ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-MOPO018

DEVELOPMENT OF AN IMPROVED CAPTURE SECTION FOR THE S-DALINAC INJECTOR*

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Abstract

For the injector of the superconducting Darmstadt electron linear accelerator S-DALINAC, the design of a new capture cavity was recently completed. This beta-reduced structure will optimize the capture of low-energy electron bunches from the gun section and therefore improve the longitudinal beam quality of the injector beam, as simulations have shown. The existing cryomodule of the injector has to be modified for the installation of the new cavity. These modifications include adaptions of the tuner frame as well as modifications of other surrounding parts. To improve the diagnostics in the low-energy section, an energy-spread measurement setup is currently also under development. In this contribution the cryomodule modifications as well as simulation results for the longitudinal beam dynamics are presented.

INTRODUCTION

The injector of the superconducting Darmstadt linear accelerator S-DALINAC [1] provides electrons with a kinetic energy of up to 10 MeV. It consists of a normal conducting section where the beam is prepared for RF acceleration and two cryomodules containing superconducting elliptical Nb accelerator structures (Fig. 1). The injector is driven by a 250 keV thermionic gun, the also existing spin-polarized gun [2] is currently being prepared for an upgrade to 200 keV [3]. In its present state, the superconducting part of the injector features a five-cell capture cavity and two 20-cell cavities similar to the structures used in the main LINAC. All cavities are operated at 3 GHz and designed for a β of 1. However, the 250 keV beam from the thermionic gun corresponds to a relativistic β of only 0.74, introducing significant phase slippage effects as the low-energy bunch travels through the current five-cell cavity. In order to increase the efficiency of the electron capture and the longitudinal beam quality of the beam after injection it is therefore intended to replace the five-cell structure with a new dedicated capture cavity. The design of the new capture structure, a 6-cell cavity with a reduced β of 0.86, has been recently completed [4,5] and its construction will start in the near future.

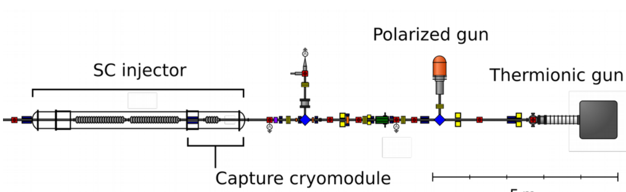

Figure 1: Overview of the S-DALINAC injector. Main subject of this project is the capture cryomodule which is part of the superconducting (SC) injector. It currently houses a 5-cell β=1 cavity.

MECHANICAL MODIFICATIONS

Inside the liquid helium vessel of the cryostat, the cavity is surrounded by its input and output RF coupler as well as the tuner system. It was already decided in the early stage of the project to keep the overall cavity length fixed, enabling the re-use of the couplers and the cryostat. However, the tuner frame has to be adapted. First CAD models of the tuner system were created in order to apply the necessary modifications. Figure 2 shows the finished tuner frame model. The tuner frame is fixed at the cavity cutoff tubes with aluminum plates (grey), which can be re-used from the existing 5-cell frame. Since the overall length of the cavity cell region will be increased by 8 mm, the tuner frame length has to be adapted. A shorter cutoff-tube at the output coupler side will compensate this additional length. However, due to the longer cell region, the titanium fixation rods (yellow), which stabilize the frame and guide the cavity, have to be modified. The piezo tuner system for microphonics compensation is

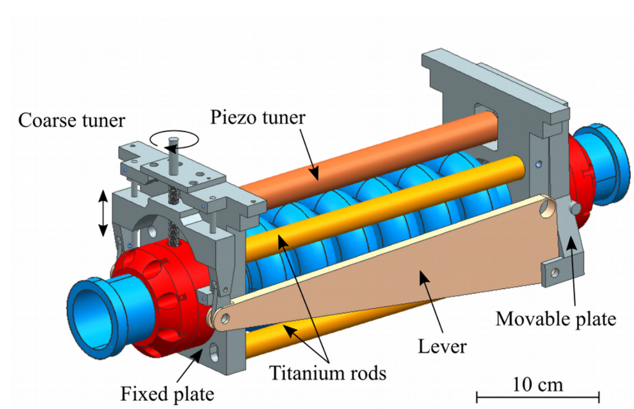

Figure 2: Trimetric view of the tuner frame CAD model with the applied modifications for the new capture cavity. The grey parts will be re-used from the existing setup, the piezo tuner and the support rods (orange and yellow) as well as the lever (pink) have to be adapted according to the increased length of the cell region. The cavity fixation rings shown in red have to be increased in diameter to adapt to the larger wall thickness of the cavity.

* Work supported by DFG (GRK 2128).
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contained in a titanium tube which also has to be adjusted. Due to the increased cavity wall thickness (to protect the cavity from deformations during installation and handling), the fixation rings which attach the cavity to the frame (shown in red) have to be increased in diameter to match the new outer cutoff tube radius. Due to the increased wall thickness of the cavity compared to the current 5-cell setup, the stiffness also increases [5]. It was therefore verified that the tuner strength of one piezo actuator is sufficient for tuning. Two actuators will be used for redundancy in the final tuner system. With the CAD model of the modified tuner frame prepared, manufacturing of the adapted parts can be carried out in the in-house workshop of the institute in parallel to cavity production.

