UPGRADE PLANS ON THE SUPERCONDUCTING ELECTRON ACCELERATOR S-DALINAC*

M. Kleinmann†, R. Eichhorn, F. Hug, N. Pietralla, TU Darmstadt, Darmstadt, Germany

Abstract

The S-DALINAC is a superconducting recirculating electron accelerator with a maximum design energy of 130 MeV operating in cw at 3 GHz since 1991 [1] at the university of Darmstadt. Polarized [2] or unpolarized beams can be accelerated and used as a source for nuclear and astrophysical experiments.

This paper will report on the upgrade plans for the S-DALINAC: A third recirculation to improve the maximum achievable energy, currently being 85 MeV in cw operation and two scraper systems to remove the halo of the electron beam.

A THIRD RECIRCULATION

The maximum design energy of the S-DALINAC (130 MeV) was not achieved in cw operation up to date.

The reason is that the cavities are well below their targeted quality factor of $3 \cdot 10^9$, even so several measures to improve were taken recently [3]. As a result, there is a higher heat transfer into the liquid helium than expected. Although the achievable gradients of the superconducting cavities are above their design value of 5 $\frac{\mathrm{MV}}{\mathrm{m}}$, the operating gradients have to be lowered due to the higher heat transfer to match the limited cooling power of the cryo-plant of approx. 120 W. As a result, the final energy in cw operation is currently around 85 MeV. In order to provide a cw beam with the designed final energy in the future, the installation of an additional recirculation path has been proposed and now is funded.

Overview

As the third recirculation will be built into an existing machine, the modifications should fit into the existing setting. Due to this there are special requirements which should be fulfilled, belonging to the following topics:

- the energy gain in both linacs (the injector and the main linac) and their fixed ratio (1:4)
- the magnetic inductions of the dipole magnets
- the pathlength of the recirculations
- an optimization of the beamlines to obtain ideal beam-dynamics

In addition, the exact position of the new recirculation has to be checked carefully against spatial constraints.

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† mkleinmann@ikp.tu-darmstadt.de

During the zero order design, two main ideas existed, only one of them (as a preferred version) will be discussed in the following. In this design, the new recirculation path will be placed in the middle of the two existing ones having a bending angle of 45 degree at the separator dipole behind the main linac. An overview (without the injector section) is shown in fig. 1.

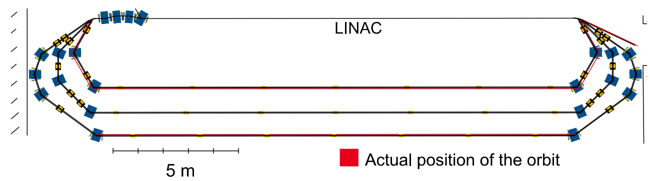


Figure 1: Sketch of the new beamline layout with three recirculations.

Due to the essential changes in the machine some parts of the recirculations and the entrance of the extraction line have to be moved slightly.

As mentioned above the design energies in different sections of the S-DALINAC will change. Table 1 gives an overview about these changes.

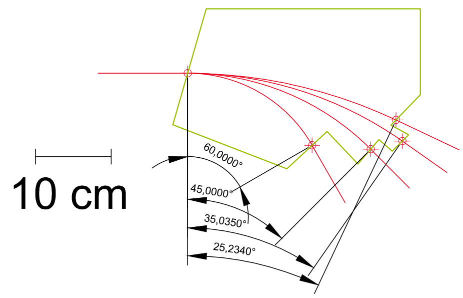
Table 1: Comparison between the actual design energies E_a and the planned design energies E_p.

Section	E_a [MeV]	E_p [MeV]
Injector linac energy gain	10	7.65
Main linac energy gain	40	30.60
After one pass main linac	50	38.25
After two passes main linac	90	68.85
After three passes main linac	130	99.45
After four passes main linac	-	130.05

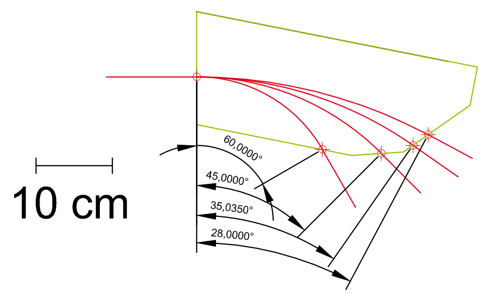
Magnet design

The most complicated magnet to design for the three recirculations layout is the separation dipole located behind the main linac and its mirrored version, the combining dipole in front of the linac. With the new set-up, four instead of three different beams have to be separated into different orbits.

