A prototype for a new 108 MHz CW RFQ for the HLI

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With the aim of developing a completely newly revised cw capable 4-rod RFQ structure for the HLI, a 108 MHz prototype with six stems was designed at IAP based on the already approved concepts from the RFQs for FRANZ and MYRRHA [1, 2]. The structure was manufactured by NTG [3] and has been delivered to IAP in November 2017. Besides for the required cooling capabilities regarding cw operation, the prototype was optimized for the prevention of mechanical vibrations of the electrodes. This was taken into consideration because the currently operated HLI-RFQ suffers from severe modulated power reflections, which evidently originate from rf affecting mechanical electrode oscillations [4, 5] and impose restrictions to stable operation as well as limit the achievable performance. The simulated properties of the prototype design shall be validated by measurements investigating the mechanical behaviour and rf performance.

RF & Mechanical Design

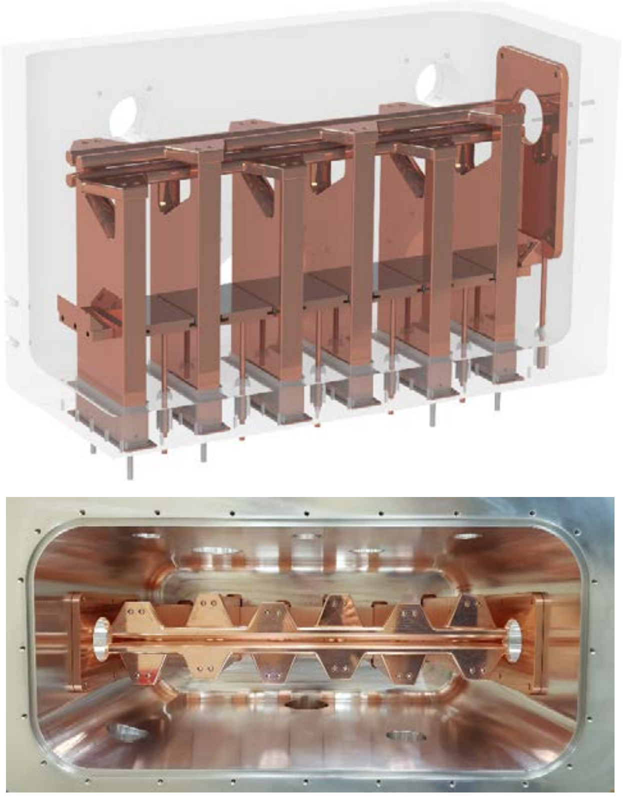

Figure 1: Rendered sectional view of the 6-stem RFQ prototype with transparent tank (above) and top view (below).

Figure 1 depicts the mechanical design of the prototype structure, which features six stems with a height of 283 mm at a distance of 120 mm. The stem arms of the lower electrode have a sideways offset of 15.9 mm (see top view) for dipole compensation. The electrode profile is non-modulated with an aperture radius of 4 mm and an electrode radius of 3 mm. The overall electrode length (including the overhang) is 702 mm. The tank is fitted with four diagnostic vacuum windows facing the electrodes for the purpose of vibrometer measurements.

Prototype Properties

The expected shunt impedance is 115 kΩm, corresponding to a power loss of 31.3 kW/m at a reference electrode voltage of 60 kV. The electric dipole component is expected to be compensated entirely. According to first estimations considering the simulated mechanical resonance response (see Figure 2) the rf affecting electrode vibration amplitudes are decreased by a factor of 20 compared to the existing HLI-RFQ.

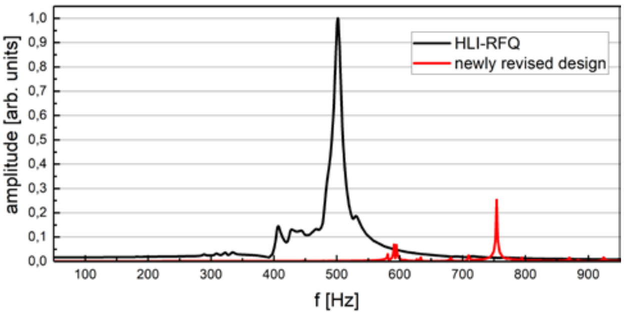

Figure 2: Comparison of the simulated mechanical resonance response for the existing HLI-RFQ and the newly revised (prototype) design (with 1 % damping ratio).

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Upgrade of the HITRAP ion trap and charge breeding system

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Production of a new cooling trap

A new design for the HITRAP cooling trap was proposed in order to improve its stability and voltage rigidity [1]. Based on this design, new electrodes were machined, gold plated and prepared for installation in 2017. The biggest challenge was the appropriate choice of insulating material between the electrodes, which needed to be thermally conductive at the same time. The very limited choices were put down to:

Material	*Conductivity*	*Hardness*	*Price*
Sapphire	40 W/mK	very high	high
Shapal ™	220 W/mK	medium	high
BIN77 ™	80 W/mK	medium	medium

Finally BIN77 was chosen as the most suitable candidate due to acceptable thermal conductivity, machinability into complex forms and moderate price.

