FINAL DESIGN AND STATUS OF THE THIRD RECIRCULATION FOR THE S-DALINAC*

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Abstract

A recent upgrade of the S-DALINAC resulted in the addition of a new recirculation beam line. The new separation dipole was designed during the preparation phase. The dipole bends the different beams energy-dependent into the various recirculation beam lines. The beam dynamics for the whole lattice was calculated and optimized with respect to strict boundary conditions and limited space. The adaption of the beam line as well as infrastructural work are nearly done. The end of the modification phase will be a series of tests and a fine alignment of all beam line elements. The new set-up enables the operation as energy recovery linac.

INTRODUCTION

Since 1991 the twice-recirculating superconducting accelerator S-DALINAC is providing electron beams for nuclear physics experiments [1]. Due to a reduced quality factor of its cavities in comparison to their design values it was not possible to operate the accelerator with its maximum design energy of 130 MeV in cw mode. To provide electron beams of this energy in the future it was decided to add one recirculation beam line in order to use the main linac four times, operating the cavities on decreased accelerating gradients. The electron beam is produced either in a thermionic gun with a pre-acceleration of 250 keV or in a source for spin-polarized electrons with a pre-acceleration of up to 125 keV [2]. The beam gets the necessary time structure for an acceleration with 3 GHz by passing a chopper and prebuncher section. Afterwards the electron bunches pass through a superconducting injector linac which accelerates the beam in case of a recirculating operation of the S-DALINAC up to 7.65 MeV. In the recirculating setting the beam is then bend into the main linac which increases the energy up to 30.6 MeV per pass. The main linac can be used once, twice or four times. In total this could lead to a maximum beam energy of 130.05 MeV with a beam current of up to 20 μA. The actual floorplan of the S-DALINAC is shown in Fig. 1. The transformation from a twice recirculating S-DALINAC to a three times recirculating setting required not only the installation of new elements. In addition the existing layout had to be adapted to the changes in the lattice. Nevertheless a few new magnets were needed. The most important one is the separation dipole with its mirrored version, the recombining dipole. A short presentation of this dipole magnet is given below. Furthermore six 45 ° dipole magnets, quadrupole magnets and several other elements are important for setting up a new recirculation. To ensure a perfect alignment of the whole lattice different adjustment phases are necessary. In a first step the measurement system was defined and coarse positions of all magnets were marked [3]. During the construction phase the positions have been checked and corrected if necessary. Finally a fine alignment will follow.

* Work supported by DFG through CRC 634 and RTG 2128
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Energy Recovery Linac Option

Each recirculation beam line offers the possibility to adjust the distance traveled by the beam between the exit of the last linac cell and the beginning of the first linac cell. In case of a conventional linac mode the total pathlength of the recirculation is set to a multiple of the rf wavelength of 10 cm to achieve optimal acceleration in the main linac. The pathlength adjustment systems of the two preexisting recirculations are placed in one arc of two for each of the beam lines. These recirculations are capable of changing the total pathlength only by a fraction of 10 cm. As all beam lines are positioned in a way that the pathlengths meet the recirculation condition, the two preexisting systems fit well their task to enable small changes around the ideal positions for setting a perfect working point. The new beam line enables a pathlength adjustment of 5 cm per arc, 10 cm in total. This system allows a phase shift of up to 360 ° for the beam. If we tune the pathlength adjustment system to a phase shift of 180 ° the bunches will re-enter the main linac on the decelerating phase so that they will give most of their energy back to the fields in the cavities. As an example for this system the first arc is shown in Fig. 2. The new set-up of the S-DALINAC enables a single- or double-turn energy recovery linac (ERL) operation. After passing the main linac the first time the beam is either directly bend into the second recirculation or into the first recirculation with further acceleration and enters later the second recirculation. In both cases the phase shift of 180 ° is done in the second recirculation so that the following main linac pass will be a decelerating one. If the beam was directly shot in the second recirculation it will leave the main linac with injection energy. If the beam was twice-recirculated and accelerated it will be twice decelerated after the 180 ° phase shift and leave the main linac with injection energy. The decelerated beam with up to 7.65 MeV will be finally deflected by the separation dipole and dumped, see Fig. 2.

