CW ENERGY UPGRADE OF THE SUPERCONDUCTING ELECTRON ACCELERATOR S-DALINAC*

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Abstract

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

This paper will report on the cw energy upgrade for the S-DALINAC which will improve the maximum achievable energy, currently being 85 MeV in cw operation. The key issues will be the embedding into the existing accelerator, the magnet design and the beam dynamics simulation.

OVERVIEW

An energy upgrade is planned to increase the final achievable energy in cw operation, being currently about 85 MeV instead of the design value of 130 MeV. The reason for this lies in the cavity performance:

The cavities could achieve a higher accelerating gradient than their design value of 5 MV/m, which means that the full energy could be reached. But operational experience shows, that the cavities running at the design accelerating gradient, have a higher dissipated power as it was expected. Consequently, the full energy is only available in pulsed mode. This is due to the fact that the cavities are well below their targeted quality factor of $3 \cdot 10^9$. The higher than expected dissipated power leads to a higher heat transfer into the liquid helium. As the cooling power of the cryo-plant, being approx. 120 W was specified for the design heat transfer, the accelerating gradients have to be lowered to match the cryo-plant power. As a result approx. 85 MeV is currently the final energy in cw operation. During the last years several measures were taken to improve the quality factor [3]. All of them failed to fully reach the design goal (which obviously was set too optimistically).

The current energy upgrade consists of building an additional recirculation path and thus uses the accelerating gradient of the cavities a 4$^{\text{th}}$ time (no additional heat load). The project of building an additional recirculation is challenging as it has to match into the existing machine and into the limited space left inside the accelerator hall. The major requirements are:

- the energy gain in both linacs (the injector and the main linac) must keep their fixed ratio (1:4)
- the magnetic inductions of the dipole magnets are limited
- the pathlength of the recirculations must be a multiple of the RF wavelength
- optimum beam dynamics must be achieved

As a result of the analyses the new recirculation path will be placed in the middle of the two existing ones having a bending angle of 45 ° at the separator dipole behind the main linac and in sum four times 45 ° bendings per arc. The new set-up (without the injector section) is shown in Fig. 1.

The major changes that will have to be done at the current lattice are:

- a parallel shift of the first recirculation
- an increase of the extraction-beamline angle from 25.234 ° to 28.000 °
- a parallel shift of the first part of the extraction beamline

All these changes were checked to be feasible.

The aim of the whole project is an increase of the final energy of the S-DALINAC available in cw operation. Due to this the energies in all recirculation paths will change. Table 1 gives an overview about these changes.

Table 1: Comparison between the current design energies E_c and the planned design energies E_p.

Section	E_c [MeV]	E_p [MeV]
Injector linac energy gain	10.00	7.65
Main linac energy gain	40.00	30.60
After one pass main linac	50.00	38.25
After two passes main linac	90.00	68.85
After three passes main linac	130.00	99.45
After four passes main linac	-	130.05

MAGNET DESIGN

For the new layout two different types of dipoles will have to be designed. First, a simple bending dipole (45 °) and second the new separation dipole (45 ° for the new path), which is identical with its mirrored version, the combining dipole. As the separation dipole is the challenging part we report here on its design.

During the design of the separation dipole, several approaches have been investigated and have successively been improved. Finally, a promising design layout was found which will be the basis for the ordering of the magnets. The main parameters of the dipole are shown in Tab. 2.

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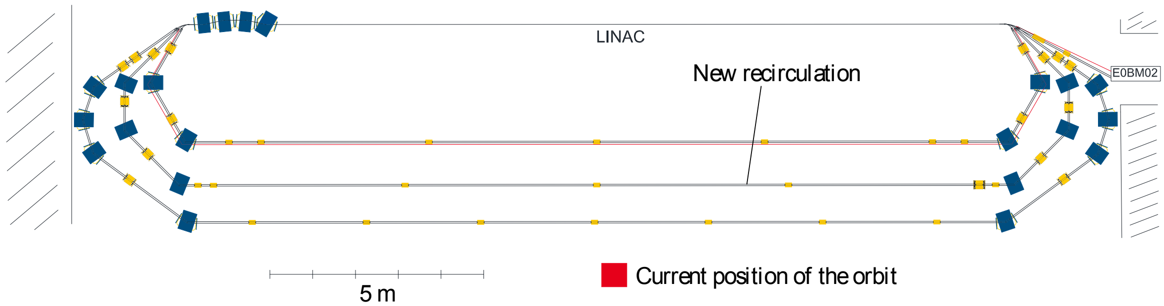


