recently measured decrease in energy spread of the beam using a non-isochronous recirculation scheme [4].

Layout of the Scraper System

After up to three passes through the linac (housing 8 independently controlled accelerating cavities) a transversal scraping, combined with an additional longitudinal collimation will ensure the highest beam quality. The system proposed is shown in Fig. 2. It consists of a dipole chicane with collimating slits at three positions. In the first dipole magnet there will be an additional possibility to extract the beam to a high energy Møller polarimeter. The transverse scraping will be used mainly for removing the beam halo and will be set up in dispersion free sections of the extraction beamline. In addition, the longitudinal scraping can further reduce the energy spread of the beam at the cost of beam current. As the dispersion is maximized in this section, a more efficient energy collimation compared to the existing system can be assured, allowing an energy definition of as low as 10 keV, a key figure for experiments.

Beam Dynamics Simulations

In order to achieve a high efficiency for the energy collimation in the scraper system the transverse dispersion at the position of the collimator has to be maximized. By doing so the correlation between horizontal position of any particle and its energy deviation to the reference particle is maximized as well. In addition the complete scraper system has to be transversely dispersion free at the end of the chicane and the beam envelopes must not exceed the beam pipe diameter of 30 mm at any position within the beam line to avoid unwanted beam losses. The results of the beam dynamics simulations are plotted in Fig. 3. At the planned

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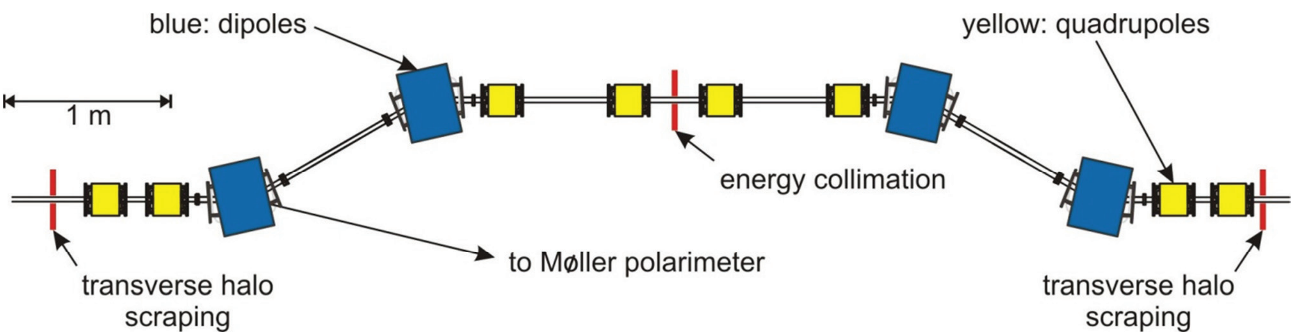

Figure 2: First layout for the proposed scraper system. The energy collimation will be done in the middle position of the chicane. The first dipole magnet can be set to positive or negative magnetic field using a bipolar power supply in order to send the beam either to a high energy Møller polarimeter or through the scraper system.

position for the longitudinal scraper at z = 4.5 m the horizontal dispersion r_{16} is increased to -18.8 mm/%. At the end of the chicane the horizontal dispersion r_{16} and the horizontal angular dispersion r_{26} equal zero as requested. The beam envelopes stay well below the beam pipe radius of 30 mm. Obviously the extension in x-plane reaches its maximum at the position of the longitudinal scraper due to the high dispersion.

Magnet design

The detailed design for the dipole magnets of the chicane has not been determined yet. In Table 1, the properties of the magnets as they were used for the beam dynamics simulations are given. As a maximum magnetic field of 0.81 T is needed conventional iron magnets can be used setting up the dipole chicane. Within the next two months the detailed design for the magnets will be done and a call for tender for the production will take place.

RF FEEDBACK SYSTEM

During operation of the S-DALINAC sometimes slow drifts as well as breakdowns of the pre-acceleration voltage of the thermionic gun are observed. Due to time of flight differences of particles at a wrong energy with respect to the reference particle these effects result in a decreased stability of the beam at the end of the superconducting injector as well. In Fig. 4 the energy and phase offset of the beam at the end of the superconducting injector at different energies of the injected beam is plotted. As the arc between injector linac and main linac is operated isochronously the phase offset results in a wrong acceleration phase in every superconducting cavity.

