HIGH CURRENT ION SOURCES FOR THE FAIR ACCELERATOR FACILITY

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Abstract

Vacuum arc ion sources and filament driven multi cusp ion sources are used for the production of high current ion beams of a variety of metallic and gaseous ions at the GSI accelerator facility.

For the future project FAIR (Facility of Antiproton and Ion Research) it is foreseen to provide in addition to the existing ion beams a high current proton beam from a separate linear accelerator (plinac) and an exclusive high current uranium beam from a new ion source injector.

The contribution gives an overview of the performance of the existing high current injector and presents the challenges for the future injectors for proton and uranium production.

INTRODUCTION

The GSI facility is known as an accelerator with a variety of ion species within a wide range of energy at the end of the accelerator. Two ion source platforms arranged as a "Y" deliver ion beams for the universal linear accelerator UNILAC [1] (the high charge state injector HLI equipped with an ECR is not topic of this paper). One of it is equipped with a Penning ion source the other allows the operation with MUCIS, MUCIS2010, CHORDIS, MEVVA and VARIS ion sources.

For low energy experiments (3.6-11.4 MeV/u) with high duty factor the ion source Penning [2] is used generally. With this working horse we are able to offer a multiplicity of ion species with a large range of mass over charge ratio (A/ζ) [3]. For injection into the synchrotron SIS18 for high energy experiments (up to 4 GeV/u) the ion sources MUCIS, MUCIS2010, CHORDIS, MEVVA, and VARIS are used generally at low duty factor.

The specific injection energy for the RFQ is 2.2 keV/u with its space charge limit of 0.25×A/ζ [mA]. The acceptance of the RFQ is 138π mm mrad within a maximum mass over charge ratio of 65.

The article gives an overview of ion source data and injection parameter of most important ion species generated from the high current injector. Due to the fact that experiments at GSI request a wide range of beam intensity (single particle up to 10^{11} per spill) the reached ion source intensities do not assign the physical limit, even when the ion source operates with non-enriched material.

LOW ENERGY BEAM LINE

Fig. 1 shows the low energy beam transport section (LEBT) from the high current terminal (terminal north) to the radial matching section of the RFQ [4]. The Penning terminal (terminal south) with its LEBT section is not shown here, because it is equipped with the same components.

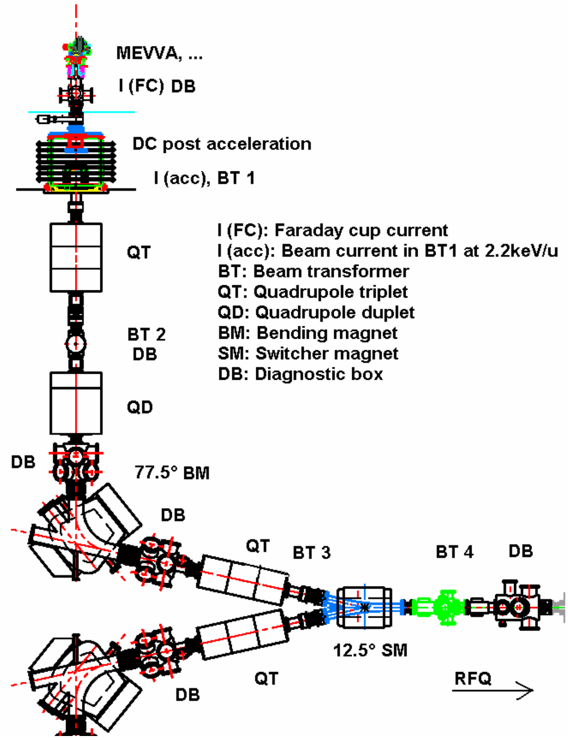

Figure 1: High current LEBT section of the UNILAC.

Close behind the ion source the LEBT section consists of a dc-post acceleration system to meet the right specific injection energy of 2.2 keV/u. In combination with the extraction system of the ion source it allows to accelerate the lightest ion species ${}^{1}H_3^+$ with an acceleration voltage of 6.6 kV up to ${}^{124}Xe^{2+}$ with 136.4 kV. A quadrupole triplet and doublet belong to the first transport section, followed by a 77.5° bending magnet for separation of the desired ion specie and charge state. The 12.5° switching magnet operates in a 50 Hz switching mode to allow the injection into the RFQ simultaneously from terminal north (max 5 Hz) and south (max 50 Hz) with two different ion species. Faraday cups, beam transformers, diagnostic grids and horizontal and vertical slits are installed to analyze the ion beam. A quadrupole quadruplet finally matches the ion beam into the RFQ.

HIGH CURRENT ION SOURCES

The ion sources MUCIS, CHORDIS, MEVVA, and VARIS are well described in the references [5-8]. All these ion sources are equipped with the same multi aperture 13-hole triode extraction system. The aspect ratio

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is 0.5, whereas the emission area is 0.92 cm^2. Generally high current ion sources are operated in the space charged limited extraction mode (SCLEM) compared to the emission limited extraction mode (ELEM) like an ECR ion source. Therefore, the extracted ion beam intensity is limited by the electrical field strength for a fixed geometry of the extraction system. Using special material for the extraction system (Elconite®) and preparation of the system under special conditions we reach field strengths of up to 11 kV/mm.

Filament Driven Ion Sources

The MUCIS and MUCIS2010 are filament driven volume type ion sources for gaseous ion production. Depending on the generated ion species the filament is made from tungsten or tantalum. All ion sources are equipped with up to six single filaments. The axial symmetric plasma chamber is equipped with permanent magnets for plasma confinement (cusp field Halbach configuration). The ion source operates generally with a duty cycle of 5 Hz and a pulse length of approx. 1 ms. Typical emission current densities are in the range of 30-120 mA/cm^2.