Figure 1: Sketch of the S-DALINAC with three recirculations, without the injector part.

Table 2: Parameters of the separation dipole and its performance on electrons with the energy E: the bending radius R, the magnetic length l, the entrance wedge angle ψ_1 and the exit wedge angle ψ_2.

E [MeV]	R [cm]	α [°]	l [cm]	ψ_1 [°]	ψ_2 [°]
38.25	18.97	60.000	19.86	+42.46	-41.15
68.85	34.14	45.000	26.82	+42.46	-41.52
99.45	49.32	35.035	30.16	+42.46	-19.75
130.05	64.49	28.000	31.52	+42.46	-26.78

During the design we had to decide about the magnetic induction strength. First, we fixed it to the value of the currently existing separation dipole (B = 0.61 T). Due to this choice and the change in energy (see Tab. 1) the existing recirculation beamlines will have to be shifted to a parallel position. As it would be very complicated to shift the current second recirculation and since the possibilities of different shifting-combinations of all beamlines are limited (because of a lack of space), too, the magnetic induction of the dipole was chosen in a way (B = 0.6726 T) so that the bending radius of the future third (currently second) recirculation will match to the corresponding beamline. Due to this choice, the first recirculation will have to be moved inwards (parallel shift), the same will have to be done for the first part of the extraction beamline. When doing the parallel shift for the first recirculation one needs to keep the correct pathlength, which has to be a multiple of the RF wavelength of 10 cm.

After fixing the parameters and the magnetic induction the wedge angles are the next major topic. In a first approach they were treated as free parameters for the beam dynamics simulation. The result would be a yoke impossible to build. So in our design the wedge angles of the dipole were fixed first to receive a smooth profile of the yoke. Due to this shape the extraction angle of the existing beamline will have to be changed from 25.234 ° to 28.000 °. This will be part of the modification of the first part of the extraction line, which needs to be done anyway because of the required parallel shift. The result of this design is shown in Fig. 2(a). As a next step the field distribution for the proposed design was calculated. The result is shown in Fig. 2(b).

All results for the separation dipole are promising and the procurement procedures with appropriate companies have started. During the next steps we want to check the multipole components at the beam exit points.

BEAM DYNAMICS

After the zeroth order design, a first order beam dynamics calculation was performed. This covered the calculation of all recirculation paths and even the first part of the extraction beamline to adjust all beamlines properly.

For the current lattice of the S-DALINAC all recirculations have been calculated already, they only need to be modified and matched to the new requirements. For the new path we had to start from scratch making that simulation more urgent and more challenging. Thus we present the output from the beam dynamics simulation of the completely new recirculation which is now the basis for the new lattice design.

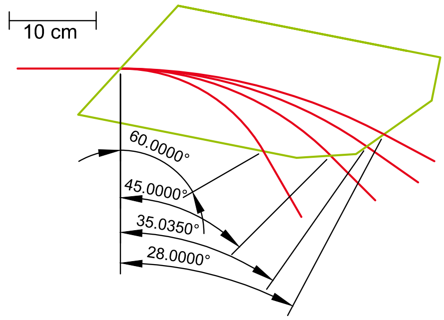
Figure 3 displays the results obtained so far. Some limiting conditions concerning the different dispersion curves had to be fulfilled: The transversal and the angular dispersion have to vanish behind each arc and the longitudinal dispersion is adjusted to -2.0 mm/% for the non-isochrones recirculation scheme [4].

