CONSTRUCTION OF A THIRD RECIRCULATION FOR THE S-DALINAC*

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Abstract

The maximum energy of the S-DALINAC will be increased by adding a recirculation beam line and thus recirculating the beam an additional time. All necessary simulations of magnets as well as beam dynamics are finished and summarized. The set-up of the new beam line offers a phase shift of up to 360° and enables to run the S-DALINAC as an once or twice recirculating ERL.

INTRODUCTION

The S-DALINAC is a superconducting electron linear accelerator running since 1991 at TU Darmstadt [1]. It was constructed as a twice-recirculating accelerator with a maximum energy of 130 MeV in cw operation. For a reliable and stable beam operation only 85 MeV (cw mode) were possible due to a lower quality factor of the superconducting cavities than previously anticipated and thus a higher dissipated power to the helium bath. Recirculating the beam an additional time together with lowering the design accelerating gradients from 5 MV/m to 3.75 MV/m will increase the maximum achievable energy close to 130 MeV in cw mode. A floorplan of the three times recirculating S-DALINAC is shown in Fig. 1. The beam is either produced in a thermionic gun with an electrostatic pre-acceleration of 250 keV or in SPIN (S-DALINAC Polarized INjector) - a source for polarized electrons with a pre-acceleration of up to 125 keV [2]. Following both sources the beam is prepared for an acceleration with a time-structure of 3 GHz in a chopper-prebuncher section. In case of a recirculating set-up the beam then is accelerated up to 7.5 MeV in the injector linac. Afterwards it is bend into the main linac with an acceleration of up to 30 MeV per pass. Recirculating the beam up to three times leads to a final energy of up to 130 MeV. Nuclear physics experiments can be performed either with the injector beam at 10 MeV or the main linac beam. In the recirculating operation a maximum beam current of 20 μA can be reached. The transformation from a twice to a three times recirculating set-up required several simulations. In a first step the most important dipoles, the separation and recombination dipole magnets, had to be designed. Additionally six new dipoles for a new beam line were needed. Simulating the whole lattice with all adaptions to new requirements was an important task as well. As the installed pathlength adjustment system of the new second recirculation can move in total a complete RF wavelength of 10 cm, it will enable an energy recovery linac test operation in once or twice recirculating scheme.

NEW DIPOLE MAGNETS

Extending the S-DALINAC by one recirculation resulted in the need of new dipole magnets. Replacing existing magnets as the separation and recombination dipoles to fit an additional beam line and strict border conditions were initial points. Furthermore the new beam line had to be equipped with dipole magnets. Both magnet models will be introduced and their positions are indicated in Fig. 1.

Separation Dipole

The new separation dipole magnet and its mirrored version, the recombination dipole, are very complex and demanding magnets. They must fit several conditions on very limited space. Bending four different beams at the same time the separation dipole is additionally a very important magnet of the S-DALINAC. Its main parameters are shown in Table 1. The designed magnetic flux is 0.75 T (0.65 T for 130 MeV) with a pole gap of 30 mm. During their design the magnetic flux inside the yoke as well as the particle tracking of all different beams have been simulated with CST [3]. Furthermore the multipole components along all beam orbits have been investigated. Having a very small width of the yoke at the exit area guaranteeing a good homogeneity of the magnetic field was a challenging task. To ensure the best magnetic field distribution additional shimming was placed in between the beams. A photograph of the installed separation dipole is shown in Fig. 2.

Table 1: Design Values of the Separation Dipole with Beam Energy E, Bending Radius ρ, Bending Angle α, Magnetic Entrance and Exit Wedge Angle $\psi_{1,2}$

E in MeV	**ρ in mm**	**α in °**	**ψ_1 in °**	**ψ_2 in °**
38.25	189.7	60.000	14.82	-11.87
68.85	341.4	45.000	14.13	-21.40
99.45	493.2	35.035	13.88	-10.25
130.05	644.9	27.000	13.75	4.69

45° Dipole

The new recirculation beam line is placed in between the two existing ones. The bending angles were chosen to eight times 45°. Together with the separation and recombination dipole this leads to six 45° dipoles whose parameters are listed in Table 2. The nominal magnetic flux was set to 0.61 T (maximum magnetic flux of 0.7 T) with a pole gap of 30 mm. In comparison to the separation dipole the 45° dipole is a quite simple one. There are no hard conditions to the magnetic parameters and especially no constraints in space. Setting the bending angle to 45° was the best choice to optimize the usage of remaining space in both arc

