A HIGH-ENERGY-SCRAPERSYSTEM FOR THE S-DALINAC EXTRACTION – DESIGN AND INSTALLATION*

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Abstract

The superconducting Darmstadt linear electron accelerator (S-DALINAC) of the Institute for Nuclear Physics at Technische Universität Darmstadt delivers electron beams in cw-mode with energies up to 130 MeV. The accelerator consists of a 7.5 MeV injector and a 30 MeV main linac where superconducting 3 GHz cavities are operated at a temperature of 2 K. With three recirculation beam lines the main linac can be used up to four times. To reduce energy spread and improve the energy stability of the beam a new scrapersystem has been developed and installed. It changes the extraction beam line into a dispersion-conserving chicane consisting of four dipole magnets and three scrapers. The system includes scraping of x- and y-halo at two positions as well as improving and stabilizing energy spread on a dispersive part.

INTRODUCTION

Since 1987 the S-DALINAC serves nuclear- and astrophysical experiments at the University of Darmstadt [1]. It is fed by either a thermionic or a photoemission gun which delivers a spin-polarized beam [2]. After pre-acceleration by the injector module the electron beam can either be used for experiments at the NRF-setup [3] or it is guided through a 180°-arc to enter the main linac. By passing the linac up to four times the maximum energy of about 130 MeV can be reached. The beam current can be adjusted from several pA up to 20 μA. The layout of the S-DALINAC is given in Fig. 1.

If not optimized, electron accelerators can generate γ-ray background from bremsstrahlung processes on beam-line components which prevents sensitive detection of photons from searched-for nuclear reactions. The background is produced by beam losses resulting from some beam halo which is generated during acceleration. In order to enable (e,e'γ) coincidence-experiments for nuclear physics, multiple initiatives for accelerator improvements have been undertaken. To improve the energy spread and the energy stability of the beam, the recirculation scheme has already been changed to a non-isochronous mode. It was shown [4] that by this method it is possible to reduce the energy spread from 120 keV down to 30 keV using electron scattering at a thin gold target. In addition, a low energy scrapersystem has been installed inside the 180°-arc to lower the energy spread even further before acceleration in the main linac [5].

In this paper a system will be presented, which has been developed to collimate the electron beam before it is delivered to the experiments. Its purpose is to remove any beam halo in horizontal and vertical direction as well as to further reduce the energy spread by longitudinal scraping. Massive blocks made out of materials with a high electron stopping power are used in scraper systems. When applied to a well-focused beam they can be used to clean the beam from its halo. For reducing the energy spread, dispersive parts of the beam line are introduced to spatially sort the beam particles according to their energy and then stop the particles above or below a given energy. The design of the system will be presented and we will report on its installation into the accelerator complex.

SCRAPER BRACKETS

To find the appropriate material for the scraper brackets several properties are important. The considered quantities are listed in Table 1. We have concentrated on high vacuum suitable materials which can be easily machined. The electron stopping power determines the minimum thickness of the brackets to stop the electrons. The heat conductivity is important to ensure a good temperature distribution and effective power transfer to the cooling water. The energy defining brackets were designed for this scraper system to withstand a maximum beam power of 2600 W which has to be absorbed by sufficient water cooling. Therefore, copper was picked because it is satisfactory in both, thermal conductivity and electron stopping power. In addition, soldering copper to e.g. stainless steel is a well-known standard procedure for creating vacuum tight connections.

Table 1: Critical Properties of Considered Materials for the Scraper Brackets

Material:	Fe	Al	Cu
Density [g/cm³]	7.87	2.69	8.92
Mass Stopping Power [MeV cm²/g]	2.005	1.921	2.001
Thermal Conductivity [W/m K]	80	236	401

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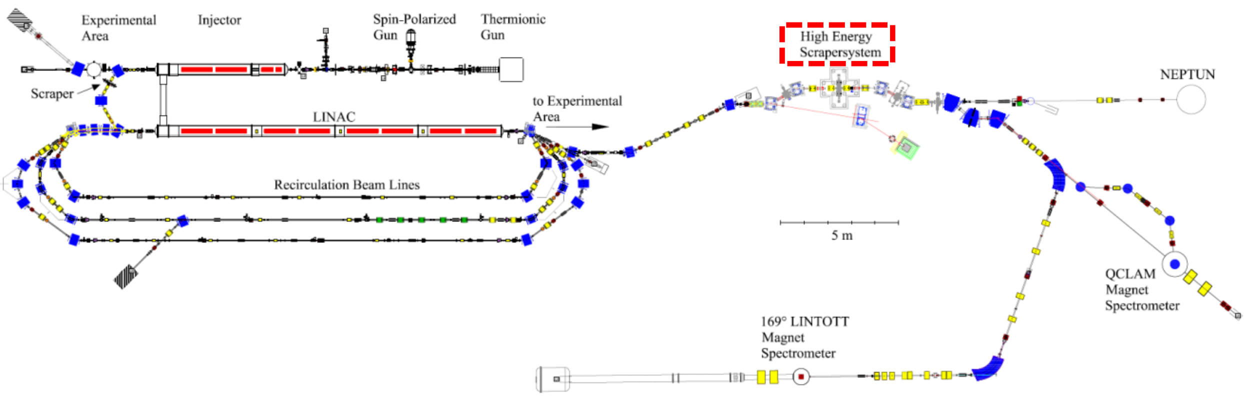

Figure 1: The S-DALINAC floor plan including accelerator hall, extraction beam lines and experimental areas. The scrapersystem is highlighted in red.

