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RF COMMISSIONING OF THE FIRST-OF-SERIES CAVITY SECTION OF THE ALVAREZ 2.0 AT GSI

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Abstract

The existing post-stripper Drift Tube Linac (DTL) of the GSI UNILAC will be replaced with the new Alvarez 2.0 DTL to serve as the injector chain for the Facility for Antiproton and Ion Research (FAIR). The 108.4 MHz Alvarez 2.0 DTL with a total length of 55 meters has an input energy of 1.36 MeV/u and the output energy is 11.32 MeV/u. The presented First-of-Series (FoS) cavity section with 11 drift tubes and a total length of 1.9 m was planned as the first part of the first cavity of the Alvarez 2.0 DTL. After copper plating and assembly of the FoS-cavity the RF-conditioning started in July 2021. These contribution gives an overview on the results of the successful RF-conditioning to reach the necessary gap voltage for uranium operation including a comfortable safety margin.

INTRODUCTION

The UNIversal Linear ACcelerator UNILAC (Fig. 1) at GSI (Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany) will serve as main operation injector for the Facility for Antiproton and Ion Research FAIR (Fig. 2 and [1,2]). The UNILAC is able to deliver ion beams (protons [3] up to uranium) for different experiments in parallel (pulse-to-pulse switch mode) with individual ion species and energies. For the upcoming FAIR project an update of the UNILAC in terms of high beam intensities, quality, and high availability is required. The construction of a completely new Alvarez-DTL 2.0 will fulfill these requirements with new beam dynamics [4]. Additionally, an increased shunt impedance per surface field on the drift tubes [5] is essential for the new RF-design (Table 1) [6]. The First-of-Series (FoS) Alvarez-Cavity was planned as the first section of the first tank of the new Alvarez 2.0 and was used for extensive prototyping. The RF-design study with CST-simulations [7] of the FoS-Cavity [8,9] was verified with a scaled model [10–12] and the mechanical cavity design [13] ended with successful LLRF-measurements of the copper plated FoS-cavity [14].

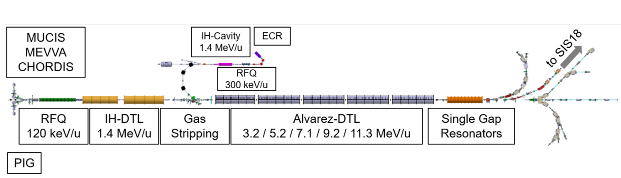

Figure 1: Schematic overview of the upgraded GSI UNILAC with five individual Alvarez-type post-stripper DTLs.

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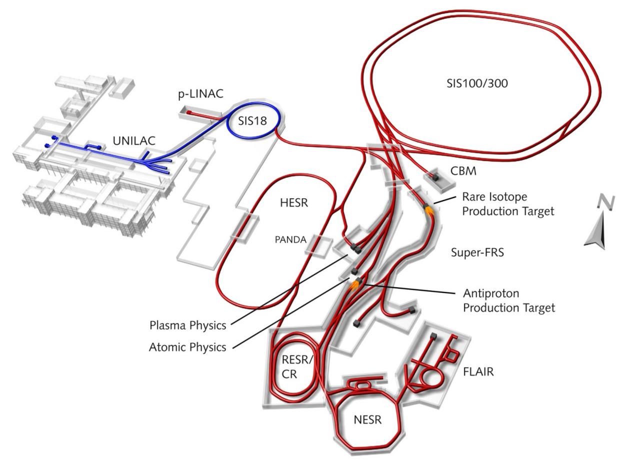

Figure 2: Schematic overview of the current GSI (blue) and the new FAIR complex in the complete expansion stage (red).

Table 1: Parameters for the Upgraded UNILAC

Parameter	Unit	Value
RF-frequency	MHz	108.408
A/q		≤ 8.5
Max. Current	mA	1.76×A/q
Synchronous phase	deg.	-30 / -25
Input beam energy	MeV/u	1.358
Output energy	MeV/u	3.0 – 11.3
Hor. emittance (norm., tot.)	µm	≤ 0.8
Ver. emittance (norm., tot.)	µm	≤ 2.5
Beam pulse length	ms	≤ 1.0
Beam repetition rate	Hz	≤ 10
Alvarez-cavities	#	5
Drift tubes / cavity	#	25 – 52
Drift tube length	mm	109.9 – 327.0
Drift tube diameter	mm	180 – 190.3
Aperture diameter	mm	30 / 35

FOS ALVAREZ CAVITY SECTION

The First-of-Series cavity (Table 2) [15] is the first tank section of the Alvarez 2.0-DTL (Fig. 3). The empty drift tubes were fabricated internally at the GSI workshop for a cost-effective high power RF-test campaign. After copper-plating of all components [14], time-consuming mounting, and challenging adjustment of the drift tubes including media supply had to be carried out in preparation for the RF-test.

