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STATUS AND FIRST TESTS OF THE REDUCED-BETA CAPTURE CAVITY FOR THE S-DALINAC*

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Abstract

The superconducting part of the injector section of the superconducting Darmstadt electron linear accelerator (S-DALINAC) [1] consisted of one five-cell capture cavity and two 20-cell cavities at 3 GHz resonance frequency. All of them were geometrically adapted to electron velocities with a beta of 1, while the thermionic gun provides electrons with a beta of 0.74. This mismatch resulted in an insufficient capture process for optimum beam quality. For this reason, a new six-cell capture cavity with a beta of 0.86 has been designed and built. Field flatness tuning, a test in the vertical bath cryostat, and an UHV furnace treatment have been carried out in-house to finalize the cavity processing. The cryostat module was adapted to house the new cavity, which has been recently installed. Following the module assembly, a first RF test run was conducted at the S-DALINAC. We report on these latest advancements towards the implementation of the injector upgrade.

INTRODUCTION

The S-DALINAC [1] is a thrice-recirculating cw electron linac operated at 3 GHz. Mainly 20-cell elliptical niobium cavities at 2 K are used as acceleration structures. In addition to the conventional acceleration mode providing energies of up to 130 MeV at a design current of 20 µA for nuclear physics experiments, the machine is also capable of an operation as energy-recovery linac (ERL [2, 3]). The possible realization of an SRF multi-turn ERL has recently shifted into the R&D focus at the S-DALINAC. In this regard, improvements of the beam quality, especially concerning the injector, are necessary.

The accelerator layout with a detail view of the injector is illustrated in Fig. 1. A DC beam is produced in the thermionic 250 keV gun, while the spin-polarized electron gun [4] presently provides 100 keV electron bunches of several 10 ps length [5]. An upgrade of this source to 200 keV is foreseen [6]. The beam is then transformed into 3 GHz bunches within the chopper/prebuncher section. The bunches then enter the superconducting injector consisting of the capture cavity and two standard 20-cell-structures, providing a total output energy of 10 MeV. In the capture cavity, sufficient acceleration has to be provided to the beam in order to match the following structures while keeping the beam quality deterioration, which occurs due to phase slippage, as low as possible. For this reason, the formerly used five-cell, β=1 capture cavity was replaced with a reduced-β structure [7-9] better adapted to the low source energies, especially in the case of beam generation in the spin-polarized gun (see Fig. 2). Key design features of the new cavity are a geometrical β of 0.86, a TESLA-shaped cell design and an increased mechanical stiffness in order to improve the stability during handling and installation. A moderate accelerating gradient of 5 MV/m is intended at a quality factor of $Q_0 > 1\text{x}10^9$. The following sections present the latest cavity processing steps, installation into the adapted cryomodule and first tests with RF power, thus summarizing the current status of the project.

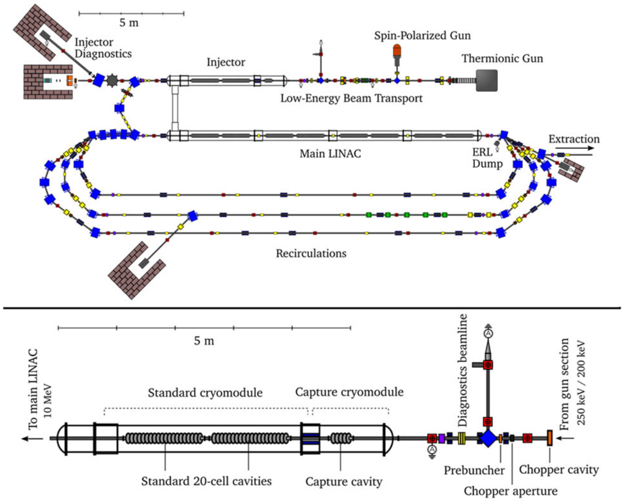

Figure 1: Schematic layout of the S-DALINAC accelerator (top) with detail view of the injector (bottom) housing the new beta-reduced capture cavity.

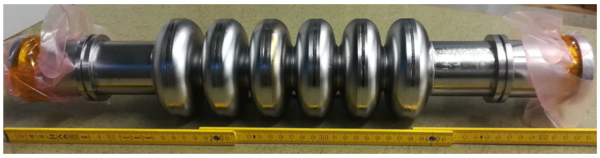

Figure 2: The six-cell reduced beta cavity after first delivery to TU Darmstadt.

IN-HOUSE CAVITY PROCESSING

The new six-cell niobium cavity has been produced by RI[1]. After delivery to TU Darmstadt, a first field-flatness tuning was applied to the cavity. During the manually applied deformation of individual cells, the target frequency of the cavity at this stage could be achieved at a length deviating only 1.3 mm from the design, while significantly improving the field-flatness at the same time (see Table 1).

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Table 1: Frequency, length and field-flatness (FF) of the six-cell at different production stages.

Cavity status	Frequency	length	FF
Welding	3.0058 GHz	537.1 mm	20.6%
130 µm BCP	3.0007 GHz	537.1 mm	22.2%
After transport	3.0007 GHz	537.1 mm	24.4%
Initial tuning	2.9936 GHz	533.2 mm	3.6%

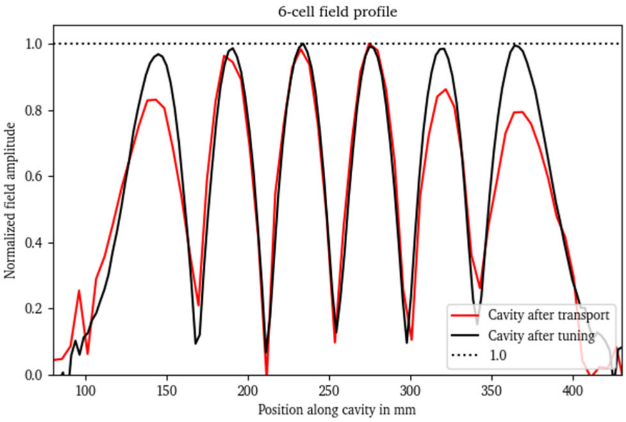

Figure 3: Field-flatness improvement of the six-cell during first tuning.

