ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOGE19

STATUS OF THE NEW INTENSE HEAVY ION DTL PROJECT ALVAREZ 2.0 AT GSI

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Abstract

The Alvarez-type post-stripper DTL at GSI accelerates intense ion beams with A/q ≤ 8.5 from 1.4 to 11.4 MeV/u. After more than 45 years of operation it suffers from aging and its design does not meet the requirements of the upcoming FAIR project. The design of a new 108 MHz Alvarez-type DTL has been completed and series components for the 55 m long DTL are under production. In preparation, a first cavity section as First-of-Series has been operated at nominal RF-parameters. Additionally, a prototype drift tube with internal pulsed quadrupole has been built and operated at nominal parameters successfully. High quality of copper-plating of large components and add-on parts has been achieved within the ambitious specifications. This contribution summarizes the current project status of Alvarez 2.0 at GSI and sketches the path to completion.

INTRODUCTION

The existing post-stripper DTL at GSI is in operation since more than 45 years. Accordingly, it suffers from increased failure rates especially of the e.m. quadrupoles inside the drift tubes. Its design has some conceptual shortcomings with respect to the high intensity demands of the upcoming FAIR facility [1]. These issues are addressed by the construction of a completely new DTL section. Subsequently, the DTL's design features are briefly summarized followed by description of extensive prototyping of critical components and procedures. Finally, the status of series production is reported, followed by an outlook on the future project planning.

GENERAL DESIGN

Like the current DTL, the new section will accelerate ions up to the injection energy of the subsequent synchrotron SIS18. All species up to the mass-to-charge ratio of A/q=8.5 are accelerated, corresponding to FAIR's reference ion of $^{238}U^{28+}$. Five cavities with lengths of about 11 m each are operated at 108.4 MHz with peak powers of up to 1.35 MW including beam loading. Figure 1 plots the new DTL together with some RF-design details of the first cavity. The normal conducting DTL covers a beam repetition rate of up to 10 Hz with flat top RF-pulse length of up to 1.0 ms corresponding to the beam pulse length. Within the cavities, transverse FDDF focusing is provided with a zero current phase advance of 65°. The large intensities cause transverse tune depressions of up to 40% along the first cavity [2]. Longitudinal focusing is from RF-phases of

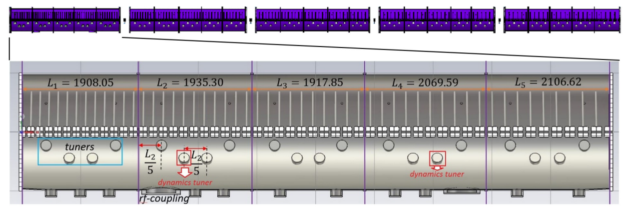

Figure 1: New post-stripper DTL Alvarez 2.0 being under construction at GSI.

-30° along the first three cavities and -25° along the last two ones. Cavities are separated by four identical inter-tank sections which serve for 3d beam envelope matching by three quadrupoles and one re-buncher. The inter-tank sections provide also for a beam current and phase probe, a sector valve, and a transverse beam profile measurement set-up.

Although the machine is mainly designed as an injector for the synchrotron SIS18, several low-energy experiments shall be served as well. The DTL design allows for switching off the RF-power of the last cavities while the transversely focusing quadrupoles inside the drift tubes remain switched on. Accordingly, the DTL output energies correspond to the individual cavity exit energies of 3.212, 5.173, 7.142, 9.237, and 11.318 MeV/u. The quadrupoles are pulsed, such that the focusing can be adapted individually to each ion species and design energy; the latter can be changed between the individual DTL pulses, i.e., within less than 100 ms. The DTL design is described in detail within the dedicated Technical Design Report [3] and the main design parameters are listed in Table 1.