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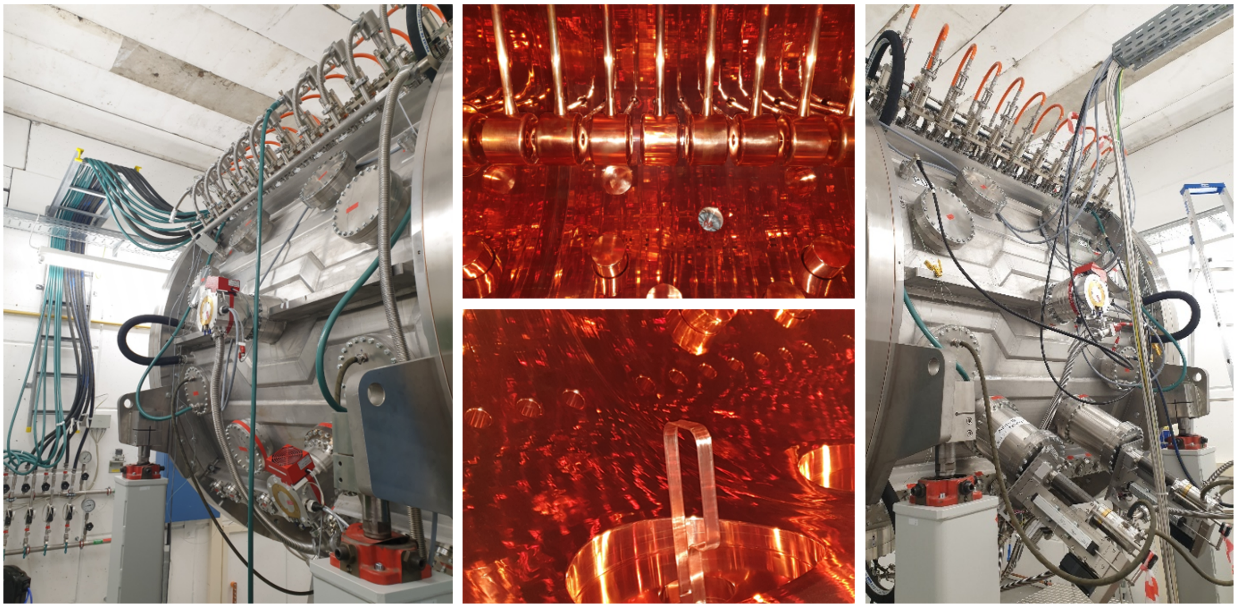

Figure 3: The copper plated FoS-Alvarez cavity section with a length of 1.9 m and 11 drift tubes. The drift tubes are installed at the top of the tank, but other combinations are possible. The bottom houses RF coupling and an service access. The new inductive incoupling loop for a 6 1/8" rigid RF-line is connected to the 1.8 MW RF-power amplifier. Three vacuum pumps and two dynamic plungers are installed at the FoS cavity.

Table 2: Parameters of the FoS-Alvarez-Cavity

Parameter	**Unit**	**Value**
RF-Frequency	MHz	108.408
Input energy	MeV/u	1.358
Output energy	MeV/u	1.705
Gaps	#	12
Gap length	mm	40.5 – 44.6
Drift tubes	#	11
Drift tube length	mm	109.9 – 121.0
Drift tube diameter	mm	180.0
Aperture	mm	30.0
Tank diameter	mm	1952.6
Tank length	mm	1880.5
Total power (sim.)	kW	318
Q - Factor (sim.)		82000

Low Level RF-Measurements

The incoupling loop is connected to a 6 1/8” rigid RF-line and has an S_{11}-parameter of -26.2 dB at an angle of about 30 degrees in the electric field without vacuum. The change in penetration depth of the dynamic plunger is 23.2 mm for a constant operating frequency at 1000 mbar and 7.6×10^{-7} mbar, respectivelly. The Alvarez-DTL 2.0 will use four dynamic plungers per cavity and for the RF-testing with the FoS-Alvarez, just one dynamic plunger was used (2nd plunger was available, but not necessary) to change the frequency in operation within the linear range.

RF-Conditioning

The high power RF-conditioning at the FoS cavity was carried out with an 1.8 MW amplifier [16] in the second half of 2021. This power amplifier for short pulse operation build by Thales [17] has been in regular operation at the existing Alvarez-DTL (A.IV) since the beam time 2019. For the RF-test a new 6 1/8" rigid line between the RF-gallery and the test cave was installed and the inductive incoupling loop has been S_{11}-optimized. The frequency spectrum shows no parasitic modes close to the operation frequency (neighboring frequencies: 67.2 MHz and 130.4 MHz). The ω_0-regulation controls the dynamic plunger ($\varnothing_a$ 190 mm) with a z-axis precision manipulator [18] to keep the operating frequency constant. The RF-conditioning of the FoS-cavity has been divided into three test modes. Uranium and non-uranium operation (Table 3) as well as the testing of the maximum possible RF-power coupling. For reasons of time, the conditioning did not start with low RF-power and then gradually increasing the RF-performance. The powerful 1.8 MW amplifier allowed to increase quickly the RF-power to high levels. This jump meant that the entire pulse was not in the flat

Table 3: FAIR-Relevant RF-Parameters for the FoS-Alvarez.

