THE UPGRADED INJECTOR CRYOSTAT MODULE AND UPCOMING IMPROVEMENTS AT THE S-DALINAC*

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Abstract

Since 1991 the superconducting Darmstadt linear accelerator S-DALINAC provides an electron beam of up to 130 MeV for nuclear and astrophysical experiments. The accelerator consists of an injector and four main linac cryostats, where the superconducting 3 GHz cavities are operated in a liquid helium bath at 2 K.

For the injector upgrade program, the RF power delivered to the beam had to be increased from 500 W to 2 kW. Therefore, the coaxial power couplers have to be replaced by new waveguide couplers introducing only small transversal kicks to the beam. Consequently, modifications to the cryostat-module and had become necessary. We review on the design of the module and some interesting features and give details on the tuning of the newly built 20-cell cavities. The paper will close with an outlook towards the installation of an additional recirculation path planed in 2013.

INTRODUCTION

The superconducting Darmstadt linear accelerator S-DALINAC [1] is a recirculating electron linac, using twelve superconducting niobium cavities at a frequency of 2.9975 GHz. It was first put into operation in 1987. Running at a temperature of 2 K the main acceleration is done by ten 20 cell elliptical cavities with a design accelerating gradient of 5 MV/m. The S-DALINAC uses cryostat modules containing two cavities per module. The first module is used in the injector section of the machine.

Behind this section, the beam can be transported into an experimental area where nuclear physics experiments at a maximum energy of 10 MeV are performed, or transferred to the main linac for further acceleration. Here, eight additional cavities are installed, providing an energy gain of 40 MeV. The final design energy of the machine (130 MeV) is obtained when the electron beam is recirculated twice.

An active experimental program around the machine, supported by the DFG within the framework of a collaborative research centre (CRC/SFB) leads to a continuous upgrade program around the machine, two of which will be described within this article.

INJECTOR UPGRADE

The injector upgrade project aims at an energy and current increase from 10 MeV with 60 μA up to 14 MeV with 250 μA in the injector linac, requiring a major modification of the cryostat module.

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The cryostat modules in operation so far use a coaxial RF transition line to deliver the RF power to the cavities. This transition line has a diameter of only 21 mm (7/16''), limiting the power transferable to the couplers and the cavities to 500 W [2]. For the beam energies and currents in the injector upgrade project new power couplers capable of up to 2000 W were designed. These power couplers feature a RF transition line now being a rectangular WR-284 (cross section 72×34 mm^2) waveguide (see [3] for more details).

Because of the increased spacious demands of the RF transition, the cryostat design had to be changed considerably [4, 5] leading to interesting features. As the WR 284 waveguide has a large aperture, resulting in excessive heat transfer by radiation from ambient to the cold, special precaution for a thermal intercept was taken. We designed a waveguide with two bars as a barrier for the heat radiation (as shown in Figure 1), connected to the 80 K radiation shield. The distance between the bars chose to give minimum reflection at the operation frequency. The RF simulations were done using CST-MWS microwave. Figure 1 also shows the RF measurement on a warm prototype of this waveguide intercept indicating that less than 1% of the RF power is reflected. The shrinkage during cool-down and thus the frequency shifting of the minimum has been taken into account. Even though the bars do not cover the complete waveguide cross section, at least 70% of heat radiation can be intercepted, reducing the heat transfer from radiation to the 2 K part to some 500 mW.

Since the design was finished, finding vendors for all the components were an issue. Especially, the flexible RF waveguides transitions from the helium vessel at 2 K to the parts at room temperature were commercially not available. Finally, an industrial R&D program was launched to build the parts as rectangular bellows out of stainless steel (see Figure 2). They were delivered a few

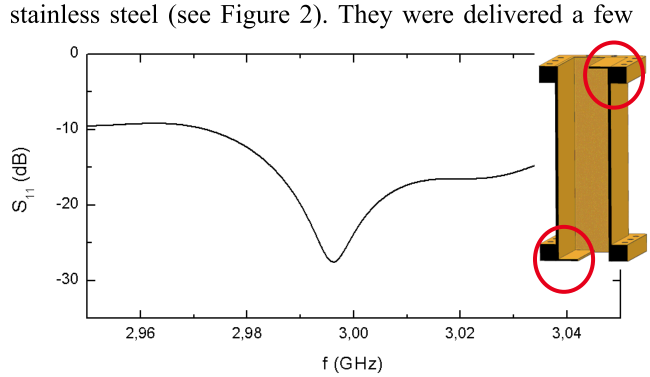

Figure 1: Heat radiation intercept of the RF waveguide at 80 K (schematic layout and RF properties).

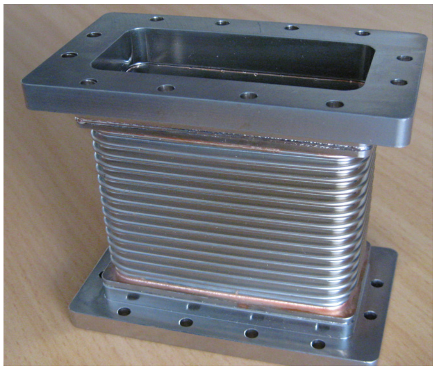

Figure 2: Rectangular stainless steel bellow (100 mm length) as part of the rf waveguide transition (WR 284) for the injector upgrade module (before copper plating).

months ago and tested for their vacuum properties. It was found that even after several cool down cycles (with liquid nitrogen) the bellows were leak tight. Currently, the copper plating is done. As the bellows are not as flexible as a circular bellow, two of them will be installed per transition line, one between the helium vessel and the liquid nitrogen intercept and one above between nitrogen and the ambient.