Table 1: Main Design Parameters of GSI's New Post-stripper DTL Alvarez 2.0

Parameter	Value
Ion A/q	≤ 8.5 ($^{238}U^{28+}$)
Input beam energy	1.358 MeV/u
Output beam energy	3.212 – 11.318 MeV/u
Electrical beam current	1.76 emA· A/q
Transv. tune depression	≤ 40 %
Beam pulse duration	0.2 – 1.0 ms
Beam repetition rate	≤ 10 Hz
Number of cavities	5
RF-frequency	108.408 MHz
max. RF-power per cavity	1.35 MW
RF-sources per cavity	1
Transv. focusing scheme	FDDF
Total length	55 m

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PROTOTYPING

Prior to launching series production, the critical steps in production and assembly were investigated by the design, construction, and RF-operation of a First-of-Series (FoS) cavity section, namely the first of five sections comprising the first cavity (Fig. 2 left). The most critical issue in cavity

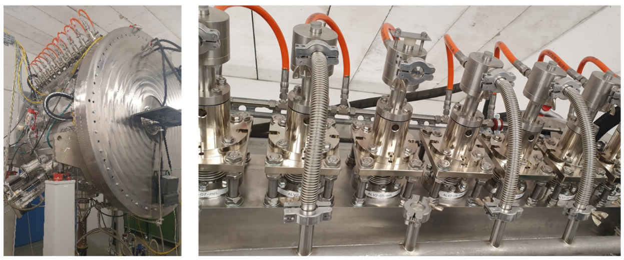

Figure 2: First-of-Series cavity section used for prototyping.

production is provision of the correct inner cavity radius. From MWS simulations it has been concluded that the mean inner radius (first cavity 972.8 mm) is to be met with a precision of better than 0.15 mm and the maximum deviation from this value along the circumference must not exceed 2.0 mm. These requirements are to be met for a total of 25 cavity sections at reasonable cost. Figure 1 illustrates in more detail the first cavity, being equipped with 36 static and four dynamic tuners allowing for a tuning range of ± 270 kHz. The cavities' tight mechanical tolerances have to be combined with huge cavity dimensions and the strong demands on the final inner surfaces' roughness of R_z 6.3.

Each drift tube must be suspended by two stems for provision of a cooling channel for the RF-heating and for water flux leads to the internal quadrupole. The stem's suspension serves also as a mean for alignment of the drift tube's axis along the beam axis (Fig. 2 right). Installation of the stems is from the cavity's inside and accordingly each cavity is equipped with a maintenance opening of 500 mm in diameter for human access and to pass the stem. Suspension and alignment of the tubes are other critical issues to be addressed during the prototyping phase.

The drift tube caps feature free-hand shapes [4], i.e., not comprising just constant radii and straight sections. This shape has been optimized for each cavity individually and is defined by 486 fixed points $r(z)$. Compared to simpler shapes, it allows for higher shunt impedance at given surface field strengths or vice versa. The latter has been set to a maximum of 1.0 E_K. The low RF-duty cycle allows for restriction of tube cooling to the mantle, i.e., the end caps are cooled indirectly. Testing of this simplified cooling has been part of the prototyping. A first set of tubes without quadrupoles has been produced in-house [5] and was used for RF-testing described in detail in [6].

Production of the 200 drift tubes including the internal quadrupole is one of the most critical project paths. Space boundaries are very tight, especially at the beginning of the DTL. The quadrupole must meet field requirements, be well-fixed and aligned inside the tube, and finally be supplied with cooling water. In order to assure reliable operation for many decades, the electrical current lead and coils shall be realized without solder joints and simultaneously well-fixed in order to withstand mechanical vibrations from Lorentz forces during pulsed operation.

Along the first cavity the beam aperture radius is 15 mm and along the other cavities it is 17.5 mm. Quadrupoles are grouped into seven families with two different yoke apertures. The shortest drift tube of the DTL (first cavity) has been successfully built and tested last year. This study provided for realistic figures on the cost and timeline for the production of the series (about 200 tubes). Figure 3 shows two photographs taken during production of this tube. Production of the longest DTL tube (last cavity) will start in Fall.

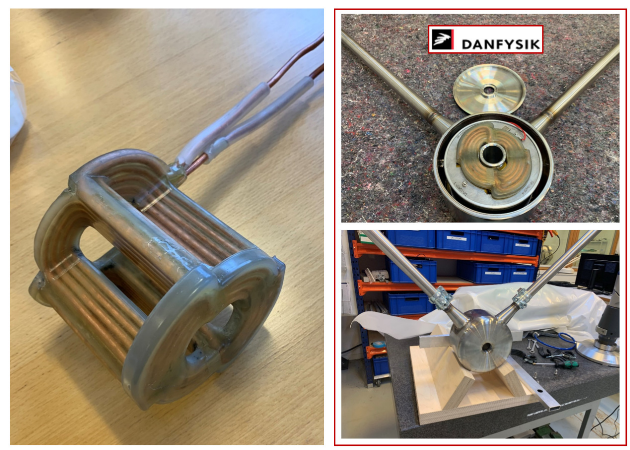

Figure 3: Production of the first drift tube of the first tank including an internal e.m. quadrupole.