Short-circuits, broken cables or discharges were so far the biggest issue, causing repeated opening and closing of the trap. A way to circumvent that problem is to reduce the number of cables, provided by a smaller number of electrodes in the new trap design, as well as to keep all trap components on a similar HV. As a consequence, the voltage in the trap is not higher than 8 kV for the outer electrodes and 1 kV for all other with respect to neighbouring electrodes. Besides, the cables also do not have large potential differences between each other, so that standard cables can be used, eliminating the existing sensitive cable connection system. The chosen cables are listed in the table below:

Type	*HV*	*Heat load*	*coax.*
UT-141B-SS Stainless steel	9600 V	10 mW/m	yes
312-KAP-MAN-025 Manganine	6000 V	0.2 mW/m	no
TFCC-020 Konstantan	500 V	0.1 mW/m	no

The finished electrode assembly of the new trap can be seen in the figure below. Assembly inside the superconducting magnet and first tests are planned for 2018.

Figure 1: New electrode stack of the HITRAP cooling trap, Photograph by J. Viering, Master thesis in preparation, TU Darmstadt

Charge breeding of metallic ions in an EBIT

The SPARC-EBIT (Electron Beam Ion Trap) has been successfully in operation as a test ion source for HITRAP for already 10 years [2]. It can routinely perform charge breeding and deliver up to 10^6 highly charged ions produced either from inert gasses or from externally injected singly charged ions [3]. The gas-based procedure is by far favourable because of its simplicity and higher yields. However, many elements, especially metals, are difficult to find in gaseous form and thus difficult to produce.

A solution to that problem was investigated with the so-called MIVOC (Metal Ions from VOlatile Compounds) method [4]. It takes advantage of a relatively large vapour pressure of organic compounds with weakly bound metallic ions to produce sufficient quantities of gaseous material for injection into the EBIT. Iron, Antimony and Boron compounds were chosen for the first studies [5], listed in the table below:

Compound	*Formula*	*vap. pressure*
Ferrocene	$Fe(C_5H_5)_2$	10^{-2} mbar
Triphenylantimon	$Sb(C_6H_5)_3$	10^{-5} mbar
Trimethylborat	$B(OCH_3)_3$	10^2 mbar

Applying vapours of these gasses inside the EBIT, the trapping, i.e. charge breeding time was varied for different gas pressures. The charge state composition of the ejected ions was analysed with a dipole magnet and by the time-of-flight method. Results have shown that production of various charge states of all three test candidates was successful. With an electron energy of about 5 keV it was possible to produce Fe^{21+}, Sb^{35+} and B^{5+}. For TOF analysis the ions were transported some 10 m along the HITRAP low-energy beamline [3] with efficiency close to 100%. The limiting factor turned out to be the dipole magnet, which was not able to separate all antimony charge states and isotopes. Nevertheless, the results show the feasibility of the MIVOC method which significantly increases the number of elements and charge states possible to produce and deliver to experiments at the HITRAP EBIT facility.

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Experiment proposal: E130
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PSP codes: none
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First beam acceleration at the heavy ion cw-Linac Demonstrator

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A standalone superconducting (sc) cw-Linac is assumed to meet the demands of GSI users on high duty factor beams at its best. Additionally, with significantly higher beam intensity the SHE production rate will be increased as well. The cw-Linac layout is based on sc Crossbar H-Mode (CH) cavities, efficient multi-cell structures combining the advantages of sc and long room temperature cavities [1]. Recently, the first Linac section (financed by HIM and GSI) as a demonstration of the capability of 217 MHz multi gap CH structures has been commissioned and extensively tested with argon and helium beams from the GSI High Charge State Injector HLI at the test demonstrator test cave.

Demonstrator test setup

The demonstrator setup, embedded in a new radiation protection cave, is located in straightforward direction of the HLI. The liquid helium (LHe) supply is covered by a 3000 l tank, while the consumed helium gas is collected in a 25 m^3 recovery balloon and bottled by a compressor. The demonstrator comprises a 15 gap sc CH-cavity embedded by two superconducting solenoids; all three components are mounted on a common support frame. The support frame, as well as the accelerator components, are suspended each by eight tie rods in a cross-like configuration balancing the mechanical stress during the cool down and warm up. The beam focusing solenoids provide maximum fields of 9.3 T, the free beam aperture is 30 mm. The solenoids are connected to LHe ports inside the cryostat by copper tapes allowing dry cooling. The sc CH-cavity (Fig. 1) is the key component and offers a variety of research and development opportunities.

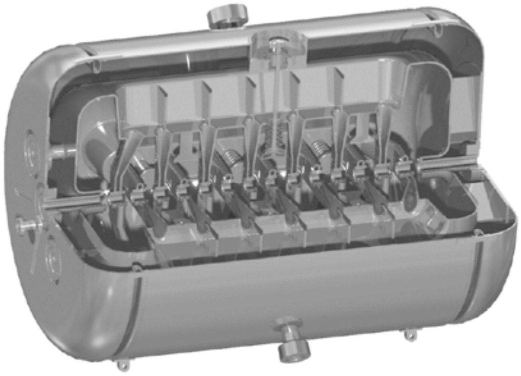

Figure 1: Sectional drawing of the 15-gap demonstrator CH-cavity.

First beam acceleration

At June 28th of 2017, after successful rf-testing of the superconducting rf-cavity in 2016, setting up the matching line to the demonstrator and short commissioning and ramp up time of some days, the CH-cavity accelerated Ar^{11+} ions with full transmission for the first time up to the design beam energy of 1.866 MeV/u (ΔW_{kin} = 0.5 MeV/u). For the first beam test the sc cavity was powered with 10 Watt of net rf-power providing an accelerating voltage of more than 1.6 MV within a length of 69 cm. Further on the design acceleration voltage of 3.5 MV has been verified and even exceeded by acceleration of beams with high rigidity (A/q = 6.7). Argon and helium ion beams with different charge states from an ECR ion source ($^4He^{2+}$, $^{40}Ar^{6+, 9+, 11+}$) were accelerated at the HLI for further beam tests with the demonstrator. For longitudinal beam matching the re-buncher settings were adapted according to the mass to charge ratio, as well as the acceleration voltage.

