BEAM DYNAMICS SIMULATIONS AT THE S-DALINAC FOR THE OPTIMAL POSITION OF BEAM ENERGY MONITORS*

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Abstract

The Superconducting Darmstadt Linear Accelerator (S-DALINAC) is a 130 MeV superconducting recirculating electron accelerator serving several nuclear and radiation physics experiments as well as driving an infrared free-electron laser. For the experiments an energy stability of 10^{-4} should be reached. Therefore noninvasive beam position monitors will be used to measure the beam energy. For the measurement the differences in flight time of the electrons to the ideal particle are compared, that means in the simulations the longitudinal dispersion of the beam transport system is used for the energy detection. The results of the simulations show that it is possible to detect an energy difference of 10^{-4} with this method. The results are also verified by measurements.

INTRODUCTION

A detailed discussion of the layout and the properties of the recirculating superconducting electron accelerator S-DALINAC is given in [1] and in Fig. 1. The electrons are emitted by a thermionic gun and then accelerated electrostatically to 250 keV. A normal conducting 3 GHz chopper-prebuncher system creates the required 3 GHz time structure of the beam. The superconducting injector linac consists of one 2-cell cavity ($\beta = 0.85$), one 5-cell cavity ($\beta = 1$) and two 20-cell cavities operated at 2 K. Behind the injector the electron beam with a maximum energy of 10 MeV can either be directed to a first experimental site or it can be injected into the main linac. There, eight 20-cell cavities provide an energy gain of up to 40 MeV. The beam can be extracted to the experimental hall or it can be recirculated one or two times. The beam energy after three passes through the linac can reach a maximum of 130 MeV. The experimental hall is shown in Fig. 2. The beam transport system leads to three experimental sites, to the high-energy experimental site (E5), to the QCLAM spectrometer (E3), and to the energy-loss spectrometer (E4). The energy should be measured in this part of the S-DALINAC because the energy stability is important for the experiments.

The dynamic of accelerated and charged particles in electromagnetic fields is complicated. For a successful operation a steady beam diagnostic is necessary. The beam diagnostic is needed for the adjustment and operation of an accelerator to reach the desired beam parameters for the experiments. Therefore noninvasive beam monitors are used

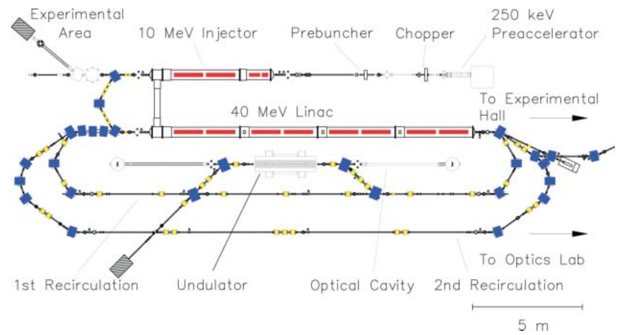

Figure 1: Accelerator Hall of the S-DALINAC

because beam parameters can be detected even during operation. The parameters 'intensity' and 'position' of the beam are measured with noninvasive beam monitors at the S-DALINAC, as described in [2]. This beam monitor consist of two rf-resonators, one is designed for the TM_{010} mode (intensity) and the other for the TM_{110} mode (position). In the following the intensity monitor is used for a noninvasive beam energy measurement for detecting an energy spread of the order of 10^{-4}. The principle of different flight time between real and ideal particle will be used. To realize that principle, a dispersive section has to be enclosed by two beam monitors. The first monitor serves as a reference monitor to the second one. From the phase difference between these two monitors one is able to get the flight time difference.

METHODS

For the beam calculation, XBEAM is used which is based on the program TRANSPORT [3] with the same matrix formalism [4, 5]. The energy measurement should be placed in the extraction section of the S-DALINAC, shown in Fig. 2.

The general conditions for the simulations are that the beam is free of divergence after the $40°$-system, especially necessary for the energy-loss mode. Also full transmission is wanted. Therefore the beam has to be divergence free after the bending magnet E1BM02 because the $40°$-system itself is divergence free and for the energy-loss mode the setting of all beam optics are defined. So there are four quadrupoles for the adjustment of the beam as labelled in Fig. 2.