For the first design approach, the three angles given by the existing layout were set and the new angle of the additional recirculation path was chosen to be 45 degree. By fixing the magnetic induction to 0.61 T being the current value of this dipole, both bending radii of the recirculations will change due to the change in energy, see tab. 1. This would lead to an outwards movement of the second



(a) First design.



(b) Second design.

Figure 2: Two designs of the separation dipole. The green lines enclose the area of ideal magnetic field, the red lines indicate the orbits of the four beams. The bending angles are given.

recirculation which will not be possible because of a lack of space. To solve this problem the magnetic induction of the new separation dipole is matched to the bending radius of the actual second recirculation and will be 0.6726 T instead. As a result, the first recirculation slightly has to move inward together with the entrance of the extraction line. As a result, we obtain the orbits of the four beams in the area of ideal magnetic induction (in between the fieldborders). With the help of these starting parameters the beam-dynamic simulation was done (see below). As a rough approach, the wedge angles of the separation dipole were chosen during the beam-dynamic simulations to obtain the best results. This lead to the profile shown in fig. 2(a).

Starting from the beam-dynamic simulation with the optimized wedge angles one ends with a magnet shape which obviously is not feasible.

As a second step, we started with the design of the ideal magnetic field area. After the same four orbits as mentioned above were drawn, the profile of the ideal magnetic field was designed by choosing a promising set-up for the wedge angles. To realize this profile one of the existing bending angles needed to be modified: The bending angle for the extraction beamline changes from 25.234 degree to 28 degree. This modification has minor consequences, as the downstream dipole magnet can adapt the changed angle easily. A sketch of the separation dipole designed in this is presented in fig. 2(b). Currently the field distribution of this magnet is calculated.

The next step will be to find the ideal set-up for the beamlines by simulating all three recirculations and the extraction beam line.

Beam-dynamics

The set-up for a new recirculation and the corresponding changes in the existing beamlines require an accurate simulation of the beam-dynamics. Figure 3 gives the results gained so far. It has to be mentioned, that the wedge angle of the separator dipole is still according to fig. 2(a).

First simulations have shown that the beam-dynamic for the latest version of the new separation dipole (as shown in fig. 2(b)) is also promising. The same is true for the slightly different dynamic in the two existing recirculation paths.

SCRAPER SYSTEM

A future backbone of the experimental program at the S-DALINAC will be investigations of nuclear transitions by electron scattering techniques combined with the analysis of emitted gammas ((e,e'γ) reactions). This increases the demands on the electron beam dramatically, as electron accelerators usually generate a huge gamma-ray background from bremsstrahlung processes coming from small beam losses, which often prevents sensitive detection of photons from the reactions.

The source of this background is the beam halo generated during acceleration in the injector and small angle scattering of the halo particles during reinjection of the recirculated beam. Therefore, the installation of beam scrapers at different locations has been proposed and was funded recently.

Beam-dynamic simulations show that the electron beam behind the injector has some low energy tail which cannot be avoided even when the accelerator is tuned optimally (which is a result of the phase slippage due to the acceleration inside the non-beta graded cavities). This longitudinal tail is still within the acceptance to get accelerated in the main linac and finally transported to the experimental areas. Providing a clean halo-free beam requires first a longitudinal shaping of the beam behind the injector, which can be accommodated inside the 180° bending arc. A suitable system and the necessary modifications are shown in fig. 4: the innermost dipole magnet has to be replaced by two half-size magnets. Inbetween energy defining slits have to be installed.

The injector arc scraper system will remove the low energy tail of the beam injected into the main linac. After three passes through the linac (housing 8 independently controlled accelerating cavities) a transversal scraping, combined with an additional longitudinal collimation will ensure the highest beam quality by removing any beam halo that has survived so far. The system proposed is shown in fig. 5. In addition, the longitudinal scraping within this magnetic chicane can further reduce the energy spread of the beam at the cost of beam current. As the dispersion is maximized in this section, a more efficient energy collimation compared to the existing system can be assured,