For the injector upgrade project it was decided to order 3 new cavities by RI company, using state-of-the-art technologies in order to get good performance cavities with high quality factors and higher gradients (7 MV/m compared to 5 MV/m for the existing cavities), ensuring the rise in beam energy. Unlike the first series where single cells were built and measured before being welded to a full 20 cell cavity, dumb-bells were produced this time, being the common way to fabricate multi-cell cavities today. As the cavities are still under fabrication the details of the process will be published in a future paper.

INSTALLATION OF A NEW RECIRCULATION PATH

So far, the final energy of the S-DALINAC has been limited to 80 MeV in cw mode, even though the accelerating field of most of the cavities are above the designed 5 MV/m gradient. The reason for this is that the quality factor is still below the design of $3\cdot10^9$ (typical values are $8\cdot10^8$). All measures taken so far failed to reach the design Q (being 75% of the BCS limit) which might have been set to optimistically 20 years ago. As a result, the limited cooling power at 2 K requires cw operation below the maximum gradient and thus with reduced final beam energy.

As a demanding experimental program exists which would greatly profit from higher energies available in cw, the installation of a third recirculation path to boost the accelerator energy got funded, leading to roughly 120 MeV. The installation has become possible recently as the old beam-line to the undulator (as part of the Darmstadt Free Electron Laser facility [6]) has been de-commissioned in 2006. A preliminary design study undertaken so far opened the option to build the new recirculation in between the two existing ones, as sketched in Figure 3.

A considerable advantage of this layout is that most of the existing beam-lines and magnets can be used further on (even so the energy of the beam changes). Beside the 4 new bending magnets to form the additional recirculation path, only the separation and recombining magnets at the beginning and the end of the recirculations have to be replaced. Currently, the design for this magnets and the additional beam line is made. The installation is planed to take place in 2013.

EFFICIENT BEAM SCRAPING

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.

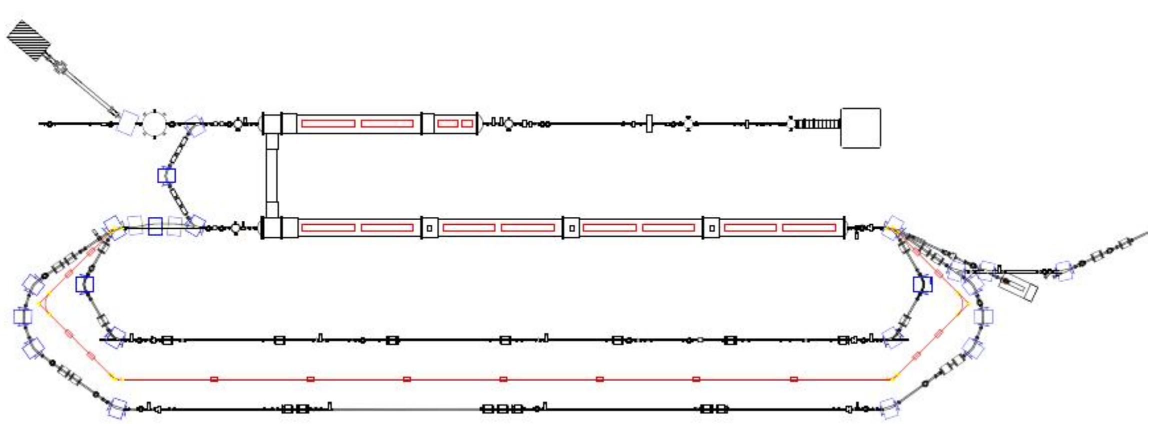

Figure 3: Floor plan of the S-DALINAC indicating the third recirculation to be added: The new recirculation beam line (red) can be placed between the existing ones minimizing the investment cost and the required shut down period.

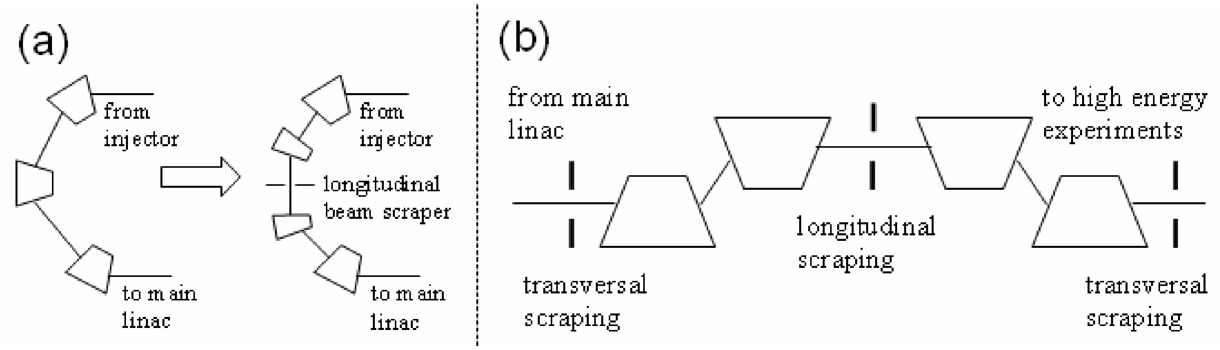

Figure 4: Left: Proposed modification of the injector bending section to implement a scraper removing the low energy tail of the beam. The proposed installation in the extraction beam line is shown on the right. As the beam is coming from the linac, a transversal scraping will remove the spatial halo. 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.

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 Figure 4 (a): the innermost dipole magnet has to be replaced by two half-size magnets. In between 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 Figure 4 (b). 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, 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 installed the additional recirculation beam line mentioned above.

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