

# AUTOMATED TRANSVERSE BEAM EMITTANCE MEASUREMENT USING A SLOW WIRE SCANNER AT THE S-DALINAC\*

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## Abstract

The superconducting linear accelerator S-DALINAC of the Institute for Nuclear Physics (IKP) from TU Darmstadt provides electron beams of up to 130 MeV in cw mode [1]. In order to improve beam simulations, it is planned to observe the transverse beam emittance at different locations along the beam line. A system of slow wire scanners in combination with quadrupole variation is foreseen to accomplish this task. For a first test a wire scanner was installed in the 250 keV section behind the thermionic electron gun of the S-DALINAC. A procedure to automatize measurements was developed and integrated in the EPICS-based control system [2]. We will show the status of the work on the automatized control and the results of first emittance measurements. A report on future plans will be given.

## INTRODUCTION

The S-DALINAC consists of a 10 MeV injector and a 40 MeV main linac, both equipped with elliptical cavities operating in liquid helium at 2 K on a frequency of 3 GHz. Both, a thermionic and a polarized source [3] for electrons are available. The final energy is reached by using up to two recirculation paths. The current layout of the S-DALINAC is shown in Fig. 1.

Several locations are interesting for emittance measurements. It is desired to observe the emittance in between the accelerating sections and also in the extraction beam line. Additionally, two scraper systems will be in use in the near future [4, 5] and will certainly affect the emittance as well. To calculate the emittance with the method of quadrupole variation, one has to repeatedly measure the beam profile for different quadrupole currents. A wire scanner was available for this purpose from previous measurements at the polarized source [6]. The main task was to develop an automatized procedure to obtain the emittance. It should be easy to use and applicable for other locations at the S-DALINAC as well.

## QUADRUPOLE VARIATION

The idea of emittance measurement with quadrupole variation is briefly recapitulated here. Detailed information can be found in many standard works on beam dynamics (e.g. [7]). In one transverse direction, a beam is commonly described with the two-dimensional  $\sigma$  matrix. The square

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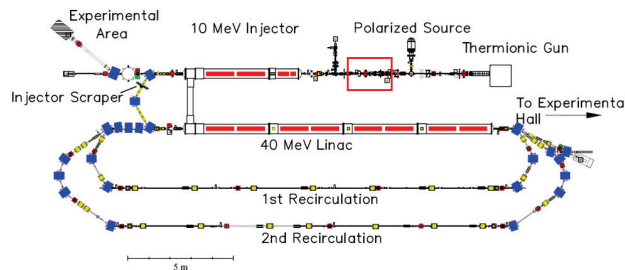


Figure 1: The section where the first emittance measurements took place is indicated with the red rectangle in this floor plan of the S-DALINAC.

root of the determinant of this matrix yields the emittance.

$$\sigma = \begin{pmatrix} \langle x^2 \rangle & \langle xx' \rangle \\ \langle xx' \rangle & \langle x'^2 \rangle \end{pmatrix} \quad (1)$$

$$\epsilon = \sqrt{\det \sigma} \quad (2)$$

For sections that only consist of drift spaces, quadrupoles and dipoles, a transport matrix  $R$  can be defined which allows to transform the  $\sigma$  matrix from location  $a$  to  $b$ .

$$\sigma_b = R \sigma_a R^T \quad (3)$$

The matrix entry  $\sigma_{11}$  at the location of the wire scanner is easily accessible experimentally as it is the square of the beam width. In this work, a Gaussian distribution is assumed and the beam size is defined as one standard deviation. After several measurements of the profile for different quadrupole currents, a set of linear equations can be formed as the measured beam widths and the transport matrices  $R$  change. All entries of the  $\sigma$  matrix at the position of the quadrupole can then be determined numerically.

## MEASUREMENT SETUP

The devices used for the first emittance measurements are shown in Fig. 2. The wire scanner consists of two perpendicular tungsten wires within a frame and is moved through the beam under an angle of  $45^\circ$  by a linear actuator. Therefore the profile in both transverse dimensions is recorded by the same device (see Fig. 3). The resulting current on the wires is picked up directly. Additionally, a linear potentiometer is attached which measures the current position of the wire scanner. Both these quantities are necessary to calculate the beam profile and have been available as EPICS process variables. A power supply for the linear actuator was developed and integrated in EPICS as well.

The quadrupole is part of a triplet in the low energy section following the electron gun. The field distribution was

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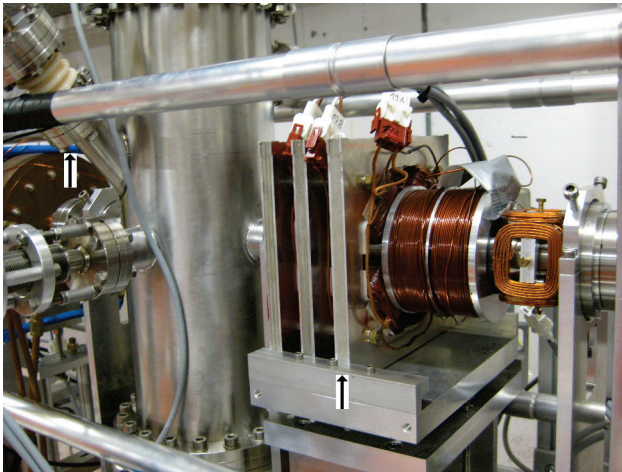


Figure 2: The arrows indicate the quadrupole and the location of the wire scanner.