The flight time difference is given by the phase difference

$$\Delta t = \frac{\Delta\varphi}{360°}T = \frac{\Delta\varphi}{360° f}. \tag{1}$$

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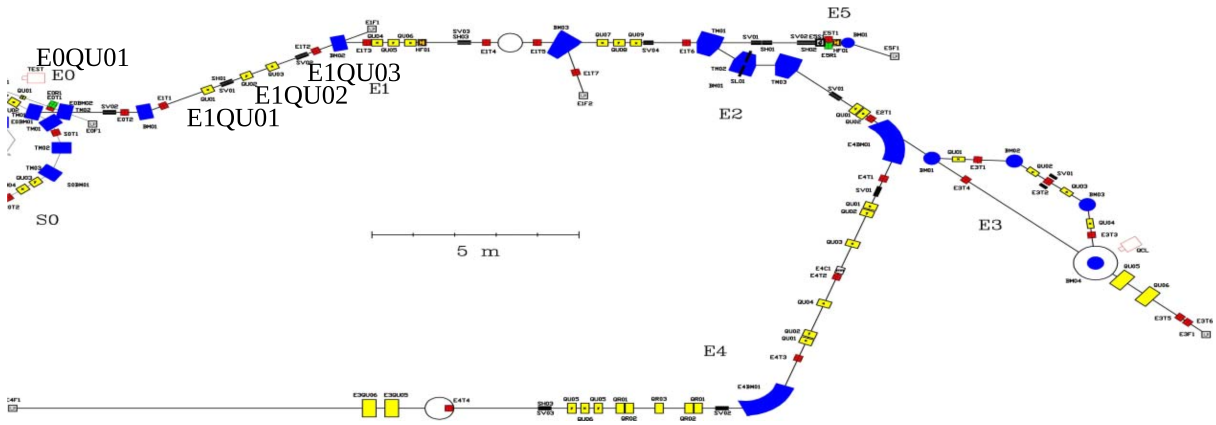

Figure 2: Extraction of the S-DALINAC: E0 Ejection, E1 Beam Optics, E2 $40°$-System, E3 QCLAM Spectrometer, E4 Energy-Loss Spectrometer, E5 High Energy Experimental Site.

Thereby, T denotes the cycle duration and f the frequency of the beam. To compare the simulation results with the measurement one has to convert the longitudinal dispersion R_{56} given in $\mathrm{mm}/\%$ to $\varphi/\frac{\Delta E}{E}$ in $^\circ/10^{-4}$:

$$\frac{\varphi}{\Delta E/E}\left[\frac{^\circ}{10^{-4}}\right] = R_{56}\left[\frac{\mathrm{mm}}{\%}\right]\frac{360^\circ}{100\ \mathrm{mm}}\frac{1}{100}. \qquad (2)$$

Thus, 100 mm is the wavelength of the beam that matches a full circle of $360°$.
The measurement set up is shown in Fig. 3. Equivalently to the simulation results, the results of the measurements have to be converted from the output signal given in mV to $^\circ/10^{-4}$. Whenever the ideal energy is known, the energy and phase difference can be retrieved from the measurement. One knows that 11 mV is equivalent to $1°$ from the electronic specification. So one has all data to calculate the needed phase difference for the detection of an energy spread of 10^{-4}.

RESULTS

In this section the optimal result of the simulations will be presented at first. In a second step it is shown that the results of the simulation can be reproduced by the measurements.

Simulation

The simulations show that a few adjustments of the beam optics satisfy the general conditions. Also one gets a serious blow-up in the x-direction for the actual extraction if one wants to have an dispersive free beam before the $40°$-system. So one has to find a compromise between the measure sensitivity and transmission. The setting of the four quadrupoles in the optimal case are listed in Table 1.
In the optimal adjustment, the beam gets a blow-up of a factor 6 in x-direction. In Fig. 4 one sees the dispersion of

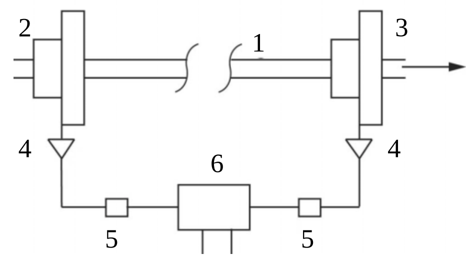

Figure 3: Set Up of the Energy Measurement: 1. Beam Tube, 2. Reference Monitor, 3. Measurement Monitor, 4. Amplifier, 5. Microstrip Filter, 6. Gain/Phase Detector.

quadrupole	E1QU01	E1QU01	E0QU02	E1QU03
field gradient (T/m)	-0.745	3.787	-3.558	5.007

Table 1: Setting of the four Parameters in the optimal case

the beam optics between the ejection and the $40°$-system. The longitudinal dispersion R_{56} is $6.0\ \mathrm{mm}/\%$. So one has to measure a phase difference of $0.22°$ between the two monitors to reach an accuracy of 10^{-4}.

Measurement vs Simulation

For a verification of the simulation results measurement and simulations are compared. All important results of the measurement are listed in Table 2.