Systematic beam measurements

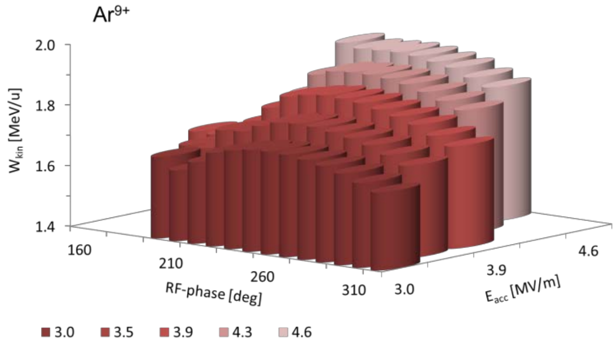

Figure 2: 3D-scan of Ar^{9+}-beam energy versus accelerating gradient and RF-phase.

In Fig. 2 a full measured 3D-scan of beam energy for a wide range of different accelerating fields and rf-phases is depicted. A linear increase of beam energy with ramped accelerating gradient could be observed for different rf-phase settings, while the beam transmission is kept high. To gain for the maximum beam energy at a given accelerating gradient the rf-phase has to be adapted slightly. In general these measurements confirm impressively the EQUUS beam dynamics, featuring effectively the non-resonant beam acceleration up to different beam energies without particle loss and without significant beam quality degradation. As measured with helium beam and recently confirmed by beam dynamics simulations, for lighter ions maximum beam energy of up to 2.2 MeV/u could be reached with the demonstrator cavity.

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New results on development of 2.7 Hz operation for heavy elements from high current ion sources

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To produce high intensity heavy ion beams with SIS100 for the future FAIR experiments such as NUSTAR, CBM and APPA a special operation mode of UNILAC is required. It will be necessary to provide four beam pulses of 100 µs length each within 1.1 s and inject them into SIS18 [1]. That corresponds to operation of the ion sources with 2.7 Hz repetition rate. For light and intermediate-mass elements (with ion charge state $q_{ion} \leq 3^+$ required for injection into the RFQ) there should be no difficulties, but for heavy elements ($Q_{ion} = 4^+$) as Au, Pb, Bi and U this is challenging. Operation of heavy elements from high current vacuum arc ion source VARIS [2] is well established with 0.5 Hz / 0.5 ms for Au, Pb and Bi using the composite materials in the cathodes [3,4], as well as with 1 Hz / 0.5 ms for U using pure material in cathodes. Thus, the operation repetition rate has to be increased almost by a factor of 6 for Au, Pb and Bi and by a factor of 3 for U.

Tests with bismuth

As shown earlier [3,4], the production of 4^+ ion beams with a flat top of more than 100 µs in temporary profile for Au, Pb and Bi is not a trivial task, and it does not work with pure materials due to their physical properties. As solution, the composite materials with modified physical properties have been used in the cathodes. Stable operation of high current 4^+ ion beam has been achieved for all three elements by using the following compositions: Au-Cr (50% Wt.), Pb-Cu (40% Wt.) and Bi-Cu (40% Wt.). However, stable operation was only possible with a low repetition rate (0.5 Hz) and long conditioning time (up to 2 hours) was noted generally for all cathodes. Further investigation of used cathodes with SEM (scanning electron microscope) have shown that the material structure plays an important role in cathode performance. In order to keep an optimal material ratio (desired/admixed) on the working surface of the cathode during the whole operation lifetime, a special production procedure has been applied: Cu formed in a "litz wire" structure was heated up and homogeneously filled with liquid Bi. As the result, a particular material structure has been achieved for Bi-Cu (40% Wt. or 69% At.) cathodes.

Two cathodes of a new type have been manufactured for tests. The tests were performed in Sep. 2017 at terminal North with VARIS. Various operation modes have been tested: 1 Hz / 2 Hz / 2.8 Hz with beam pulse lengths between 0.3 and 0.4 ms. The test results were very successful: is was possible to get stable Bi-operation even with 2.8 Hz repetition rate achieving up to 10 mA of Bi^{4+} ion beam current in UH1-section (in front of the HSI-RFQ). The new type cathodes require much shorter conditioning time: 5 mA of Bi^{4+} beam current was reached after 15 min. operation with 1 Hz, and a full performance − after 30-40 min. The operation lifetime of the cathodes was estimated to about 20 hours by 1 Hz / 0.35 ms and about 8 hours by 2 Hz / 0.4 ms.

Tests with uranium

Increasing the repetition rate from 1 Hz to 2.8 Hz at U-operation with VARIS leads to an increasing of a surface temperature of the cathode, growth of the neutrals flux from the surface during the beam pulse, as well as an increasing of a temperature of extraction electrodes. That causes a number of inhibiting factors for operation, such as arc ignition failures, shifting the ion spectrum to the lower charge states and sparking in the extraction system of the ion source. These factors result in the loss of operation stability and general performance drop of the ion source. One of the possible solution of this problem is modifying the physical properties of the cathode material, improving the thermal characteristics and refractoriness by admixing a more refractory metal. Tungsten has been chosen as the admixed material to uranium. After study of the production possibilities of U-W composition a set of the test cathodes with U-W (5% Wt.) and U-W (12% Wt.) has been manufactured by Framatome company (formal AREVA GmbH) for the tests at GSI.