The energy defining scraper has to be designed to absorb up to 100 % of the beam power for machine-safety reasons, even while it is not necessary in the case of halo-scraping. To determine the optimal geometry (Fig. 2) of its scraper brackets several simulations using GEANT4 [6] have been done.

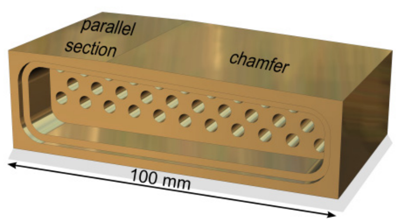

Figure 2: Schematic of the scraper brackets geometry.

Using a realistic beam profile and energy distribution the angle of the chamfer and the length of the continuing parallel section were varied. For a smooth temperature distribution the chamfer angle turned out to be very important. Its optimum showed up at 2.5 °. The length of the parallel section can lead to an increase of energy spread when chosen too long. If chosen too short the temperature distribution shows a hot spot at the end of the chamfer. It was found that a length of 32 mm is the optimal value. To find the most effective layout of cooling water drills, calculations via CST MPHYSICS STUDIO 2015 [7] have been undertaken. By the use of 32 cooling water bores the beam power deposition leads to a maximum temperature of 321 K.

CONSTRUCTION

The presented high energy scrapersystem resembles a chicane which consists of four dipole magnets, eight quadrupole magnets, four vertical steerers and the three scraper chambers themselves. The system is depicted in Fig. 3. Beam scraping will be done in three different positions. This is necessary because beam dynamics have to be adjusted individually for halo scraping and for the energy defining scraper (see section BEAM DYNAMICS). The system consists of three spherical vacuum chambers, each measuring 9” in diameter. The two chambers for halo scraping contain guided, water cooled copper blocks which are positioned using a stepping motor outside the vacuum. In this set-up a positioning accuracy better than 0.01 mm is possible. Downstream the halo scrapers BeO-screens can be inserted to check for beam position and shape. The amount of beam current, which is stopped during halo-scraping, is in the order of 1% of the total beam intensity, energy defining scraper is outlaid to deal with the full beam power. Additionally to the increased cooling water system, both scraper brackets are mounted electrically isolated from the beam pipe. By measuring the current, one gains information about the amount of beam current which is stopped on each bracket. This will be useful to find the optimal position of the slit and in addition identify energy fluctuations of the beam. Monitoring this measure will also help to detect and cure irregularities of the rf-system to further decrease the potential of failure.

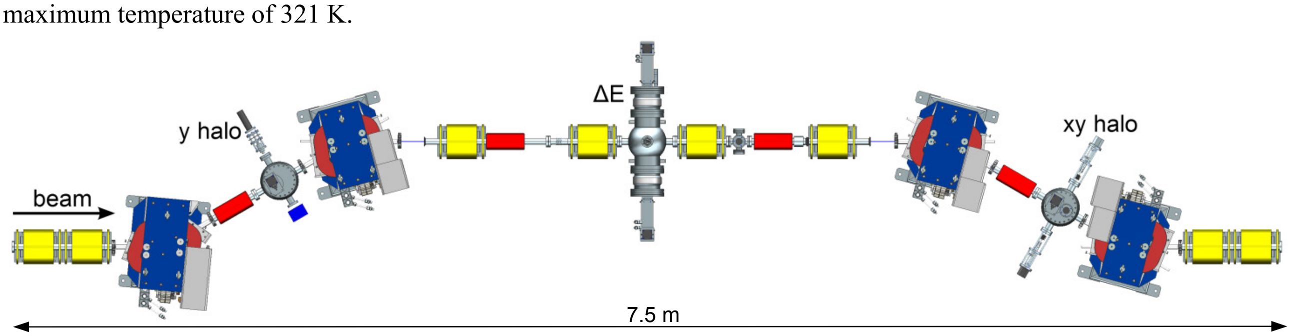

Figure 3: The high energy scrapersystem: from left to right the chambers for y halo-, energy defining- and xy halo-scraper can be seen.

