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A LOW ENERGY ELECTRON-SCRAPER SYSTEM FOR THE S-DALINAC INJECTOR*

L. Jürgensen#, T. Bahlo, C. Burandt, F. Hug, T. Kürzeder, N. Pietralla, T. Schösser, C. Ungethüm,
Technische Universität Darmstadt, Germany

Abstract

The S-DALINAC is the Superconducting Linear Accelerator of the Institut für Kernphysik at Technische Universität Darmstadt (Germany). In order to improve the energy spread and the energy stability of the beam for further acceleration a new scraper system has been developed and installed between the 10 MeV injector and the main linac. The system was designed to ensure energy spread of dE < 10^{-3}. Design and construction have been done in-house. After installation several tests have taken place, the results will be presented in this paper.

INTRODUCTION

Since 1987 the S-DALINAC serves nuclear- and astrophysical experiments at the University of Darmstadt [1]. It is fed by either a thermionic gun or a photoemission gun which delivers a spin-polarized beam [2]. After pre-acceleration up to energy of 10 MeV 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 three times the maximum energy of about 130 MeV can be reached. The beam current can be adjusted from several pA up to 60 µA. The layout of the S-DALINAC is given in Fig. 1.

In order 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 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 [4]. In theory this mode reproduces the same energy spread as before acceleration in the main linac. In order to lower the energy spread even further this leads to the necessity to improve the beam right before injection into the main linac. Therefore it was decided to install a low energy scraper system right behind the injector.

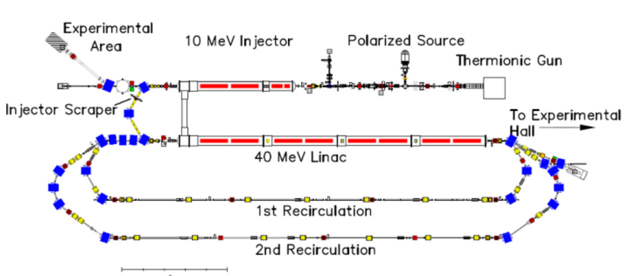

Figure 1: Floor plan of the S-DALINAC.

The electron beam leaves the injector module with a broadened energy spread. Also energy drifts have been observed. There are several reasons why these errors in energy are added to the beam. Instabilities of the high voltage terminal of the electron gun merge with errors which come from an inexact beta-grading of the first superconducting cavities. The RF control system can also contribute by residual errors in amplitude and phase to the acceleration.

ELECTRON SCRAPER SYSTEMS

Scraper systems work mostly like a slit by stopping parts of the beam using massive blocks made out of materials with a high electron stopping power. They can be used to clean the beam from its halo. By applying such a system to a beam which is expanded by dispersion also energy definition is possible.

CALCULATIONS

To find the appropriate material for the scraper brackets several properties are important. The considered quantities are listed in Tab. 1.

We have concentrated on high vacuum suitable materials which can be machined by our in-house workshop. 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. To avoid activation of the scraper brackets also the neutron separation energy should be considered. For this scraper system a maximum beam power of 200 W have to be absorbed. Therefore copper was picked because it is best in both, thermal conductivity and electron stopping power.

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
Neutron Separation Energy [MeV]	11.2	13.06	9.91

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#ljuergensen@ikp.tu-darmstadt.de

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To determine the optimal geometry of the scraper brackets several simulations using *GEANT4* [5] have been done. Figure 2 shows a schematic of the used geometry. Using a realistic beam profile and energy distribution the angle of the chamfer and the length of the continuing parallel section were varied.

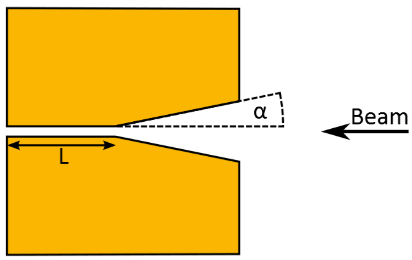

Figure 2: Schematic of the scraper brackets geometry.

The chamfer angle turned out to be very important for a smooth temperature distribution, its optimum showed up at 3°. 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. A length of 20 mm showed up to be the optimal value.