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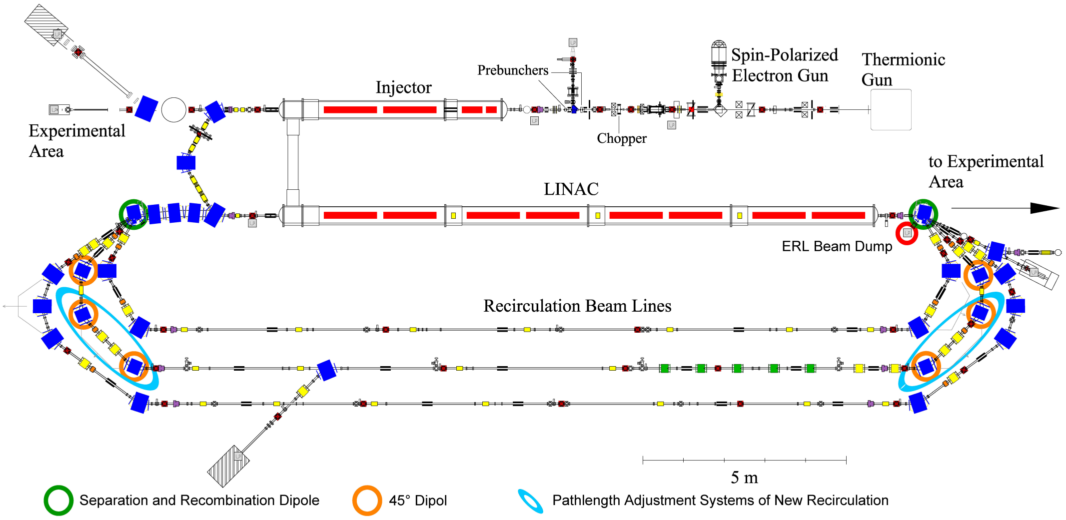

Figure 1: Floorplan of the S-DALINAC with three recirculations in the final set-up. The positions of all new dipoles as well as the ERL beam dump and both new pathlength adjustment systems are indicated.

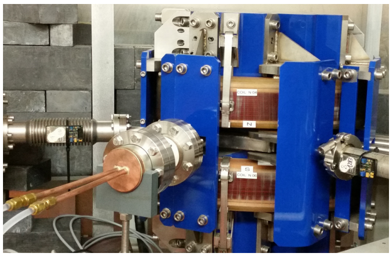

Figure 2: The separation dipole in its final position. On the left hand side the ERL beam dump is mounted on an insulator and the vacuum chamber.

Figure 3: On of the six 45° dipoles is shown on its final position in the first arc.

sections for a new beam line. Choosing 17° as entrance and exit wedge angles ensured a smooth result in beam dynamics simulations. A photograph of one of the installed 45° dipoles is shown in Fig. 3.

Table 2: Design Values of the 45° Dipole with Beam Energy E, Bending Radius ρ, Bending Angle α, Magnetic Entrance and Exit Wedge Angle $\psi_{1,2}$

E in MeV	**ρ in mm**	**α in °**	**ψ_1 in °**	**ψ_2 in °**
68.85	376.5	45.000	17.00	17.00

BEAM DYNAMICS

Another main pillar of the design was the beam dynamics simulations. On the one hand side a lattice of a complete new beam line needed to be designed. On the other side the existing lattice must be adapted to all new boundary conditions. For simplifying the design it is very important that in case of a horizontally deflecting accelerator the transversal dispersion as well as the angular dispersion vanish after each arc-section. The longitudinal dispersion (r_{56}) depends on the accelerator mode. In case of an isochronous operation r_{56} must be zero. Running the S-DALINAC in non-isochronous mode [4] leads to a non zero longitudinal dispersion. A working point is defined through a combination of a suitable r_{56} together with a change in the main linac RF phase. Optimizing the working point requires a linear behavior of the quadrupoles in all arc sections which is another constraint to the simulations. Setting the operation mode to a non-isochronous scheme increases the energy-resolution significantly. Figure 4 shows a first start-to-end simulation beginning behind the injector linac until one of the experiments in the experimental area. The beam is recirculated three times and the 1-σ envelope is presented for x- and y-direction. The beam dynamics was simulated with xbeam [5] (a matrix based code up to first order) and *elegant* [6]. Using a laser tracker for the alignment ensures a high precision implementation of the whole lattice [7].

