BEAM BASED ALIGNMENT SIMULATIONS AND MEASUREMENTS AT THE S-DALINAC*

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Abstract

Operational Experience at the Darmstadt superconducting linac (S-DALINAC) showed unexpected effects on beam dynamics and beam quality. So operators could observe transverse beam deflections by changing phases of the SRF-Cavities. Furthermore there has been occurred a growth of normalized tranverse emittance by a factor of 2. The beam current in the S-DALINAC does not exceed 60 µA so space-charge effects could be eliminated to be the reason for the observations. In this work the effect of misalignment of the SRF-Cavities in the linac has been examined using beam-dynamic simulations with the tracking code GPT and measurements on the electron beam of the S-DALINAC. By measuring the transverse deflection of the beam by changes of the phases of the SRF-Cavities and comparing results with GPT-simulations a misalignment of the 5-cell capture cavity and first 20-cell cavity of several mm in both transverse directions could be found. This misalignment can explain transverse deflections as well as emittance growth. A correction of misalignment has been carried out using the described results. First measurements showed no more emittance growth and less beam-deflections by SRF-Cavities.

INTRODUCTION

The recirculating superconducting Darmstadt electron linear accelerator (S-DALINAC) was first put into operation in 1987 [1]. It operates at a frequency of 2.9975 GHz and consists of twelve superconducting cavities with a design accelerating gradient of 5 MV/m. The electron beam leaves the thermionic gun with an energy of 250 keV and gets bunched before it enters the injector. The injector consists of two capture-cavities with two and five cells and two 20-cell cavities to reach a maximum energy of 10 MeV. After having passed the injector the electrons can be used for low energy experiments or be bent into the main linac consisting of eight 20-cell cavities with a maximum energy gain of 40 MeV. The main linac can be passed three times using the recirculating paths to reach the maximum design energy of 130 MeV. The beam then can be transferred to several experiments in the adjacent experimental hall. The layout of the accelerator is shown in Fig.1.

In this paper we will report on simulations and measurements concerning the injector. During operation two unexpected effects have been observed. First observation is a transverse deflection of the electron beam when changing the accelerating phases of the injector cavities. As changes of the phase change the electric field seen by the electrons as well an influence on beam energy and energy spread would be expected but no transverse deflection of the beam. This deflection makes commissioning of the beam much more difficult for the operators. The second observation is a growth of normalized transverse emittance of the beam by a factor of 2 comparing measurements in front of and behind the injector. As beam currents in the S-DALINAC do not exceed 60 µA space charge effects can only explain an emittance growth of about 1%.

Due to these observations a misalignment of SRF-Cavities has been assumed to be the reason for the transverse deflection of the beam as well as for the emittance growth in the injector. Because there is no possibility to check the exact position of the five-cell capture cavity inside its cryostat module we used the method of beam based alignment [2] to check and correct misalignment of the SRF cavities in the injector.

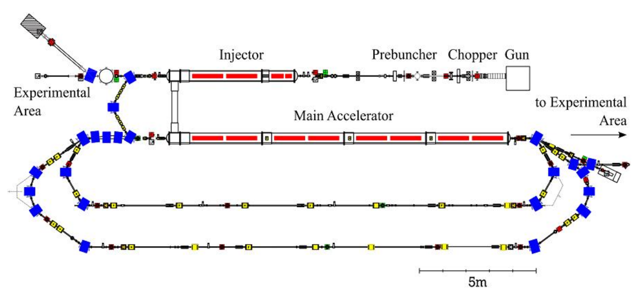

Figure 1: Floor plan of the S-DALINAC.

MEASUREMENTS

First the injection into the five-cell capture cavity (#1) had to be adjusted properly by using correction steerers (S1,S2). (See Fig.2 for a detailed view on the injector devices used in the measurements described here.) These steerers have been varied until the cavity did not deflect the beam any more with changes of the RF-phase. This is the expected behaviour for a well aligned cavity. Behind the injector a bending magnet (B) with a Hall-probe was used for checking beam energy and for finding the correct RF-phase for the prebuncher and the capture cavity. Second the first 20-cell cavity (#2) have been put into operation and the steerers inside the injector (S3) have been adjusted like described before. Different to the injection into the capture cavity it was not possible to find an injection into cavity #2 with no deflection of the beam by changes of the RF-phase. In the next step the RF-phase of this cavity has been changed over a wide range and the position of the beam for different values of the RF-phase have been located on a BeO-target (T). (See Fig.3) In a further step the second 20-cell cavity (#3) have been put