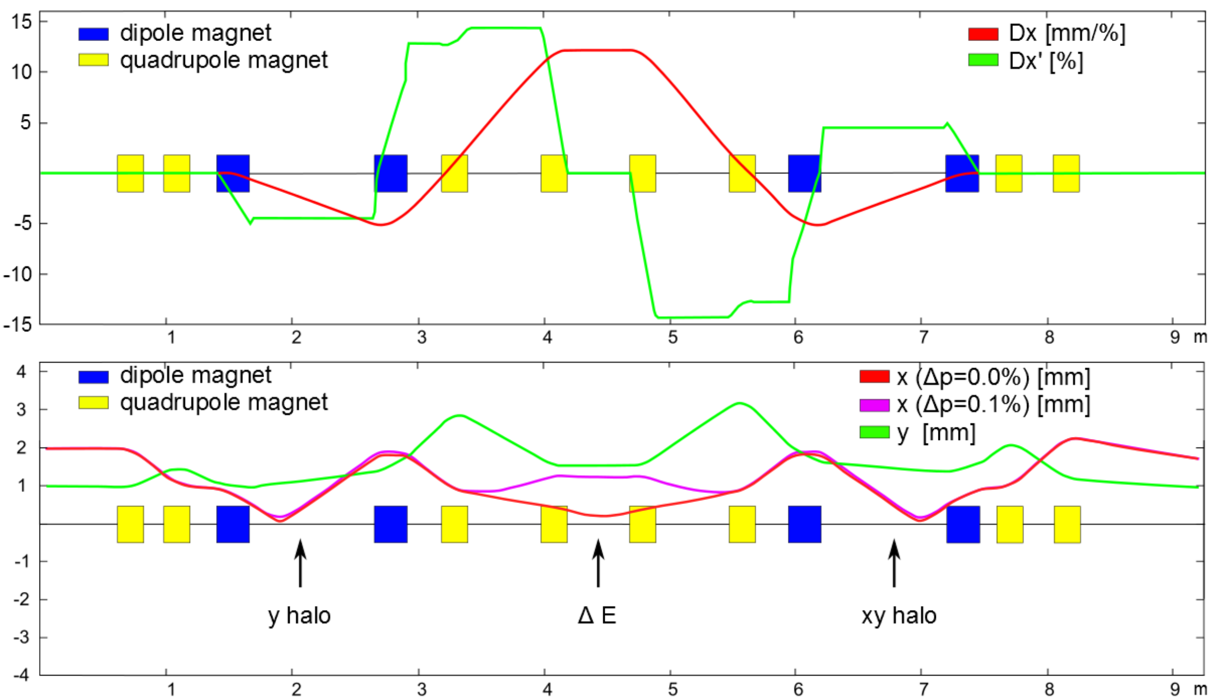

Figure 4: Beam dynamics calculation: The upper graphic shows the dispersion and its derivative along the new beam line. The beam envelope (1σ radius) for Δp = 0 % and Δp = 0.1 % is plotted below. The locations of the energy defining scraper (ΔE) and the halo scrapers are indicated by small arrows.

BEAM DYNAMICS

The new system replaces a straight part of the former extraction beam line and therefore has to conserve dispersion and allow beam tuning independently for the rest of the beam line. The chicane had to be built within a space of 8 m x 2 m which set the limits for beam line design. The final results of the beam dynamics calculations using the XBEAM [8] code are shown in Fig. 4. Dipole positions and dipole chamfer angles, quadrupole positions and their gradients were outlaid to build a fully symmetric system with high transverse dispersion and small horizontal beam size at the position of the energy defining scraper. The width of the slit together with the dispersion at this position, determine the energy width which can pass the scraper. A horizontal beam focus in this point allows using a narrow slit without losing too much beam current. The halo scrapers are positioned where dispersion and beam width are small.

INSTALLATION AND OUTLOOK

The high energy scrapersystem was built up in the extraction beam line of the S-DALINAC within the installation period for the third recirculation path [9]. Due to radiation shielding for the neighbouring experimental areas, the former extraction beam line has been placed inside a tunnel of concrete blocks which had to be opened and slightly changed to gain space for the chicane. After the removal of the old beam line, the chicane including dipole and quadrupole magnets were positioned. For the optimal performance of the system it is of great importance to meet the calculated drift lengths and magnet positions within accuracy of less than 0.1 mm. In a first step the positions of the stands were marked using a laser tracker system. The fine adjustment has been done in close collaboration with our partners from the geodetic groups of the Frankfurt University of Applied Sciences and Technische Universität Darmstadt [10]. In current status the concrete tunnel is closed and the vacuum system is already pumped. To finalize, radiation shielding has to be put on after several connections for cooling water, compressed air and electrics have been installed. Commissioning of the system is planned for summer together with the new recirculation beamline [9].

CONCLUSION

The new high energy scrapersystem at the S-DALINAC will help to improve beam quality by halo and energy scraping of the beam after acceleration. Using this new feature (e,e'γ)-experiments with high resolution and low noise can be approached. The main components of the system have already been assembled and the fine adjustment has been completed. Besides remaining infrastructural work the system is ready for the first beam commissioning in summer.

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