The necessary cooling power has been derived using *CST MPHYSICS STUDIO 2013* [6]. By the use of simple water cooling the temperature of a "worst case" hot spot, when a beam of 200 W hits the front of one bracket, could be reduced to 338 K. These cooling drills can be seen in Fig. 3.

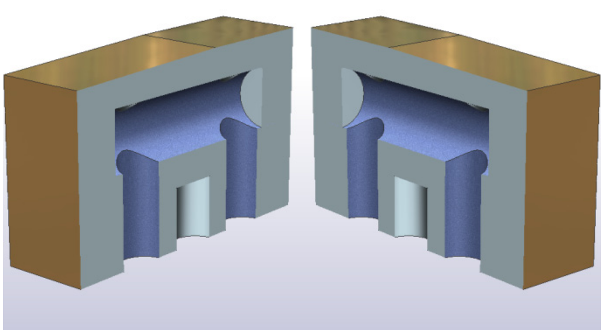

Figure 3: 3D-CAD model showing the cooling drills of the scraper brackets. The overall length of the bracket is 50 mm.

BEAM DYNAMICS

To clean the beam from its energy spread, a position had to be chosen where it is expanded by dispersion. Inside the 180°-arc between injector and main linac it was possible to change the positions of quadrupoles and therefore to gain some space in z-direction for a system with an overall length of up to 200 mm. The beam dynamics were changed in such way that the arc stays achromatic and isochronous. The new beam dynamics calculation done using *XBEAM* [7] is shown in Fig. 4. The achieved dispersion on x-axis is constant at the place where the scraper system is set up with a value of 4 mm/%.

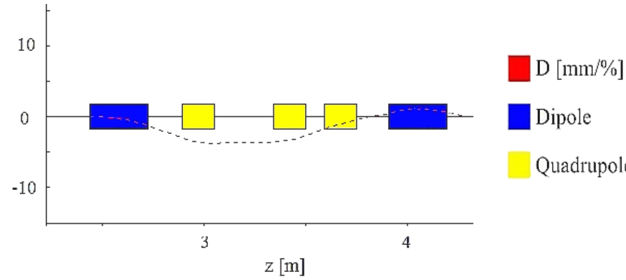

Figure 4: *XBEAM* simulation of the beam line showing a constant dispersion at the scraper's position.

CONSTRUCTION

Due to the limited space in the direction of the beam the design of the chamber including scrapers and a light emitting target to check beam shape and position behind the scraper brackets had to be very short. In addition the two scraper brackets have to be mounted electrically isolated to measure the ratio of beam current deposited in each. It is foreseen to use this new measure to stabilize the injector module adding an extra control unit in addition to the RF control system.

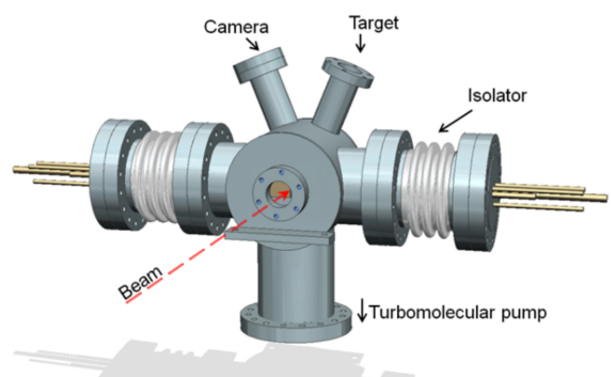

Figure 5: 3D-CAD model of the scraper chamber. The overall width is 523 mm, length in direction of beam is 168 mm.

The final design of the scraper chamber is shown in Fig. 5. A sectional view of the system is given in Fig. 6. The scraper brackets are guided via three brass bars and the two cooling water pipes made out of copper. The membrane bellows allow a stroke of 30 mm. The position where the target can be moved into is right behind the scraper brackets. This allows a control of beam size and position also when the scraper brackets are moved in. The motion of the scraper brackets is done using a self-developed articulated jack with a step motor at the end of each side which can be seen in Fig. 7. The minimum step size is calculated to less than 0.1 mm.