BEAM DYNAMICS

In order to obtain first estimates of the beam quality improvement introduced by the new capture section, the longitudinal phase space downstream the superconducting injector was simulated with ASTRA [6]. The input bunch length and energy spread for the 250 keV thermionic gun beam were estimated to 5 ps and 3 keV, respectively using the properties of the chopper/prebuncher section within the normal conducting part of the injector. In a first set of simulations, the phase of the three injector cavities (the

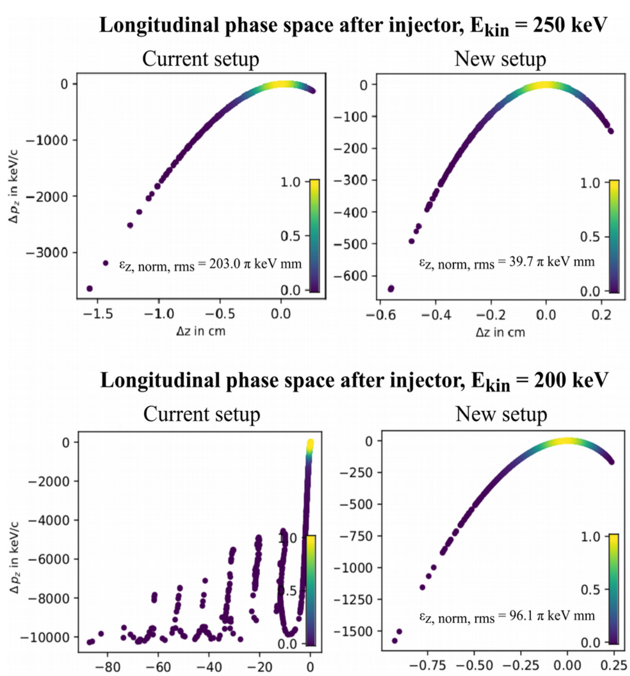

Figure 3: Simulated longitudinal phase space for the 250 keV input bunch (top) at injector exit for the existing 5-cell setup (left) and the new 6-cell capture structure (right). The phases were set according to the maximum energy gain of the beam. Relative phase space density is indicated by the colormap. The bottom figures show a similar simulation for the 200 keV input bunch. With the current capture structure it is not possible to maintain a stable bunch structure along the injector for this input energy, while the 6-cell cavity shows an efficient capture also in this case.

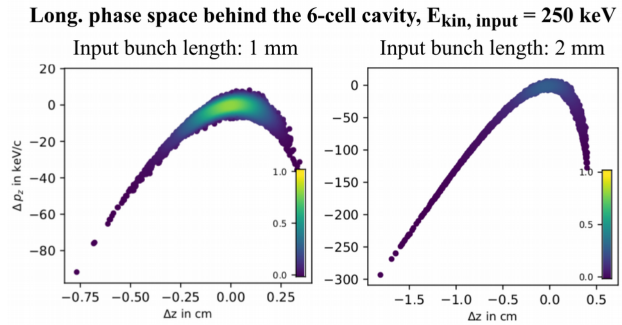

Figure 4: Simulated longitudinal phase space behind the new 6-cell capture structure for different input bunch parameters. The quality of the beam after the capture highly relies on proper prebuncher settings, which determine the input bunch length. A diagnostics setup is needed in front of the SC injector entry to verify this parameter.

capture cavity followed by the two 20-cell cavities) was set according to the maximum energy gain, the peak electric field on axis was 10 MV/m. Figure 3 shows the phase space at injection exit for the current 5-cell setup (left) and for the new capture structure (right) for an input bunch energy of 250 keV (top) and 200 keV (bottom), corresponding to the two electron guns. A large low-energy tail is generated by the phase slippage in the 5-cell cavity, producing halo and beam loss as the bunch travels towards the main LINAC. This tail gets significantly decreased in the case of the new 6-cell structure. A similar simulation was run for the 200 keV beam delivered by the spin-polarized gun after the planned upgrade. For 200 keV, the β-mismatch of the 5-cell gets too large to maintain a compact bunch structure, while the 6-cell is able to maintain a stable bunch throughout the injector. Furthermore, a phase setting of the capture structure leading to a minimum energy spread at injection exit was found through simulations. For this operation mode, the energy gain of the capture section is still close to the maximum while leading to a significant energy spread reduction at the end of the injector. Overall, the benefit of the new capture structure for beam dynamics could be validated. The structure is expected to yield an efficient electron capture for both the 250 keV and 200 keV beam. However, the beam quality at the end of the injector highly depends on the input bunch shape, which was seen in a third set of simulations where the input bunch energy spread and length was varied for the new setup (6-cell cavity). For the lowest longitudinal emittance, the bunch has to be as short as possible when it enters the first cell of the capture structure (Fig. 4). As expected, a small energy spread of the input bunch also contributes to a good beam quality after the injector. However, there are no diagnostics at the end of the normal conducting injection section so far to measure this properties of the input bunch. Therefore, a dipole spectrometer setup for energy spread measurement is currently being planned.

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An existing vertical diagnostic beam line located behind the prebuncher could be used for this setup.

CONCLUSION AND OUTLOOK

For an efficient electron capture in the first cavity of the superconducting injector of the S-DALINAC, a new beta-reduced structure will replace the current 5-cell cavity. CAD models of the relevant tuner frame parts within the cryostat were created and modifications were applied according to the geometry of the new cavity to prepare the installation. Longitudinal beam dynamics simulations were carried out in order to validate the expected improvement in beam quality introduced by the new structure. They can be also used as a guideline for the phase settings of the injector during commissioning of the new capture section. In order to get a better understanding of the real bunch properties after the normal-conducting injection, a measurement setup is needed close to the SC injector entrance. Measurements of longitudinal beam parameters of the normal conducting injection could then be performed to support the commissioning. Furthermore, upgrade options of the normal conducting injection can be investigated.

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