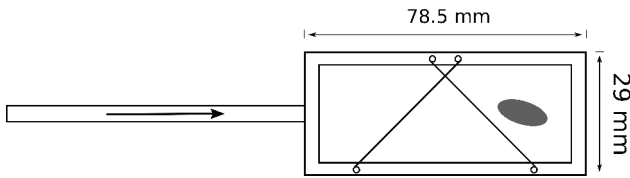


Figure 3: The head of the wire scanner is moved through the beam under an angle of  $45^\circ$ .

measured with a hall probe beforehand. As the beam energy in this section is only 250 keV, the quadrupole is rather small and does not have a uniform field (see Fig. 4). The thin lens approximation cannot be used for that reason. To find the best hard edge representation, simulations were performed. Single electrons were tracked through rectangular field and the resulting paths were compared to the particles which passed the measured field distribution (see Fig. 5). The aspect ratio of these rectangles was varied while the surface area remained equal to the measured field.

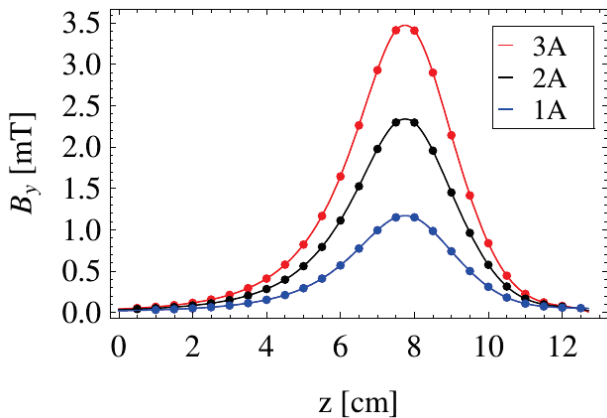


Figure 4: The field profile of the used quadrupole was measured for three different excitation currents.

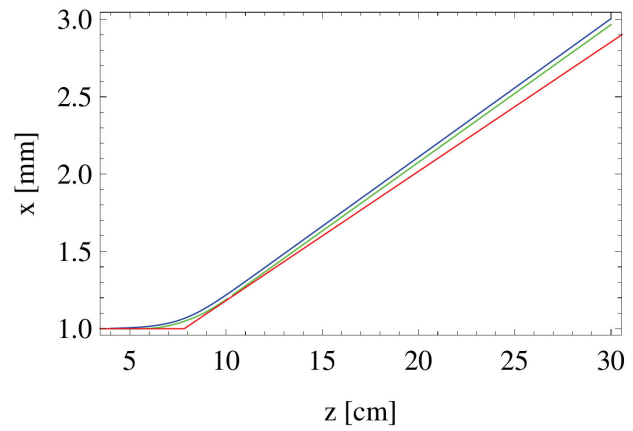


Figure 5: The numerically calculated trajectory of a 250 keV electron which passes the measured field is displayed in blue. In green and red are the trajectories for particles that pass a hard edge and a thin lens quadrupole with the same integrated strengths.

## MEASUREMENT CONTROL AND DATA ANALYSIS

Operators at the S-DALINAC use graphical interfaces created with Control System Studios (CSS) to display and control a variety of EPICS process variables. Therefore it was decided to use a CSS interface as well for the emittance measurement. Since the needed quantities to obtain the profile are accessible via EPICS command line tools, the data is read out conveniently with shell scripts. The further data processing and displaying is then done with python and gnuplot scripts. For each profile measurement, Gaussian functions are fitted to the data and the results are displayed. The operator can also alter the parameters for every fit within the interface if needed. After several profiles have been recorded, least square fits are performed to obtain the sigma matrix of the beam. The emittance is then calculated from eq. (2). The whole procedure is controlled through the CSS interface (see Fig. 6).

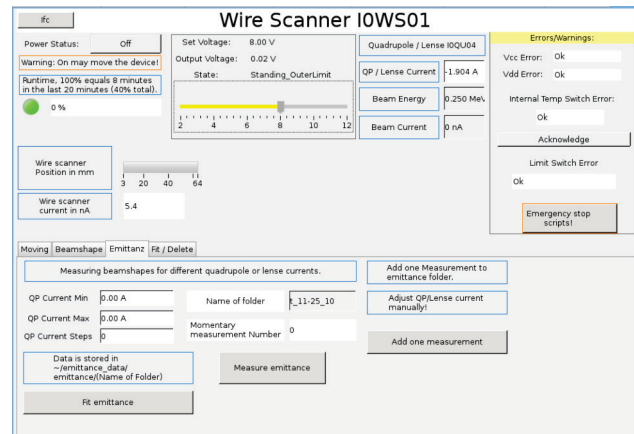


Figure 6: The graphical CSS user interface of the emittance measurement.