SUMMARY AND OUTLOOK

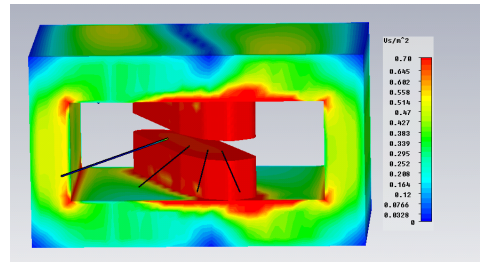
We reported on the future energy upgrade for the S-DALINAC, realized through a third recirculation. This project is expected to be finished by the end of 2013.

Some modifications, as the parallel shift of the first recirculation and of the first part of the extraction beamline, will have to be done to match the new recirculation path into the S-DALINAC.

A major part of developing this beamline is the magnet design. We reported in detail about the tasks during the design of the separation dipole and showed our design including the result of field distribution calculation. Another main issue is the simulation of the beam dynamics which



(a) Sketch of the new separation dipole with indicated orbits and bending angles (top view). 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.



(b) Distribution of the magnetic induction inside the yoke of the new separation dipole (side view).

Figure 2: The current design of the new separation dipole.

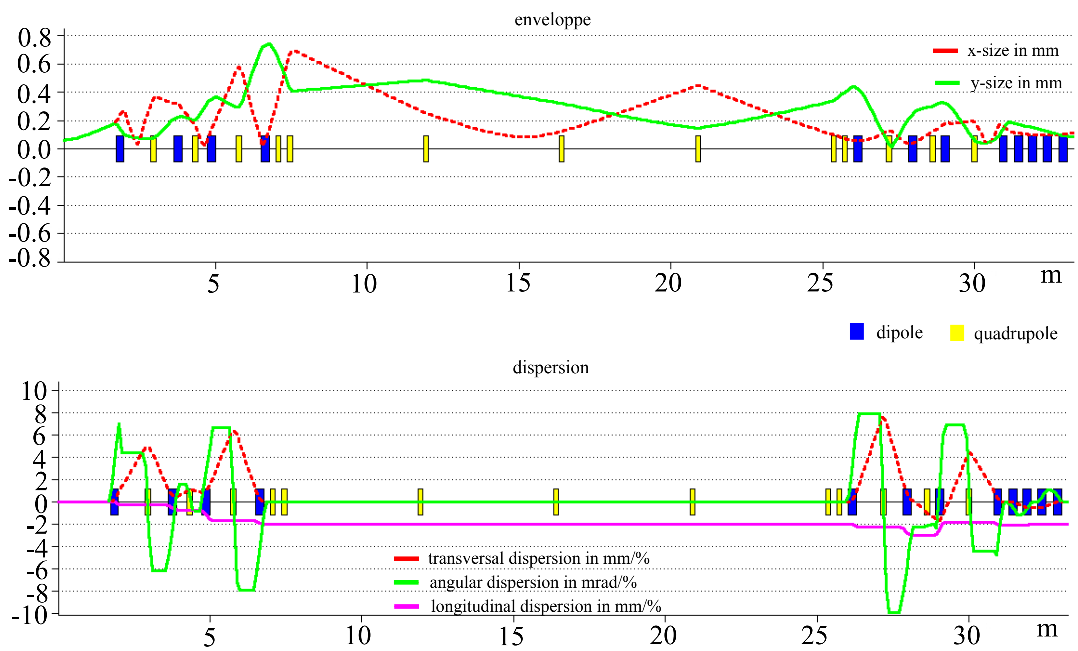


Figure 3: Beam dynamics of the new recirculation under the lattice assumed so far.

was done for all recirculations and the first part of the extraction line to get an overview of the whole beam dynamics of the S-DALINAC with three recirculations. The results of the simulation for the complete new beamline were presented.

Next we will optimize the design of the separation dipole. All required dipoles and power supplies will be ordered for the new recirculation. In addition we will proceed with the planning for the implementation of the entire new beamline.

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