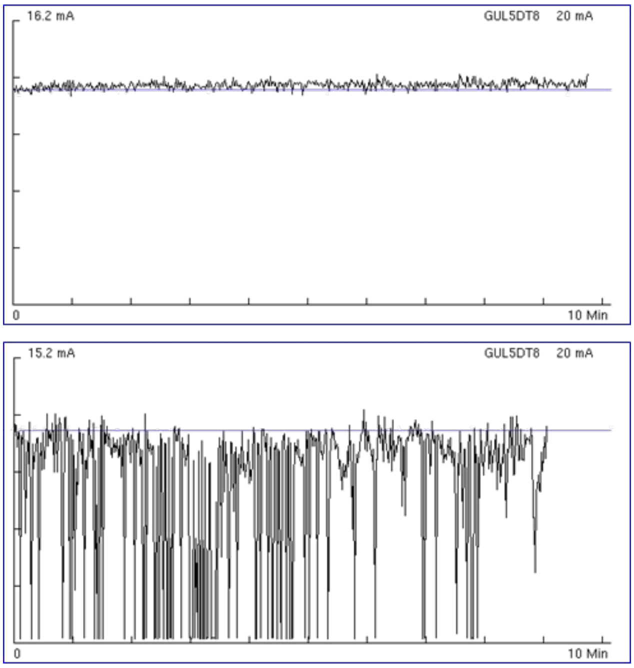

Figure 1: Operation stability of U-W composite cathode at repetition rate of 2.8 Hz recorded over 10 min. during the stable (upper) and unstable (lower) phases.

The tests were performed in the period from Sep. 2017 to Feb. 2018 at terminal North and have shown quite promising results: it was possible to get a stable operation by 2.8 Hz / 0.4 ms (total beam pulse length) with up to 18 mA of U^{4+} beam current in UH1-section (Fig.1). The pulse shape of U^{4+} beam had an appropriate temporal structure with over 120 µs flat top and very low (for vacuum arc ion sources) intensity fluctuations: <10%. Taking into account also excellent pulse-to-pulse repetition stability with fluctuations below 10% (Fig.1) all this represents the perfect conditions for tuning the ion beam in the UNILAC and further injection into SIS18. The conditioning times of the cathodes were pretty short: 10-15 min. at 2.8 Hz.

Figure 2: Shrinkage cavities in U-W alloy, formed during the production process.

Nevertheless, there was one notable disturbing factor observed generally for all test-cathodes: so called "unstable phases" in cathode operation. These are the operation phases with extremely unstable burning of the arc discharge leading to beam intensity fluctuation up to 70% during the pulse as well as with very high rate of arc ignition failures: more than 50% of the beam pulses were missing. Figure 1 demonstrates the operation stability of U^{4+} ion beam during both stable (upper) and unstable (lower) phases. It was noted, that during the first hours of cathode operation the bad phases were short (5-10 min.) and appeared seldom (in average one per hour). While closer to the end of the cathode lifetime these phases were longer (up to 30 min.) and appeared more often. The average operation lifetime of one U-W cathode reached up to 7 hours by 2.8 Hz repetition rate. The total time of unstable phases was ~1.5 hours per cathode. The origin of unstable phases in cathode operation is not clear at the moment and has to be further investigated. A possible reason could be shrinkage cavities inside the U-W composition material, formed conceivably during the cooling phase of the production process. Figure 2 shows one of such cavities located on side surface of the cathode.

Conclusions and outlook

The use of particular "litz wire" Cu-structure in Bi-Cu composite cathodes has allowed to increase the repetition rate for Bi-operation to 2.8 Hz (requested by FAIR) and to reduce the conditioning time of cathodes by a factor of three. It is planned to implement and test this new structure with Pb-Cu cathodes. In the case of successful tests the new type composite cathodes with enriched Pb-isotopes (^{206}Pb and ^{208}Pb) will be used in the beamtime in 2018. The use of U-W composition in the cathodes could be the possible solution to reach the FAIR requirements for the operation duty cycle for U^{4+} ion beam if the factor of unstable phases will be excluded. To understand the origin of the unstable phases it is planned to investigate the material and the surface structure of used U-W cathodes under the scanning electron microscope (SEM) in cooperation with Framatome GmbH (Erlangen).

The recent development status for all four heavy elements with respect to the future FAIR requirements is summarize in the Table 1.

Table 1: Currently achieved ion beam parameters for heavy elements in UH1-section (in front of the HSI-RFQ)

Ion sort	Achieved parameters		Efforts w.r.t. FAIR requirements
	Beam current	Rep. rate	
Au^{4+}	4 mA	1 Hz	intermediate
Pb^{4+}	6 mA	0.5 Hz	intermediate
Bi^{4+}	10 mA	2.7 Hz	few
U^{4+}	15 mA	< 2 Hz	large

The last column introduces the future efforts to achieve the requirements of FAIR experiments. For Bi the required ion beam parameters are already achieved, however manufacturing procedure of composite cathodes with particular structure has to be routinized. For Au and Pb the operation repetition rate has to be increased that could require further development on composition materials for cathodes. The biggest efforts are expected for U: not only the operation repetition rate has to be increased, but also a beam brilliance. It will be required to achieve 23 mA of U^{4+} ions inside an emittance of 260π mm·mrad in front of the HSI-RFQ [5].