## MEASUREMENT RESULTS

The measurement of the beam profile as shown in Fig. 7 is the basis for emittance measurements with quadrupole variation. The two peaks in the figure result from the two wires which pass the beam one after the other.

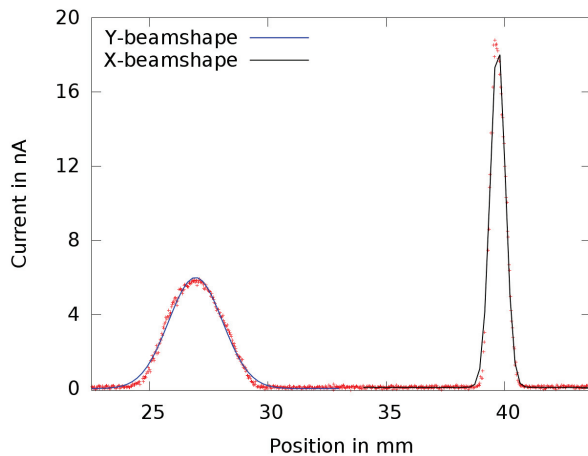


Figure 7: One of the beam profile measurements with automatically performed Gaussian fits.

The standard deviations of the Gaussian fits are extracted and plotted against the quadrupole current in the next step. A least square fit is performed which yields the beam shape in the phase space of both transverse directions as well as the expected correlated standard deviations. Figure 8 shows the data and fit in  $x$  direction.

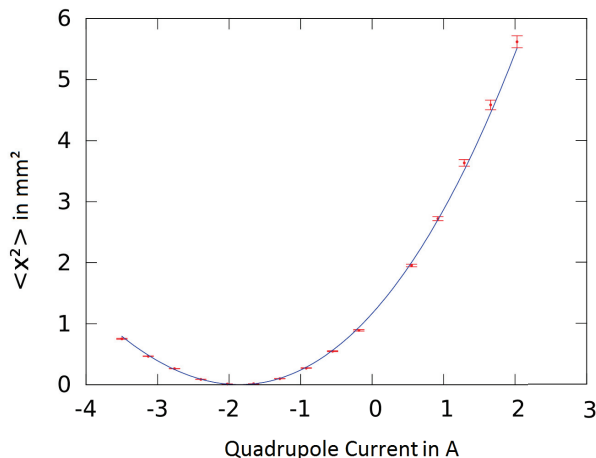


Figure 8: The measured beam widths to the square are plotted against the corresponding quadrupole excitation current. A least square fit was performed to obtain the two-dimensional beam shape before the quadrupole.

For several measurements of the beam shape, the fits had to be redone with different parameters to achieve an acceptable result. The algorithm to automatically determine the

fit range is not yet stable enough and should be further improved. Another issue is that the fit of the beam matrix parameters as shown in Fig. 8 does not work out for all beam adjustments upstream the quadrupole. Sometimes the resulting numerical errors after this step became very large due to unfavorable proportions of the beam in phase space. However in the overall picture, the automatized method was successful. At the S-DALINAC, the following geometric emittances were measured using the previously described CSS interface.

$$\epsilon_x = 0.45(4) \pi \text{ mm mrad} \quad (4)$$

$$\epsilon_y = 0.51(9) \pi \text{ mm mrad} \quad (5)$$

## CONCLUSION

The main achievement of this work is the development of the automatized emittance measurement. Several series of measurements were gathered this way. A seamless transition to normal beam operation is possible. The way this method was implemented allows to install further wire scanners at other locations and use them simultaneously.

Before more wire scanners are produced, another test of the existing method in the high energy region of the S-DALINAC is proposed. Furthermore, a change in design of the head of the wire scanner (see Fig. 3) is suggested. Currently, the wires are taut in a closed frame which passes the beam in every run. A fork would be better suited.

The S-DALINAC will be undergoing several changes in its layout [5]. A third recirculation is expected to be installed in the following months. In the course of this reconstruction, some space for wire scanners will be reserved.

## REFERENCES

- [1] A. Richter, Operational Experience at the S-DALINAC, Proc. of EPAC 1996, Bristol.
- [2] C. Burandt et al., The EPICS-based Accelerator Control System of the S-DALINAC, Proc. of ICALEPCS 2013, San Francisco.
- [3] Y. Poltoratska et al., Status and recent developments at the Polarized-Electron Injector of the Superconducting Darmstadt Electron Linear Accelerator S-DALINAC, J.Phys.: Conf. Ser. 298 (2011) 012002.
- [4] L. Jürgensen et al., A Low Energy Electron-Scrapersystem for the S-DALINAC Injector, Proc. of IPAC 2014, Dresden.
- [5] F. Hug et al., Operational Findings and Upgrade Plans on the Superconducting Electron Accelerator S-DALINAC, Proc. of PAC 2011, New York.
- [6] C. Eckardt et al., Wire Scanners for Emittance Measurements at the 100 keV Spin Polarized Electron Beam Line at the S-DALINAC, Proc. of BIW 2012, Newport News.
- [7] H. Wiedemann, Particle Accelerator Physics, Springer-Verlag Berlin Heidelberg, 2007.