Parameter	Unit	**Uran-Beam**	**Non Uran-Beam**
Repetition Rate	Hz	10	10
Beam Pulse length	ms	1.0	< 2.5
RF-Power P_f	kW	269 + 40 %	≪ 269

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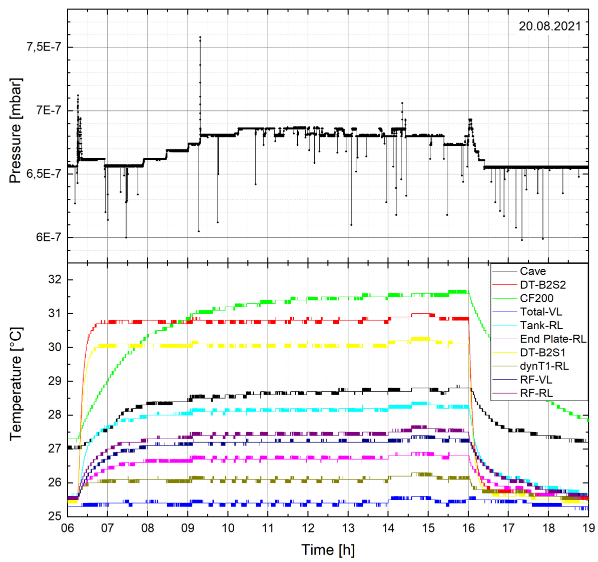

Figure 4: Measured vacuum pressure (top) and temperature (bottom) for constant RF-operation of the FoS-Alvarez at P_f=333 kW, P_r=3.3 kW.

top and the tank was conditioned from high to lower power, while the desired high RF-coupling could already be preconditioned in parallel. The repetition rate was at 10 Hz throughout the conditioning campaign, while the pulse length was varied. The RF-conditioning started on Juli 28, 2021 and for a short time, the conditioning had to be done manually at the beginning. The RF-amplitude control became operational on August 4, 2021 and the ω_0-control has been activated on August 10, 2021. After conditioning the reverse RF-power was about 1% of the forward RF-power. The tank pressure during the RF-conditioning was in the range of 7×10^{-7} mbar with a pump capacity of 2100 l/s (Fig. 4 top). The temperature increased at an uncooled DN 200 CF blank flange from about 25.5 °C to 31.5 °C and the water cooled drift tubes at constant RF-operation with P_f=333 kW remained at 31 °C

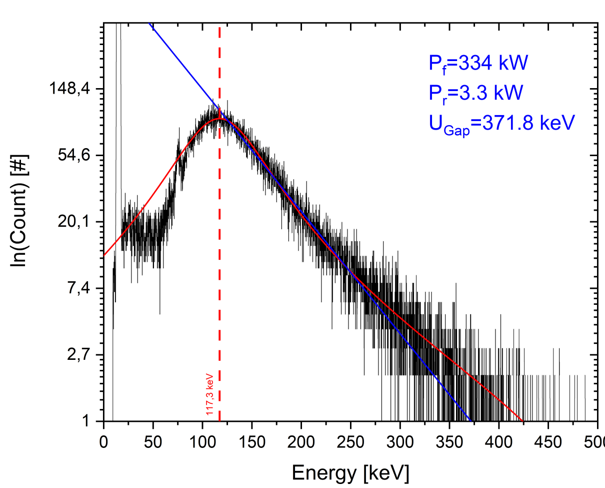

Figure 5: Gap voltage verification with X-ray energy measurement for the forward RF-power.

at the uncooled front side (Fig. 4 bottom). The drift tube of the new Alvarez-DTL has just a water cooled mantel and no active end plate cooling.

The gap voltage has been verified with X-ray energy measurements (Fig. 5). The channels on the gamma spectrometer have been calibrated with the excitation energies of ^{241}Am (E_γ=1771 keV) and ^{152}Eu (E_γ=2200 keV). Several gamma spectra were measured during the RF-conditioning and an example of the uranium beam operation with safety margin is shown in the Fig. 5. The gap voltage estimated from the X-ray energy measurements for the uranium case as well as other RF-settings confirmed the gap voltages corresponding to the RF-power expected from simulations.

OUTLOOK

After the successful RF-test, tendering of all Alvarez-tank sections has started. At the present time the first Alvarez-tank (2x end plates and 5x tank sections) are already being built and will be delivered in Q1 2023. A study of the longest drift tube with an aperture of 35 mm has been started and 52 drift tubes for the first tank have been tendered.

The FoS-Alvarez tank will continue to be used as an RF-test stand in order to have an RF-load available for necessary RF-investigations on the Thales high-power amplifier.

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The full performance high power RF-test was a milestone of the R&D work for the new Alvarez-DTL 2.0 and we would like to thank our colleagues of different GSI departments like Linac-RF, Vacuum Systems, Galvanic Workshop, Technology Laboratory, Transport&Installation and Mechanical Workshop for giving strong support to develop and test the FoS-Alvarez.

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