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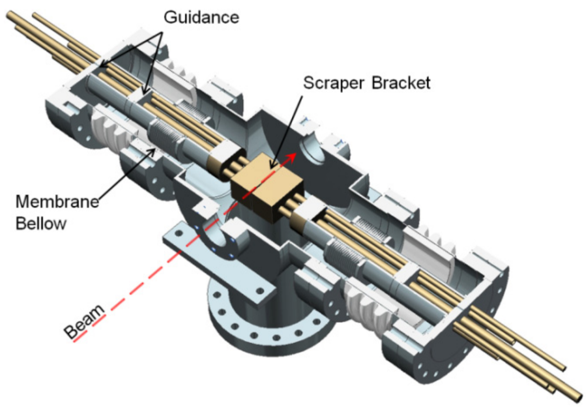

Figure 6: 3D-CAD model showing the sectional view of the scraper system.

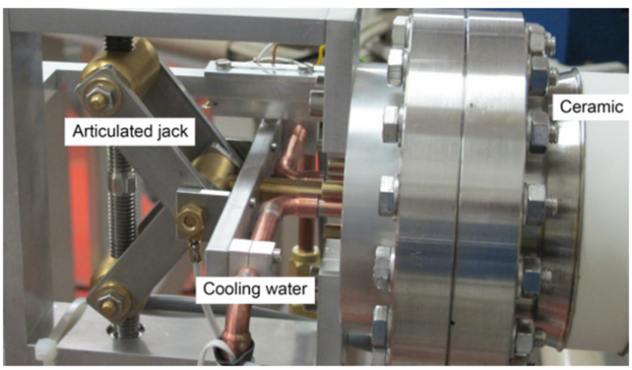

Figure 7: Articulated jack driven by a step motor for exact positioning.

COMMISSIONING

During the last hours of beam time in 2013 the system was tested with a beam at 5.8 MeV and about 140 nA. The beam passed the main linac only once (single pass mode) to prevent effects from our recirculations on the energy spread. At a final energy of 24.6 MeV the energy spread and the beam current were measured with a spectrometer using electron scattering at a thin Au-foil of 1.0 mg/cm². The results are shown in Fig. 8.

It can easily be seen that the closing of the slit between the scraper brackets reduces energy spread from about 15 to less than 10 keV. The system also decreases transmission which had to be expected for a destructive beam cleaning method. The bumpy curve for the beam current shows fluctuations of the injector energy as suspected. These may be caused by RF-fluctuations of the injector module or HV instabilities of the electron source.

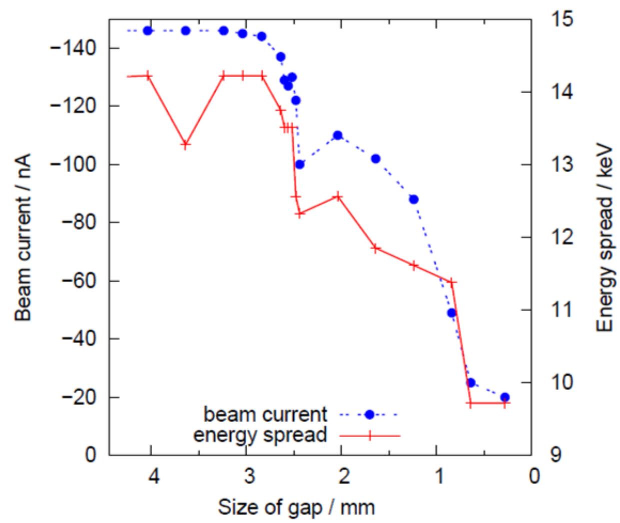

Figure 8: First commissioning by measuring the change of energy spread using electron scattering at a thin Au-foil (1.0 mg/cm²). The beam energy was 24.6 MeV in single pass mode.

CONCLUSION

The new low energy electron-scrapersystem at the S-DALINAC was tested successfully and showed a great potential in decreasing the energy spread of the beam behind the injector module. This also had strong influence on the energy spread measured at the experiment after acceleration in the main linac.

For further commissioning test at higher beam currents and in recirculation mode are foreseen.

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