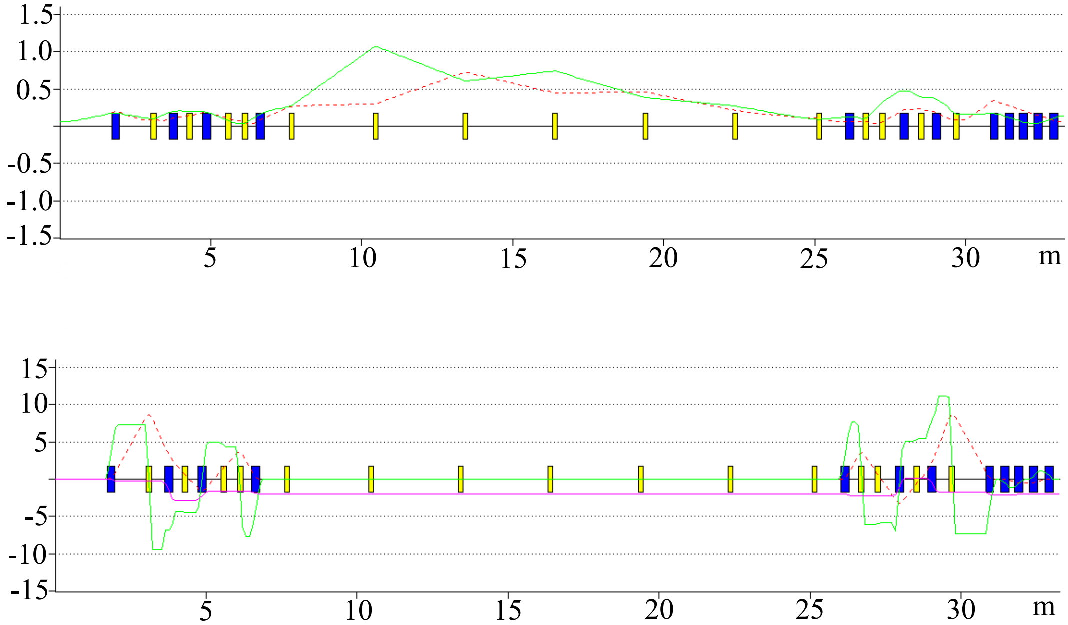


Figure 3: Second recirculation: The upper graph shows the beam envelope in mm as a function of the path length. Blue boxes are indicating dipole magnets, yellow boxes stand for quadrupole magnets. The red curve describes the envelope in x, the green one in y direction. In the lower graph, the red line illustrates the transversal dispersion in x direction in $\frac{\text{mm}}{\%}$, the green one the angle dispersion in $\frac{\text{mrad}}{\%}$ and the purple one the longitudinal dispersion in z direction in $\frac{\text{mm}}{\%}$.

allowing an energy definition of as low as 10 keV, which also is a future demand for the electron beam.

The installation of the injector arc system is scheduled for 2012, the extraction beam line scraper will follow the year after during a major shutdown also used to install the additional recirculation beam line mentioned above.

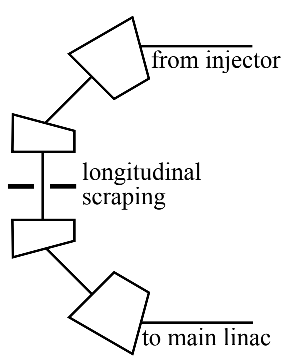


Figure 4: Proposed modification of the injector bending section to implement a scraper removing the low energy tail of the beam.

SUMMARY AND OUTLOOK

We reported on the two future upgrades for the S-DALINAC: The third recirculation and two scraper systems, both upgrades are funded and expected to be finished in 2013.

To realize a third recirculation slight and viable changes on the existing set-up of the S-DALINAC will be done.

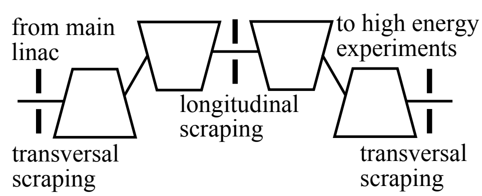


Figure 5: The proposed installation in the extraction beam line is shown here. As the beam is coming from the linac, a transversal scraping will remove the spatial halo. Within the magnetic dipole chicane the dispersion will be maximal in the symmetry plane. Scrapers located at this place will remove the energy tails. A final collimation will be done behind the fourth dipole.

Currently, we are in the progress of designing this new recirculation and determine the final position for all beamlines on basis of the corresponding beam-dynamic simulation.

In addition the layouts of two planned scraper systems to improve the beam quality were presented.

REFERENCES

[1] A. Richter, "Operational experience at the S-DALINAC", EPAC'96, Sitges (1996) 110.

[2] C. Eckardt et al., "Implementation of a polarized electron source at the S-DALINAC", IPAC'10, Kyoto (2010) 4083.

[3] R. Eichhorn et al., "Improving the Superconducting Cavities and Operational Findings at the S-DALINAC", Proc. of the 2008 Lin. Acc. Conf.,Victoria, BC, Canada (2008) 395.