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CW LINAC Advanced Demonstrator beam dynamics investigations

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For future experiments with heavy ions near the coulomb barrier within the super-heavy element (SHE) research project a multi-stage R&D program of GSI/HIM and IAP is currently in progress. It aims for developing a superconducting (sc) continuous wave (CW) LINAC with multiple CH cavities as key components downstream the High Charge State Injector (HLI) at GSI. The LINAC design is challenging due to the requirement of intense beams in CW mode up to a mass-to-charge ratio of 6 while covering a broad output energy range from 3.5 to 7.3 MeV/u with minimum energy spread. After successful tests with the first CH-cavity in 2016 demonstrated a promising maximum accelerating gradient of 9.6 MV/m, the worldwide first beam test with this sc multi-gap CH cavity in 2017 was a milestone in the R&D work of GSI/HIM and IAP [1]. In the light of experience gained in this research so far, the beam dynamics layout for the entire LINAC is recently being updated and optimized.

Beam Dynamics Simulations

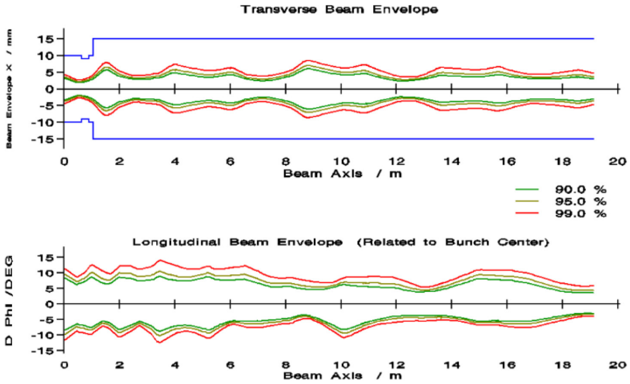

Figure 1: Transv. (x) and long. (phase) envelopes for a LINAC setup as shown in Fig. 3; LORASR-simulations with $A/q = 6$, 100001 particles and $I = 0$ mA.

Up to now, the reference design for the CW LINAC dates back to the proposal of Minaev et al. in 2009 [2]. Meanwhile, significant expertise has been gained in design, fabrication and operation of superconducting CH-cavities and the associated components. In this context, a revision of the beam dynamics layout was recommended. Optimized cavity layouts resulted in modified voltage distributions. Furthermore, the cryomodule layout and inter-tank sections were specified in a more detailed way. Promising RF- and beam testing with the 15-gap CH0 showed, that higher accelerating gradients can be achieved, thus leading to a more efficient design approach. Consequently, extensive beam dynamics studies are carried out to determine the best layout with respect to the beam and all other RF and mechanical requirements. Figures 1-3 show an exemplary layout, which has been currently studied. Applying an accelerating gradient of up to $E_a = 7.1$ MV/m for the CH-cavities results in acceleration from 1.4 MeV/u up to 8.0 MeV/u (thus exceeding the required 7.3 MeV/u of final energy). For further details please refer to [3].

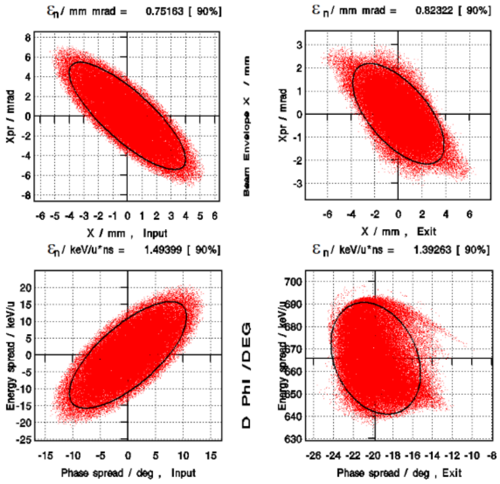

Figure 3: Phase space distributions for the recent beam dynamics layout; top: x - x', bottom: $\Delta\varphi$ - ΔW, left: Input for first cryomodule, right: Output of fourth cryomodule.

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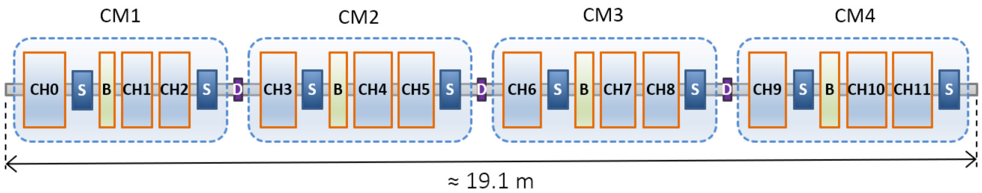

Figure 2: Exemplary LINAC layout with twelve superconducting CH-DTLs in four cryomodules. Captions: CM = Cryomodule, S = Solenoid, B = 2-Gap-Buncher, D = Diagnostics.