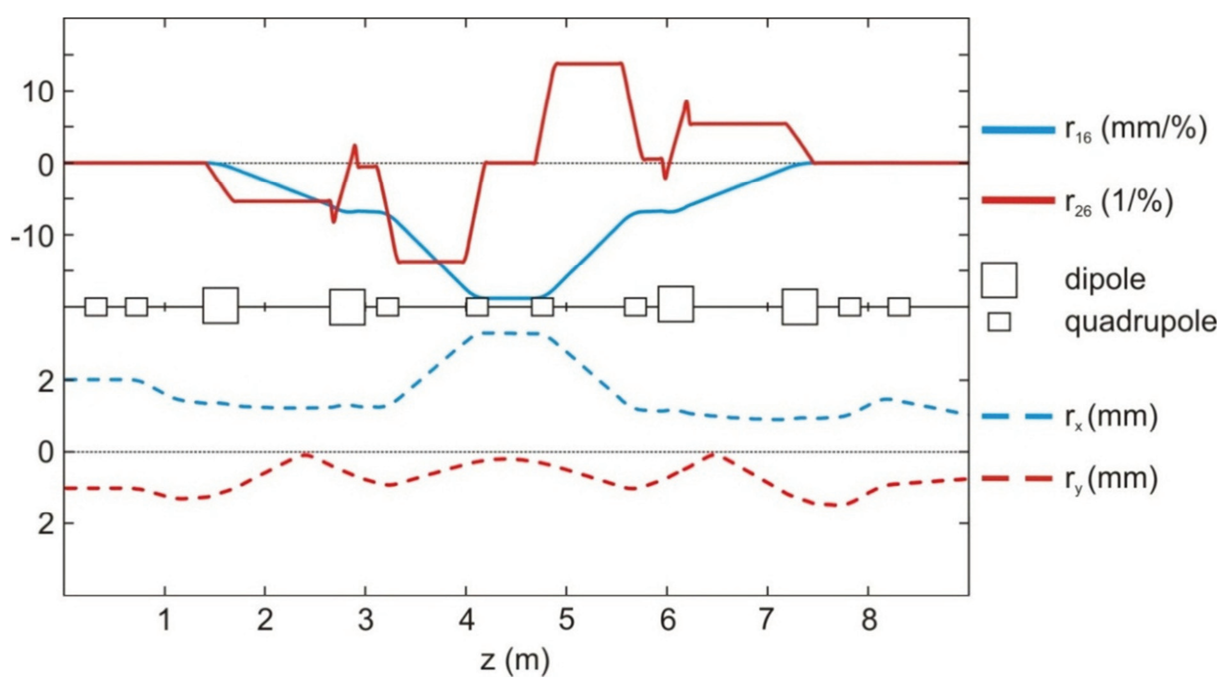

Figure 3: Transverse beam dynamics in the scraper system. The upper curves show the amount of transverse dispersion (r_{16}) and transverse angular dispersion (r_{26}) along the beamline. In the middle plane the transverse dispersion is maximized for providing an optimal collimating efficiency. At the end of the scraper the transverse dispersions vanish as requested. The lower curves show the beam envelopes along the scraper beamline.

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Table 1: Specifications for the Scraper Dipole Magnets.

Beam energy	130 MeV
Bending radius	0.484 m
Bending angle	30°
Magnetic length	0.2534
Gap height	3 cm
Max. field	0.81 T
Wedge angles	+16°

So the electrons will experience a wrong acceleration voltage in the main linac and the total energy offset increases further. Due to the acceleration on edge of the acceleration field the energy spread increases as well. For increasing the operational stability of the S-DALINAC in future an rf feedback system is planned in order to stabilize the phase of the electron beam injected to the main linac.

Feedback system setup

The rf feedback system will consist of an rf monitor at the end of the injector linac which will be used for detection of the mean phase of the bunches. These rf monitors are used as part of the S-DALINAC beam instrumentation for non-destructive beam current and position measurements [5] as well as time of flight measurements for detection of the longitudinal dispersion in the recirculation arcs [6]. The detected phase signals will be amplified and sent to the LLRF system of the S-DALINAC [7,8] as a feedback signal (see Fig. 5). This

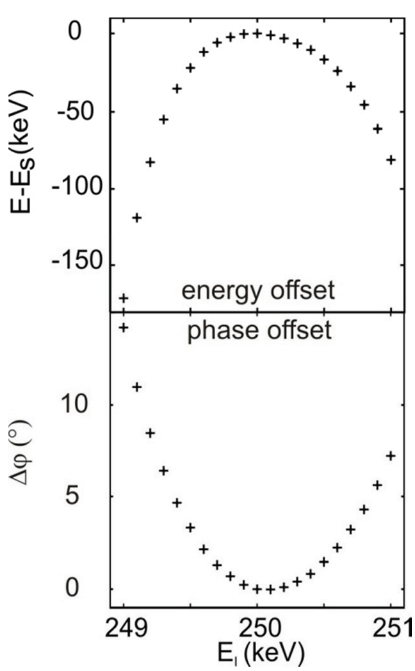

Figure 4: Simulation of energy offset (top) and phase offset (bottom) behind the superconducting injector linac for different energies of the injected beam.

signal is planned to be used for controlling the reference phase of either the prebuncher or the chopper cavity. For differentiating which cavity is more convenient for stabilizing the beam, more detailed simulations are going on.

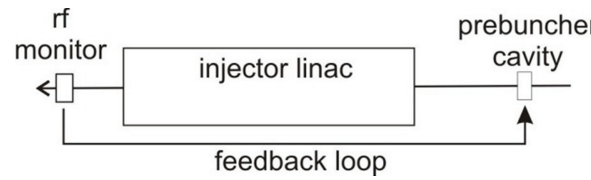

Figure 5: Layout of the rf feedback system for stabilizing the phase of the injector beam. The measured phase signal of the extracted beam in the rf monitor will be used as a control signal for the prebuncher or chopper cavity.

SUMMARY AND OUTLOOK

Within this paper we presented two ongoing projects to increase the stability and beam quality of the S-DALINAC in future.

The high energy scraper will provide a halo free and energy collimated beam for the nuclear physics measurements. Currently the magnet design needs to be finished in order to acquire the dipole magnets. Delivery of these magnets is projected in mid 2014. In the meantime the detailed beamline design and the production of the other components like quadrupole magnets, scraping slits and beam diagnostics will go on. The first operation of the high energy scraper system is planned for fall 2014.

In order to further increase the stability of the recirculated beam an rf feedback system for stabilizing the phase of the injector beam is planned. Currently the rf monitor cavity is under construction and will be installed at the injector linac soon for first tests with electron beam. More detailed beam dynamics simulations are going on as well. The start of operation of the feedback system is planned for October 2013.

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