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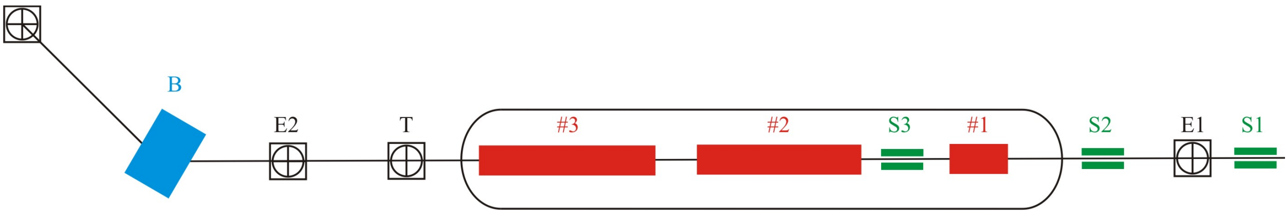

Figure 2: Shematic view of the injector. Devices used in the described measurements are steerers (S1-S3, green), SRF-cavities (#1-#3, red), a bending magnet with corresponding target for energy determination (B, blue), a BeO target (T, black) and positions for emittance measurements (E1, E2, black). The beam enters this section from the right side.

into operation and the same procedure have been carried out once more. As this cavity showed no beam deflection it is assumed that the alignment of the two 20-cell accelerating cavities is correct. These two cavities are built into one cryostat module and share one supporting bench so a misalignment is unlikely possible. The last measurements carried out were emittance measurements in front of (E1) and behind the injector (E2). The results are shown in Tab.1. The growth of transverse emittance from position E1 to E2 exceeds a factor of 2 like it was mentioned already above.

Table 1: Emittance measurements in front of (E1) and behind the injector (E2).

Position	**Beam energy [keV]**	ε_{nx} **[π mm mrad]**	ε_{ny} **[π mm mrad]**
E1	250	0.35	0.17
E2	5710	0.9	0.4