Development and upgrade of the ECRIS facility

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Double Frequency Heating

Experimental investigations at the ECRIS (Electron Cyclotron Resonance Ion Source) test bench were carried out with the aim to enhance the extracted ion currents in pulsed mode. In the so called afterglow mode an increase of pulse current of highly charged ions is obtained by pulsing the microwaves feeding the plasma [1]. The current of the highly charged ions can also be significantly raised by applying microwave based techniques like frequency tuning or double frequency heating. Recent experimental results proved that the combination of microwave frequency tuning and afterglow operation mode allows to further enhance the intensity of pulsed highly charged ion beams [2]. In order to analyse the effect of superimposing different frequencies in pulsed mode and in CW mode the experimental set-up at the CAPRICE-ECRIS shown in Fig. 1 has been used. A coaxial power combiner is installed to connect the two microwave generators to the TWTA (Traveling Wave Tube Amplifier). A waveform generator modulates the amplitude of a microwave generator to provide for the microwave pulses for the afterglow mode. For the present investigations argon was used as main gas with helium as support gas.

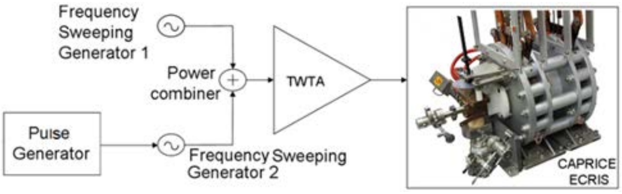

Figure 1: Block diagram of the experimental set-up.

After tuning the ECRIS parameters with a single microwave generator set at 14.5 GHz in cw mode for optimized production of Ar^{12+}, frequency sweeps were performed to identify frequencies showing enhanced intensities with respect to 14.5 GHz. The highest intensity of Ar^{12+} was measured at 13.125 GHz. Therefore 14.5 GHz and 13.125 GHz were chosen for the multiple frequency injection. In pulsed mode different duty cycles were investigated for a pulse period of T_p = 100 ms. The highest afterglow intensity is obtained for a duty cycle of 40% (pulse length of 40 ms). So this combination was used for the experiments. When setting the two microwave generators to the same optimized frequency no enhancement of the afterglow current is observed. A current intensity enhancement, both for the steady state current and for the afterglow peak is observed only when the pulsed power is provided at 14.5 GHz and the CW power is provided at the optimized frequency of 13.125 GHz (see Figure 2). Figure 3 shows a comparison of argon spectra obtained in pulsed mode with single frequency and in double frequency operation (pulsed power + CW power). For each setting the maximum intensity of the afterglow peak (AG) and in the steady state range (StSt) is presented. It appears that the superposition of cw power and pulsed power for optimising the afterglow intensity is sensitive to the selected frequencies. However, the single frequency tuning combined with the afterglow mode turned out to provide the highest and widest afterglow peaks of high charge state ion beams from the ECRIS [3].

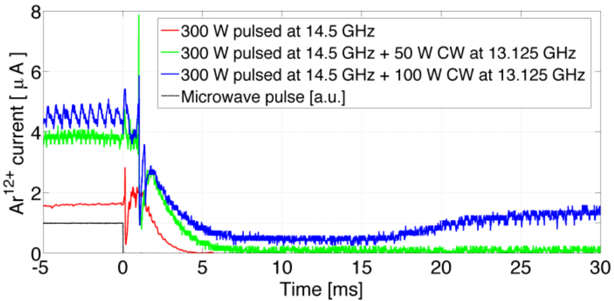

Figure 2: Ar^{12+} currents when the microwave generators are set at different frequencies.

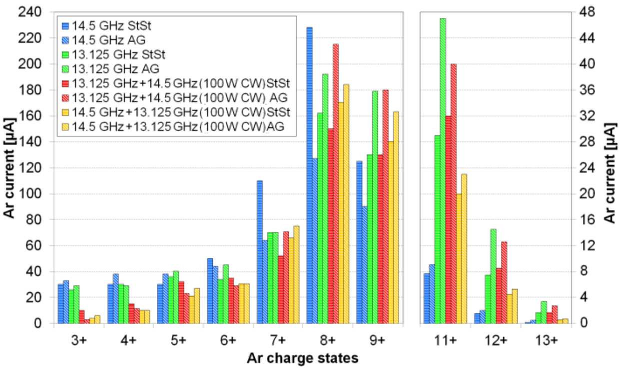

Figure 3: Ar spectra for different single frequencies and for the combination of two microwave frequencies in pulsed mode (AG: AfterGlow) and cw mode (StSt: Steady State). (Different scale for Ar^{11+} to Ar^{13+}; right)

Collaboration on ECRIS technologies

The EU-ENSAR2-MIDAS networking activity (NA) is a collaboration of teams developing ECRIS and beams for the needs of the ENSAR2 facilities [4]. The ECRIS team of GSI is participating together with corresponding teams from Finland (JYFL), France (GANIL, LPSC), The Netherlands (RUG-KVI-CART), Hungary (ATOMKI), Spain (UCLM) and CERN. The objective of the MIDAS-NA is to enhance the networking and dissemination of best practices between the partner teams.

In the framework of this collaboration a first training workshop on microwave technologies for ECRIS was organized at GSI. During the workshop theoretical and practical knowledge about the handling of microwave devices and components was imparted and the main issues about microwave generators, resonance cavities and coaxial/waveguide components for the implementation of microwave lines for plasma generation were handled. Operation methods of the ECRIS like frequency tuning by sweeping the microwave frequency and double frequency

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heating by combining two microwave generators were experimentally executed. Active discussion sessions provided a good dissemination and exchange of knowledge.