COPPER PLATING

The total inner cavity surfaces sum up to about 400 m^2 and must be copper plated with a layer of about 120 μm inhabiting the conductivity of about 96% IACS. GSI's workshop has plated cavity mantles of comparable size more than 20 years ago. Since then, regulations, procedures, and electrolytes have been modified. Accordingly, the process needed to be re-validated using a dedicated dummy cavity of equivalent size. This comprised heavy handling, tailoring, positioning, and fixation of the anodes as well as defining the different bathes compositions. Finally, the duration and strength of the applied electric currents needed to be determined. Figure 4 illustrates some of the various steps of plating the dummy cavity.

Since GSI's in-house galvanic facility will be fully loaded with the 25 cavity sections' mantles and 10 end plates, all additional parts (especially the 200 stems and drift tubes) need to be plated externally. This add-on part plating is another critical project path. Within the realization of the FoS cavity, a potential partner has been identified and the resulting fully coppered cavity is shown by the photograph of Fig. 5.

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Figure 4: Illustration of the copper plating procedure of a dedicated dummy cavity at GSI's galvanic facility.

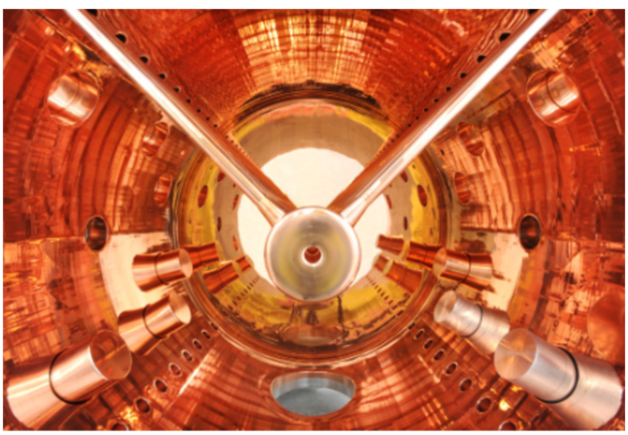

Figure 5: Finally copper plated and assembled First-of-Series cavity section prior to high power RF-testing.

SERIES PRODUCTION

RF-testing is described within the dedicated contribution [6]. It shall be briefly mentioned that all design RF-parameters have been met and even exceeded. Visual inspection of the FoS cavity afterwards did not reveal any damages to the copper surface. Cooling of the cavity mantle and the drift tubes worked as expected even at power levels that exceeded the design values by 40%. These tests have been completed in late 2021. Within the same year, tendering of the series production of the cavities has been prepared. Accordingly, RF-testing finished in-time to place the order for series cavity production in early 2022. The order comprises the 25 cavity sections as well as the 5×2 cavity end plates. Production of the mantles and end plates is ongoing and Fig. 6 depicts rolling and welding of a cavity section at the beginning of August. Copper plating is planned to take place upon arrival of each cavity section on-site, respectively. The sections comprising the first cavity shall be delivered in Spring 2023 and all sections shall be on site at the end of 2025.

Figure 6: Rolling and welding of a cavity section.

Tendering of the 52 drift tubes including internal quadrupoles of the first cavity (15 mm of aperture) has been started in Spring. Two bidders have been identified and the order shall be placed in January 2023. The orders for the tubes with 17.5 mm of aperture will be placed upon successful testing of the according prototype in Spring 2023. Currently, a production rate of about one tube per week is anticipated and series delivery is expected to last from 2023 to 2026. This must be well matched to the tubes' copper plating and according negotiations with potential providers are ongoing.

Tendering and ordering of various add-on parts has been started. Seven ground bodies of high power RF-coupling loops were ordered in late 2021. Sealing and alignment of the stems is by 400 bellows which are under production as well as 12 RF-pick-up probes. A total of 200 tuners will be installed of which 10% are dynamic. Single components for tuners have been ordered. Their final immersion lengths will be determined from low-level RF-measurements at each of the assembled cavities. During these measurements, tuning and field optimization [7] is done using 40 manual dummy tuners per cavity made from aluminium. These tuners will be ordered soon.

Current planning foresees the DTL to be ready for installation in 2027. However, the exact time slot for installation will be determined in view of the overall FAIR project status at that time.

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