ENERGY RECOVERY LINAC OPTION

All recirculations of the S-DALINAC have a capability to change their total length. This change is done by moving dipoles along their axis. Both former beam lines can be adjusted by a fraction of a RF wavelength of 10 cm to find an optimum for re-entering the main linac on the correct

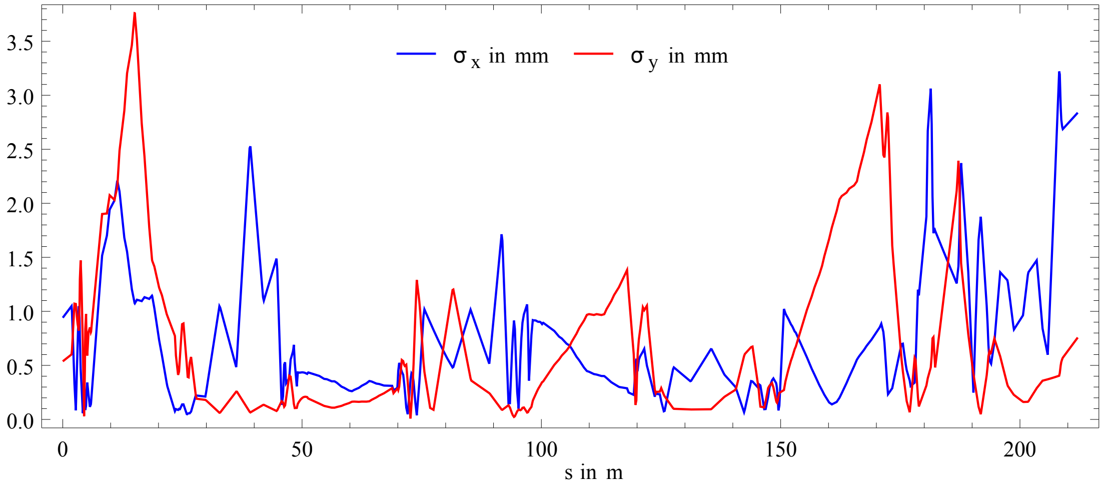

Figure 4: Simulating the whole lattice from behind the injector linac to an experiment in a three times recirculating set-up yields to the shown start-to-end simulation done with *elegant* [6]. The 1-σ envelope along the beam line in x- and y-direction is presented and still in progress to be optimized.

phase. The new beam line was designed in a way, that a change of a full RF wavelength of 10 cm is possible. Due to the large but necessary dipole movements the system was split up and installed in both arcs (see Fig. 1). Changing the phase by up to 360° the new beam line is capable to shift the bunches from an accelerating do a decelerating phase. This system allows to operate the S-DALINAC as an once or twice recirculating ERL test facility. In the once recirculating case the beam first is accelerated in the main linac before it is deflected into the second recirculation. The corresponding pathlength adjustment systems are tuned to enable a phase shift of 180°. The beam re-enters the main linac on an decelerating phase. Passing the main linac the beam exits with injection energy and is stopped in the ERL beam dump (see Fig. 1). The elements are shown in Fig. 5. Choosing a twice recirculating ERL operation is also possible. The first acceleration in the main linac is identical with an once recirculating ERL case. But now the beam is injected into the first recirculation which pathlength is optimized to match the beam on an accelerating phase. Traveling a second time through the main linac the beam is accelerated even further. Now the separation dipole bends the beam into the second recirculation with a pathlength setting for ERL operation. Passing through the main linac the beam loses energy and is deflected a second time into the first recirculation. The pathlength of the first recirculation fits so that the beam enters the main linac on a decelerating phase again and is stopped in the ERL beam dump.

CONCLUSION AND OUTLOOK

This complex and demanding modification of the S-DALINAC started in autumn 2015 and is one year later close to its finalization and commissioning. During the commissioning recirculating up to three times will be investigated as well as an ERL test operation. Beginning of 2017 the S-DALINAC will continue performing nuclear physics experiments.

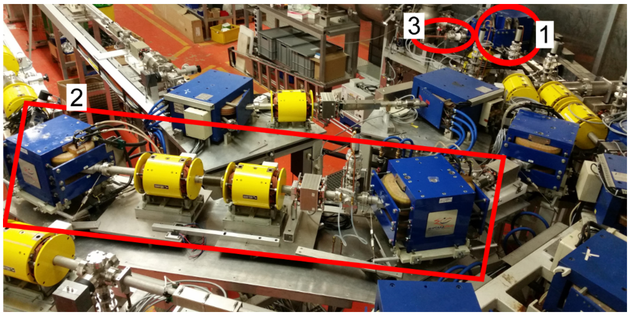

Figure 5: This photograph shows the first arc section of the S-DALINAC. The beams are bend by the separation dipole (1). In case of an ERL mode the pathlength adjustment system of the second recirculation causes a phase shift of 180°. The system in the new beam line is split up into both arcs (2: system of first arc). After the deceleration to injection energy the beam is stopped in the ERL beam dump (3).

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