BEAM DYNAMICS

The whole lattice of the S-DALINAC had to be simulated with all the changes in the beam lines and, of course, with the new recirculation path. These simulations must fulfill certain conditions, for example a small beam envelope which will

ISBN 978-3-95450-147-2

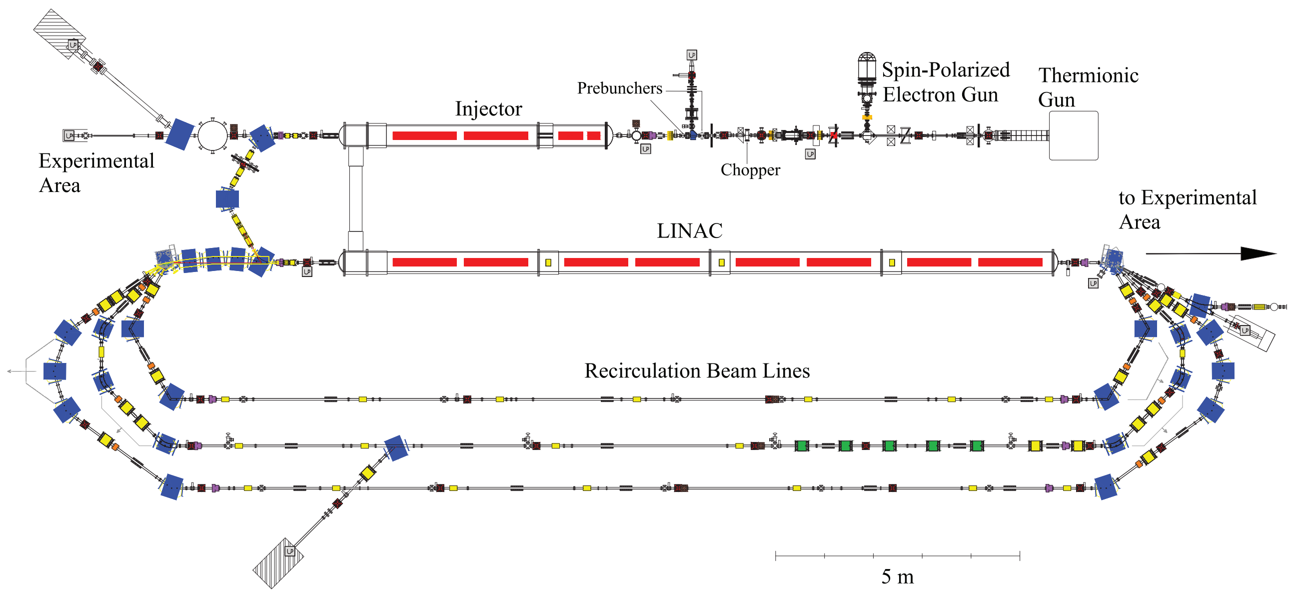

Figure 1: Floorplan of the S-DALINAC with three recirculations.

fit the beam tube at every point. Other important points are the different dispersion curves. The S-DALINAC deflects the beam only in the horizontal plane. To simplify beam adjustments, all arcs are operated in such a way, that the transversal and the angular dispersion vanish after passing of an arc. The longitudinal dispersion is set either to 0 $mm/\%$ or to a value $\neq 0$ $mm/\%$ which changes the operation mode of the S-DALINAC from an isochronous to a non-isochronous scheme if the rf phase is changed in a demanded manner [4]. To achieve a perfect working point it is necessary to have a linear dependence of the gradients of the quadrupoles in the arcs and of the resulting longitudinal dispersions. The simulation of the beam dynamics was done with XBeam [5] - a matrix based code which calculates beam dynamics up to first (linear) order. As an example of all simulations the envelope of the new recirculation is displayed in Fig. 3.

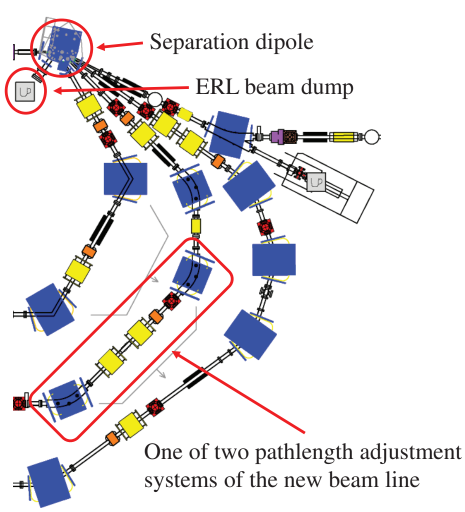

Figure 2: The new separation dipole magnet including the ERL beam dump and one of two new constructed pathlength adjustment systems.

SEPARATION DIPOLE MAGNET

The separation dipole is the most important and most complex dipole in the S-DALINAC. It bends electron beams with up to five different energies to their corresponding beam lines. Its mirrored version is the recombining dipole which merges the beams in front of the main linac. The addition of an another beam line resulted in adjustments of the two existing recirculations as well as of the beginning of the extraction beam line. The separation dipole fits all conditions, its final parameters are shown in Table 1. The design value for the magnetic field is 0.75 T with 0.65 T for the maximum beam energy. It has a pole gap of 30 mm.