Figure 3 shows the field-profile result of this first tuning, which already fullfilled the S-DALINAC field-flatness criterion of < 5%. The tuning was followed by a cold test in the in-house vertical test cryostat (VTC [10]) with the primary goal to experimentally obtain the cool-down frequency shift, which was an important information necessary to set-up the target fequency prior to the module cool-down.

After the six-cell received the second BCP (20 µm, 150 µm in total) at RI, the final in-house surface processing was conducted. The usual S-DALINAC procedure of a 800°C hydrogen bake [11] followed by a field-flatness refinement, soft chemical treatment with hydroflouric acid (HF-rinse) and ultrapure water rinse cleaning was chosen.

CRYOMODULE ASSEMBLY

The tuner frame components based on the original setup were adapted to the modified cavity geometry previously [12] and could be successfully installed around the six-cell. Furthermore, the conserved compatibility with surrounding cryomodule components enabled the re-use of the couplers. After finishing the clean-room-assembly, the dressed cavity was mounted into the cryomodule support frame (see Fig. 4). At this stage, also the new Piezo fine tuner, which is used for fast automated tuning within the LLRF control loop, was installed. After setting up the warm target frequency and improving the coarse tuner range to 1 MHz in order to safely reach the operational frequency after cool-down, the cold-string was installed into the helium tank. The cryostat was then re-assembled and installed at the accelerator.

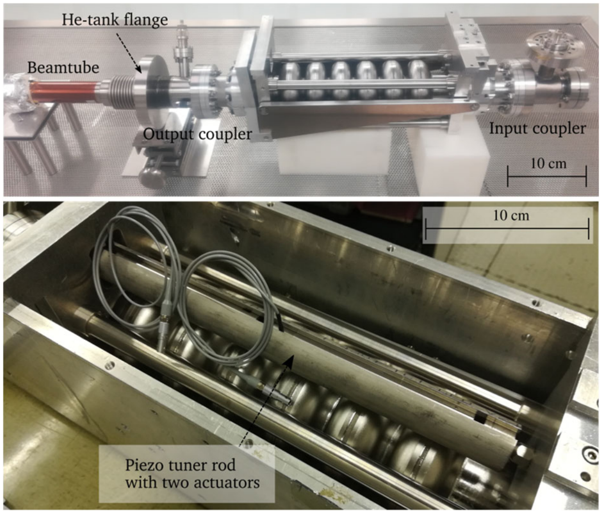

Figure 4: Assembly of the coarse tuner frame and couplers around the six-cell capture cavity (top). The six-cell was equiped with a new Piezo tuner (bottom).

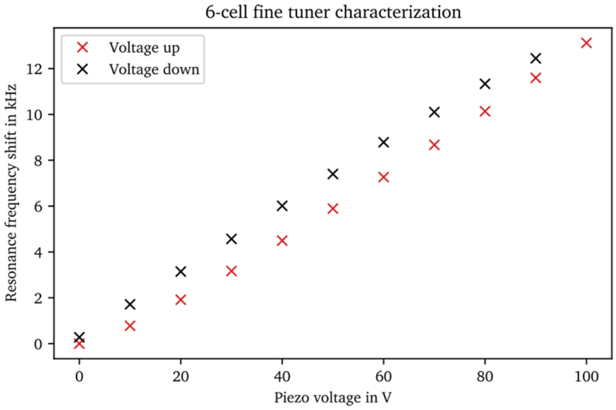

Figure 5: The Piezo tuner frequency shift as a function of the applied voltage shows the expected linear behaviour. Despite of the increased mechanical load compared to the other cavities, the six-cell fine tuning system is therefore fully operational.

COOL-DOWN AND FIRST RF TESTS

After cool-down of the injector, the coarse tuner range proved sufficient to reach the operational frequency of 2.9973 GHz. Because the six-cell features a modifed transition between end-cells and cutoff-tubes [5], a stronger input coupling compared to the other S-DALINAC cavities was expected and measured. Therefore, the coupling first had to be reduced to achieve the usual $Q_\mathrm{L} \approx 1.5$ x 10^7 by adjusting the variable input coupling system. Some adaptations were afterwards applied on the software and hardware side of the LLRF control system. The new Piezo tuner had to be tested in regard to compatibility with the cavity, especially concerning the increased mechanical stiffness. A fine tuning range of 12 kHz featuring the expected linear behaviour with a slight hysteresis was measured (see. Fig. 5), thus proving the correct functioning of the Piezo tuner. The six-cell could then be operated in a stable way

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for several days at a low accelerating gradient (1 MV/m) within the LLRF control system framework. As so far no HPR treatment had been carried out, the cavity's accelerating gradient was limited in this first test installment. Effects caused by multipacting near the input coupler and field emission could be identified and are expected to disappear following the recent HPR treatment that has been carried out at the clean-room environment at Mainz University. Following this treatment, the 6-cell structure is ready for re-installation and scheduled to be fully commissioned in July 2021.

CONCLUSION

The six-cell reduced-beta capture cavity for an improved beam quality of the S-DALINAC injector was manufactured, installed and tested at the accelerator. Compatibility with all tuning and coupler components as well as a stable cavity operation within the LLRF control system framework at low gradients was shown. The cavity has undergone HPR treatment since and is ready for commissioning at the S-DALINAC in July.

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