Upgrade of ECRIS Injector at the HLI

At the High Charge State Injector (Hochladungsinjektor HLI) of GSI the CAPRICE ECRIS is in operation since 1992. The total number of its operating hours delivering beam to the accelerator exceeded more than 5000 hours per year. Even though upgraded repeatedly the ion source and its ancillary equipment show age related deterioration. In order to maintain the availability and reliability of the machine a program has been started to upgrade and improve the infrastructure equipment of the ECRIS. In 2017 this comprised the reconditioning of the high pressure water cooling system of the ECRIS including the replacement of thermal sensors and flowmeters to achieve a contemporary standard. In addition a reconditioning of the current leads and connectors was performed. The interlock system of the ion source and the supply units is subject to an extensive renewal by replacing the former relay technique by a modern PLC based system. The development and implementation of this system is ongoing and will be performed stepwise. It will provide a detailed fault memory which facilitates an easy fault analysis during operating periods.

Performance upgrade of ECR Ion Sources

Besides the degradation of the infrastructure equipment the technical standard of the CAPRICE ECRIS itself is outdated nowadays and implies the replacement by adequate technologies.

Future user defined ion beam requests comprise FAIR science (APPA, CBM, NUSTAR) as well as UNILAC science (SHE physics & chemistry, materials research, biophysics, plasma physics). Main requests concern the increase of available intensities of established ion beams, but also the availability of novel ECRIS ion beams to be developed, both including beams of rare isotopes.

In order to follow these raised requirements an evaluation was performed, as to which strategy is to be pursued to provide enhanced performance and availability of ion beams from ECRISs for GSI/FAIR.

For ECRISs a well-established and proven semi-empirical scaling law indicates the proportional dependence of the achievable ion beam intensity of a given ion species A^{q+} on the square of the ECR-frequency. This directly implies the increase of the microwave operating frequency which in turn requires the proportional increase of the B-field of the magnetic confinement. For highest magnetic fields superconducting magnet systems are indispensable.

Generally cw operation of the ECRIS perfectly fulfils the requirements of a cw-LINAC, while pulsed afterglow operation is fully compatible with synchrotron requirements (up to 10 pulses per second from the ion source).

Finally, the following two-step approach is proposed as upgrade strategy. At a first stage a moderate upgrade with a conventional ECRIS operating at 18 GHz as replacement of the 14.5 GHz CAPRICE ECRIS is intended. A full performance upgrade with a Superconducting-ECRIS operating at frequencies beyond 22 GHz, installed at a separate injection beam line, is planned as second stage. Two redundant injection lines are foreseen in order to provide high flexibility for utilizing the appropriate ion source depending on the demands of the requested ion beam. Furthermore it would greatly improve the availability of ion beam in case of a failure of one of the ion sources.

Presently promising projects on 18 GHz ECRISs utilizing new technologies and new materials are pursued based on well-established techniques:

HIISI (University of Jyväskylä, Finland) utilizes a permanent magnet hexapole and conventional room temperature (RT) solenoid coils [5], while AISHA (INFN-LNS Catania, Italy) applies a hybrid concept with a permanent magnet hexapole and LHe-free SC solenoid coils [6].

28 GHz SCECRISs have already proven to be capable of providing considerably increased intensities of highly charged ions beyond those of an 18 GHz ECRIS. Utilizing established cryogenic technology adjustable axial and radial magnetic fields are provided for optimum adaptation of the working point for medium and high charge states. During the past decade several projects have been realized like VENUS-SCECRIS at LBNL (USA) [7], RIKEN-SCECRIS at RIKEN (Japan) [8] and SECRAL-SCECRIS at IMP-Lanzhou (China) [9].

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Accelerator infrastructure: UNILAC
PSP codes: none
Grants: EU-H2020 contract No. 654002 - WP3 - NA3

Shutdown report 2017

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This report is a follow up of the shutdown report 2016 [1] and describes the further development of the main service and upgrade measures of the GSI accelerator facilities, which were started in 2016 and will be continued until mid-2018. The presented information is based on the work of the shutdown coordination and the corresponding MS-Project shutdown schedules.

General Overview

In July 2016 began the longest shutdown GSI has ever seen. It is expected to end in May 2018. The bulk of the workload was finished in 2017.

The coordination process was continued as described in the last report: In weekly meetings with the machine coordinators and representatives of all involved departments, including civil construction and infrastructure, the actual progress is monitored, pending work and critical incidents are discussed and the overall schedule is adapted accordingly.

Work Packages

Civil construction

The largest work package is the civil construction project GAF (GSI Anbindung an FAIR, Link of GSI to FAIR), which comprises additional shielding of SIS18, fire protection measures, as well as the connection of the new beam line tunnel towards FAIR to the existing TR hall. In 2017, it was complemented by the project WTK (Westwand TransferKanal, west wall of the transfer line building), which comprises a beam dump for the planned proton linac and preparation works for the p-linac building at the west side of the transfer channel.

GAF and WTK works are ongoing, tasks inside the SIS18 ring tunnel must be stopped end of April, forcing some rest work to be postponed until after beam time 2018.

One issue of these construction works was water penetrating into the SIS18 tunnel and in an electronics room: extensive cleaning works caused interruptions of other tasks for several weeks. Another issue was the shift of the transfer channel building during WTK. This forced us to break the vacuum and open the beam pipe.

UNILAC

The modernization of post-stripper RF systems at the UNILAC, which started in 2015, was continued. This project comprises a prototype Thales power amplifier for Alvarez 4, refurbishment of control racks and new high voltage power supplies.