Due to these limiting conditions the design of the yoke was a very complex and demanding task. Several calculations have been performed for ensuring the quality of the magnetic field for every beam [6]. In Fig. 4 the distribution of the magnetic flux inside the yoke is shown. As demanded an equal distribution as well as no field peaks at the edges of the profile were achieved by the optimization of the pole shape. The particle tracking was checked with conservatively starting conditions of the beam: a diameter of 10 mm,

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 $^\circ$	ψ_1 in $^\circ$	ψ_2 in $^\circ$
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	5.00

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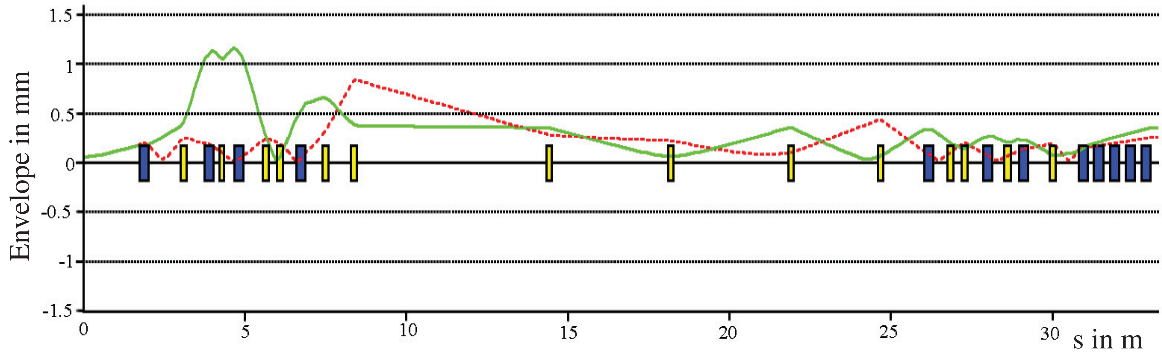

Figure 3: XBeam simulation of the new recirculation beam line with dipoles in blue and quadrupoles in yellow. The envelope in x- (red) and in y-direction (green) is shown.

an energy spread of $1 \cdot 10^{-3}$ and an angular spread of 0.1°. All different energies including the decelerated beam of the ERL option are shown in Fig. 5. It is very important that all beams fit to their tracks that are defined over the bending radius and the bending angle. In addition several calculations concerning the multipole components of all beams along the orbit were performed to minimize these components during the design process of the yoke. The manufactured separation dipole with its vacuum chamber is presented in Fig. 6.

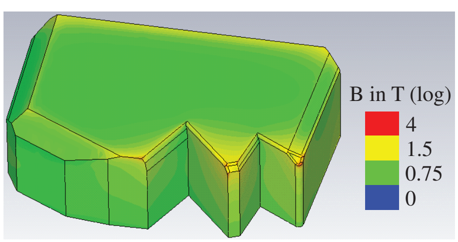

Figure 4: CST (EM Studio) simulation of the magnetic field inside the yoke.

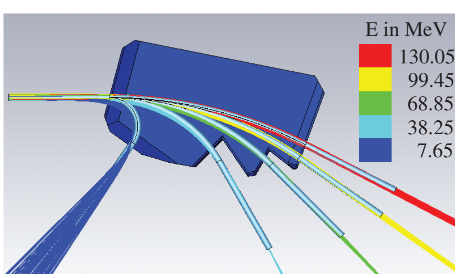

Figure 5: CST (Particle Studio) particle tracking of the different beams through the separation dipole.

CONCLUSION AND OUTLOOK

Beginning in autumn 2015 a complex and demanding modification phase for the S-DALINAC started. Its final energy will be increased with the addition of a new recirculation beam line and an ERL operation scheme will be possible in the future.

Before the commissioning of the three times recirculating S-DALINAC will start in summer 2016, some remaining tasks such as tests of the vacuum system, finalization of the cabling and final alignment of all magnets must be fulfilled. First ERL mode tests will be performed during the commissioning. The high energy scraper system [7] will be commissioned at the end of 2016 so that an improved beam quality as well as higher energies can be used for nuclear physics experiments from the beginning of 2017 on.

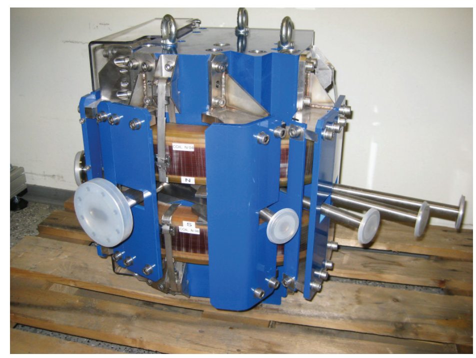

Figure 6: Picture of the separation dipole with its vacuum chamber.

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ISBN 978-3-95450-147-2