The average result of the measurement is that a phase difference of $0.291°$ is detected to reach an accuracy of 10^{-4}. One has to say that in the measurement the general conditions for the ideal case are not realized.
In the fitting simulation you get $0.29°/10^{-4}$ as shown in Fig. 5. Also one sees that the beam is not dispersion free so one has a variation of the settings.

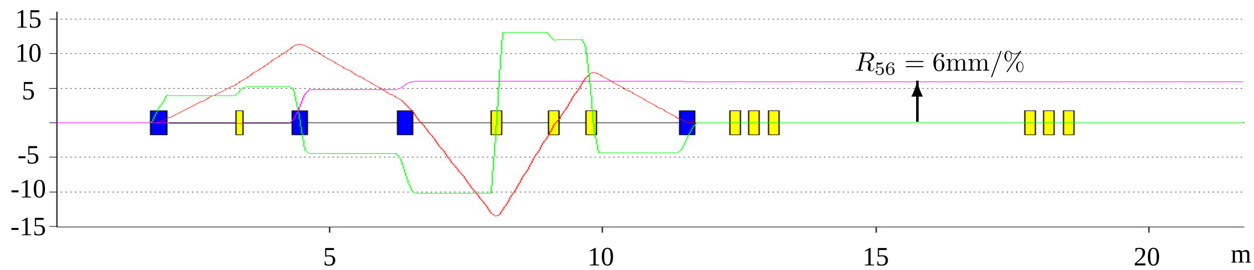

Figure 4: XBEAM Simulation: Dispersion R_{16} (red) in $\mathrm{mm}/\%$, R_{26} (green) in $\mathrm{mrad}/\%$ and R_{56} (purple) in $\mathrm{mm}/\%$

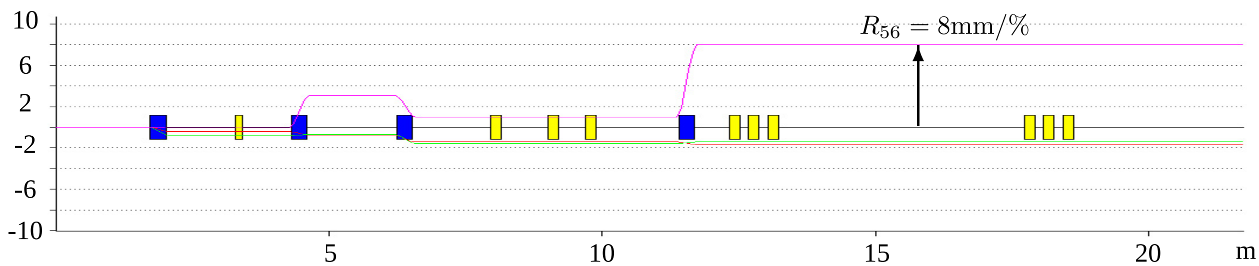

Figure 5: XBEAM Simulation: Dispersion R_{16} (red) in $\mathrm{mm}/\%$, R_{26} (green) in $\mathrm{mrad}/\%$ and R_{56} (purple) in $\mathrm{mm}/\%$

Table 2: Result of the Measurement for the ideal energy of 23.1 MeV

Energy (MeV)	Phase (mV)	Phase/relative Energy ($°/10^{-4}$)
22.903	14	1.3/3.896
22.912	23	1.2/3.463
22.920	25	1.4/3.463
22.928	12	1.1/3.896
22.937	13	1.2/3.463
22.945	12	1.1/3.463
22.953	12	1.1/3.463
22.961	13	1.2/3.896
22.970	03	0.3/3.463
22.978	06	0.55/3.463

As one can see, the results of the simulation and of the measurement fit together:

$$\mathrm{Sim.} = 0.29°/10^{-4} \simeq 0.291°/10^{-4} = \mathrm{Measure.} \quad (3)$$

These optimal settings can be used because the beam monitors and the electronic equipment are able to detect a phase difference down to $0.2°$.

CONCLUSION

In this work an optimal position for two beam monitors in the extraction part of the S-DALINAC is found for the energy measurement. The expected metering precision from the simulation can be confirmed by measurement. In the actual design of the S-DALINAC extraction one optimal setting is possible and presented in this paper. A big advantage of this setting is that only two beam monitors are used for all three experimental sites in the extraction. Also in this setting the costs for electronic equipment are low because the smallest possible distance between both beam monitors can be used and the electronic equipment is cheap and easy.

Due to the difficulties during the measurement by using the two recirculations to get a dispersion free beam for the energy-loss mode a changing of the ejection without a big deal is thought.
First simulations show that one can reach a better measurement sensitivity of the beam and a bigger acceptance for the beam transport system if you change a little at the ejection design. In further investigations this aspect has to be looked on in more detail. Based on the results that you can detect the energy spread of 10^{-4} in this form, an rf-control system will be established.

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