This project was severely impaired by two issues:

- During a test of the emergency switches, a main power switch was damaged, and left the RF gallery without electricity for nearly 3 months.
- The refurbishment of the Heating, Ventilation and Air Conditioning (HVAC) system of the UNILAC tunnel was scheduled to interrupt the RF works from September until December 2017. Instead, stable conditions of the air cooling could only be reached mid-March 2018.

Thus, three of the 5 Alvarez power amplifiers are left unchanged and need to be refurbished in the next shutdown period. Several tasks for the refurbishment need to be finished and all renewed systems still need to be tested.

Remaining issues with the ventilation of the RF systems need to be solved urgently to ensure enough test time for the RF systems and stable operation during the beam time 2018.

The refurbishment of UNILAC vacuum controls had to be postponed, beam time 2018 has to be operated with the old vacuum control system (age of component ~40years). Therefore higher failure rates must be tolerated, causing extra effort for remedial maintenance. We expect several issues per month, taking 3 hours each for repair.

Cooling water leaked into the beam pipe in the transfer channel, in the TK3 stripper section. This issue caused a lot of effort for repair: The TK3 section has been opened and about 400 l of water were removed. All profile grids in the section TK3 were removed and had to be replaced. Faraday cups, phase probes and transformers were removed and had to be cleaned.

Control system

The retrofitting of the FAIR control system to SIS18, ESR and HEST is progressing well. To ensure a smooth commissioning several Dry Runs were scheduled beginning October 2017 to test all devices with the new control system. The control system refurbishment also implies beam diagnostics upgrades and the implementation of modern consoles for SIS18 and ESR in the main control room. These consoles are the first of series for the new FAIR control room consoles and are already used during the Dry Runs.

ESR

The vacuum refurbishment of the ESR northern arc is progressing well. Bake-out is scheduled for June 2018.

Repair of a short-circuit fault in the electron cooler of the ESR was aborted. During the preparation, asbestos-containing heating jackets were found. They will be disposed according to official directives and afterwards, the section will be closed and baked out.

HEST

The shutdown work in the HEST concentrates on the upgrade of the HADES beam line with respect to the aperture and beam diagnostics. The new vacuum chamber is installed and the installation of the new beam diagnostics will be ready for beam time 2018.

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For the HEST vacuum we expect a more reliable operation due to replacement of old ion getter pump controllers and of old total pressure gauges.

The preparation for the Mini CBM is ongoing and should be finished in time.

SIS18

The new transformer station North (SIS18/SIS100 pulse power) was successfully commissioned and power tests of the new dipole power converter with maximum ramp rates and pulse power started in March 2018.

All three modules of the new h=2 RF cavities have been installed. A new high frequency cavity for smoothing of the spill structure is under construction and sector 11 is prepared for the installation.

The magnet GTS1MU1 will be replaced by a new one, which will steer the extracted beam from SIS18 either to the fragment separator, to the experimental hall or to the upcoming SIS100. The new magnet has been delivered. However, the corresponding beam pipe is delayed. Hence, the old magnet will be used in 2018.

Alignment

Due to civil construction not only in GAF but also for the new FAIR buildings, the accelerator tunnel floors moved significantly and the corresponding accelerator components accordingly. In the transfer channel, there are significant displacements in horizontal and vertical direction (~1cm). Vertically the SIS18 is moving down significantly in the east-northeast direction. Re-adjustment in a tilted plane is planned to minimize general adjustment and offset towards HEST. Nevertheless, survey and alignment is estimated to take 2-3 months.

Others

Development of the cw-demonstrator is completed. The first tests with beam are completed and showed good results.

The commissioning of CRYRing is proceeding well. Many features of the new control system were tested there during the implementation work for the retrofitting to SIS18.

Shifted Tasks

Several tasks had to be shifted to the next shutdown period after beam time 2018:

The electrostatic acceleration section of terminal north has not been renewed. However, development of high current sources proceeded well.

The refurbishment of UNILAC vacuum controls had to be postponed.

A major part or the refurbishment of the UNILAC RF systems needed to be rescheduled in the next shutdown.

The beam pipe for the new magnet TS1MU1 will not be delivered in time, therefore, the old magnet will be reinstalled.

The budget for the new chopper in the transfer channel was late, thus the old one is used and higher failure rates are expected.

The new IPM (profile measurement) in SIS18 is not yet ready.

The beamline from FRS to ESR will be refurbished later.

The repair of the short-circuit fault in the ESR electron cooler was postponed.

Status and Outlook

In March 2018, preparation of the beam time is under way. Many tasks have to be fulfilled timely in order to start the user beam time as scheduled. The main risks are:

The air cooling of the UNILAC RF systems may not run reliably.

The commissioning of the RF systems, new and legacy, may reveal unexpected problems.

The new power connection together with the new main magnet power supplies of SIS18 must be commissioned successfully (AEG-Tests).

Bake-out of SIS18 and ESR bears an intrinsic risk of resulting in a vacuum leak. This would delay commissioning by 2-3 weeks.

Survey may reveal an ongoing movement of the accelerator buildings. This would increase the effort for the alignment and might compromise the performance of the accelerators and/or the beam quality.

References

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Experiment beamline: none
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC / SIS18 / ESR / FRS / CRYRING / HEST
PSP codes: none
Grants: none
Strategic university co-operation: none