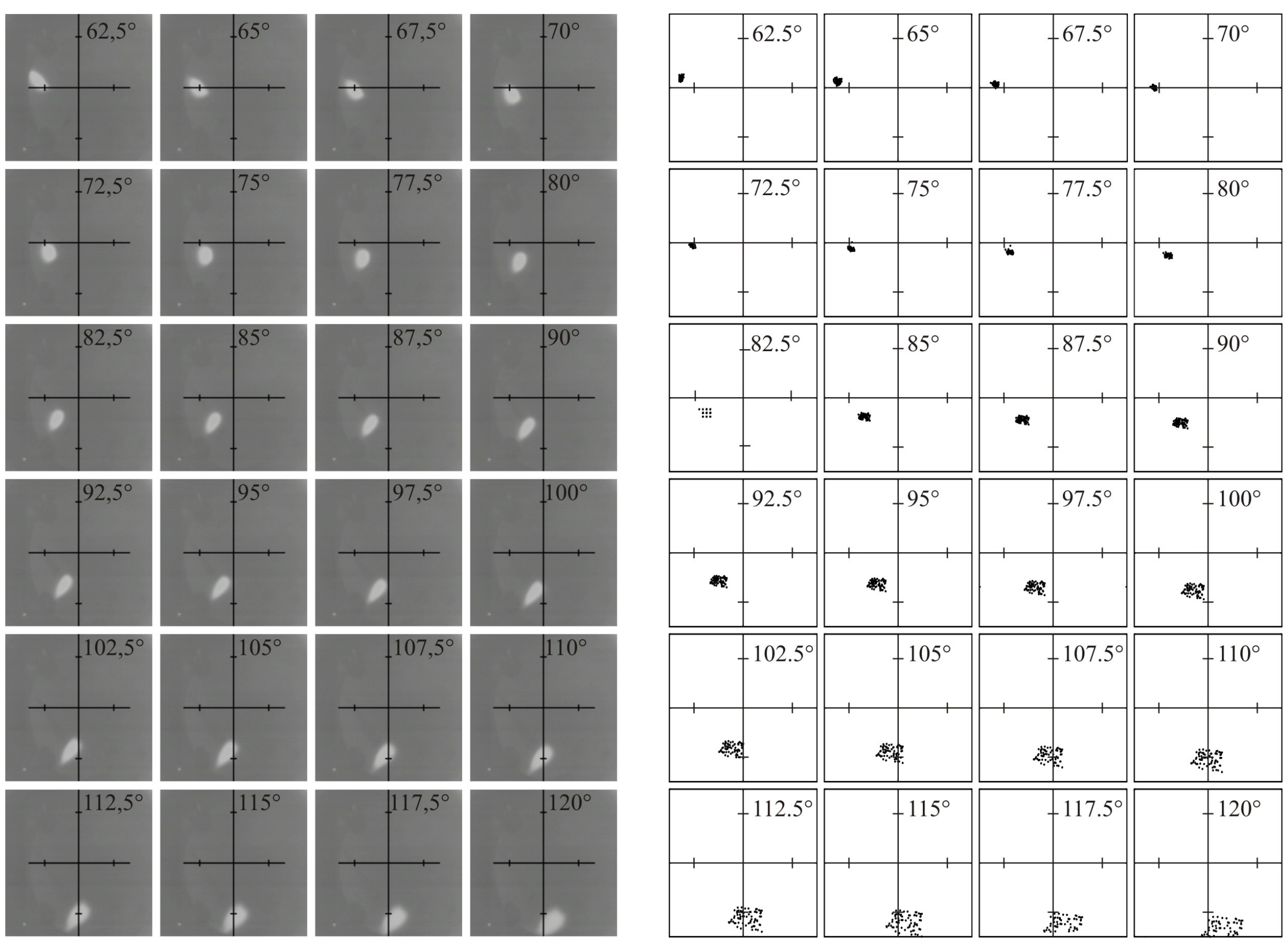

Figure 3: Measurement (left) and GPT-simulation (right) of the transverse position of the electron beam on the BeO target (T) for different RF-phases of cavity #2. The tics on the axes mark 1 cm.

SIMULATIONS

Subsequent to the measurements simulations of beam dynamic in the injector have been carried out. For the simulations the tracking program “General Particle Tracer (GPT)” was used. This tracking code allows free positioning of any device used which is helpful for simulations of misalignment.

First simulations have been run without misalignment of any device finding the right settings of amplitudes and phases of every device used in the injector and reproduce the same energy gain per cavity used in the measurements. In these runs also the effect of space charge on the beam quality was analyzed. Space charge effects enlarge the emittance of the beam only about 1% and so were not longer taken into account for further simulations to save simulation time.

After the on axis simulations a misalignment of the capture cavity (#1) and the first 20-cell cavity (#2) was set to different values. The positioning failure has been varied in steps of 0.5 mm. For every misaligned position of cavity #2 the RF-phase was changed in the same way like described in the measurements (phase steps of 2.5 °) and the transverse position of the beam at the target was saved for every RF-phase value. These positions were compared to the measured ones and the run with best reproduction of the measurement was identified. Fig. 3 shows a printout of the simulated positions beside to the measurement for the best run. As it can bee seen, the measurement could be reproduced well by the simulation. The misalignment is calculated to 7 mm in horizontal and -6.5 mm in vertical direction. The resulting emittance using this misalignment in the simulation is shown in Tab.2. A growth of transverse emittance in the injector occurred in the simulations like it was seen before in the measurements.

In summary simulations have shown the same effects observed in the measurements when taking misalignment into account. In addition it was possible to quantify the magnitude of the misalignment of the first two cavities in the injector.

Table 2: Simulated transverse emittance in front of (E1) and behind the injector (E2).

Position	Beam energy [keV]	ε_{nx} [π mm mrad]	ε_{ny} [π mm mrad]
E1	250	0.28	0.16
E2 without misalignment	5170	0.28	0.16
E2 with misalignment	5710	0.54	0.27

CORRECTION OF MISALIGNMENT

The described results were used to correct the misalignment of the first two cavities. For changing the positions of the cavities their cryostat modules had to be moved completely but not to be opened or dismounted. Afterwards measurements in the same way like described before have been carried out following simulations with GPT again. These measurements showed a correct horizontal alignment but in vertical direction still some corrections were necessary because the beam was still deflected by cavity #2 vertically with changes of its RF-phase. A measurement of transverse emittance showed a growth in vertical direction which was less than observed before and a constant value in horizontal direction (Tab.3). So the good alignment in horizontal direction after correction is approved also by this measurement.

Table 3: Emittance measurements in front of (E1) and behind the injector (E2) after first correction of misalignment.

Position	Beam energy [keV]	ε_{nx} [π mm mrad]	ε_{ny} [π mm mrad]
E1	250	1.7	0.74
E2	5710	1.7	1.23

In a second correction step the vertical alignment has been corrected again. First observations show no more deflection of the beam by RF-phase changes in the injector. An emittance measurement has to be carried out soon to verify the correct alignment.

SUMMARY AND OUTLOOK

Misalignment of SRF-cavities can explain the effects of transverse deflection of the beam by cavities and emittance growth during the first accelerating section in measurements as well as in simulations. The positioning error could be quantified and corrected without needing to dismount the cryostat.

The method of beam based alignment allows to check the alignment of SRF-cavities in the injector of the S-DALINAC by measuring beam properties and comparing them to simulations with a tracking code. It has been tested successfully at the injector and can be used in future at any place of the accelerator where a check of alignment may be useful.

REFERENCES

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[2] P. Tenenbaum et al., “Beam Based Alignment of the TESLA Main Linac”, EPAC '02, Paris (2002) 515.
[3] General Particle Tracer, Version 2.6; http://www.pulsar.nl/gpt.