Table 1: Ion species for gaseous ion production from filament driven ion sources

ion	I_{FC} [mA/kV]	I_{ACC}/I_{RFQ}/SCL [mA]	current fraction [%] 1+/2+…
$^{1}H_3^+$	40/6.6	15/1/0.75	H_1:37, H_2:8, H_3:55
$^{2}H_3^+$	90/13.2	50/2/1.5	D_1:30, D_2:5, D_3:65
$^{14}N^+$	20/10	12/2.5/3.5	N:69, N_2:31
$^{12}CH_3^+$	30/8	12/1.2/3.75	div., C, H, CH,...
$^{14}N_2^+$	35/12	25/5.5/7	N:50, N_2:50
$^{20}Ne^+$	60/13	26/4/5	80/20 nat. mat.
$^{40}Ar^+$	65/20	42/20/10	80/20
$^{40}Ar^{2+}$	50/16	16/1.5/5	65/35
$^{80}Kr^{2+}$	60/22	28/0.15/10	17/53/29
$^{86}Kr^{2+}$	80/23	34/9/10.75	48/45/7 enriched
$^{132}Xe^{3+}$	25/18	17/0.02/11	79/18/3
$^{136}Xe^{3+}$	40/21	18/0.8/11.3	78/21/1 enriched
$^{136}Xe^{3+}$	40/21	18/0.07/11.3	78/21/1 nat. mat.

Table 1 gives an overview of ion species generated for standard operation. I_{FC} represents the ion beam current in the Faraday cup close behind the ion source with the corresponding extraction voltage. The beam current which is accelerated to 2.2 keV/u is given by I_{ACC}, the beam current in front of the RFQ by I_{RFQ}, and the space charge limit of the RFQ is given by SCL. The CHORDIS is equipped with a smaller plasma chamber compared to the MUCIS and MUCIS2010, the plasma electrode is on cathode potential, which results in a higher extracable emission current density, and the electron repeller inside the plasma chamber is electrically and not magnetically controlled compare to MUCIS type. For these ion sources the maximum charge state is one fold if the ion source is operating in the high density plasma mode. In consequence only for low plasma density operation it is possible to shift the mean charge state from one to two fold, e.g. for krypton or xenon operation.

The emittance of these low ion temperature ion sources is given by the geometry of the extraction system and the divergence angle. For all these ion sources the divergence angle is between 30 and 40 mrad, the outer diameter of the multi aperture extraction system is 20.5 mm. This results in an emittance value of roughly 500π mm mrad (320π mm mrad for the 90 % 4-rms value). The lifetime of the ion sources is limited by the lifetime of the filaments and in the range of several days (for xenon) up to weeks (for hydrogen).

Vacuum Arc Ion Sources

Vacuum arc ion sources of MEVVA and VARIS type are used for metallic ion production and for aggressive gases like oxygen. Here oxygen is used as an auxiliary gas and will be ionised in a secondary plasma process. These ion sources use a high density vacuum arc for plasma production. External magnetic fields and auxiliary gases influence the plasma production in a way that it is possible to shift the mean charge state from one fold up to four fold. Therefore, there is a wide range of ion species from these ion sources for the synchrotron injection. Table 2 summarize ion species for metallic ion production for GSI´s vacuum arc ion sources.

Table 2: Ion species for metallic ion production from vacuum arc ion sources

ion	I_{FC} [mA/kV]	I_{ACC}/I_{RFQ}/SCL [mA]	current fraction [%] 1+/2+…
$^{24}Mg^+$	80/18	28/2/6	24/62
$^{40}Ca^{2+}$	40/15	15/5/5	6/94
$^{58}Ni^+$	60/22	40/8/14.5	72/22/5
$^{58}Ni^{2+}$	60/18	17/5/7.25	8/76/16
$^{94}Mo^{2+}$	50/18	19/0.5/11.75	6/56/28
$^{100}Mo^{2+}$	50/18	19/0.5/12.5	6/56/28
$^{107}Ag^{2+}$	40/18	23/3/13.4	13/81/6
$^{142}Nd^{3+}$	80/28	32/1.5/11.8	0/4/87/9
$^{150}Nd^{3+}$	80/28	32/0.4/12.8	0/4/87/9
$^{181}Ta^{3+}$	75/24	31/7/15.1	0/0/56/35/8
$^{181}Ta^{4+}$	80/24	34/8/11.3	0/0/35/51/13
$^{197}Au^{4+}$	207/32	50/4.5/12.3	0/10/40/43/7
$^{208}Pb^{4+}$	210/32	46/6.5/13	0/0/30/65/5
$^{209}Bi^{4+}$	120/32	46/15/13	0/0/17/64/19
$^{238}U^{4+}$	150/35	55/20/15	0/0/18/67/15

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A typical repetition rate for these ion sources is 1 Hz with a pulse length of 0.5 ms. The explosive ion generation process in vacuum arc ion sources results in a higher transverse energy of the ions compared to low ion temperature filament driven ion sources and therefore in a larger divergence angle. For the vacuum arc ion sources the minimum divergence angle is 90 mrad resulting in 1000 π mm rad for the total emittance and 650π mm mrad for the 90 % 4-rms value. The explosive plasma generation process defines the transverse ion energy, which strongly depends of the material. However, the relation between longitudinal and transversal energy is the same for all materials. Therefore, the emittance (divergence angle) is not a function of the material.

FUTURE INJECTORS

Uranium Injector

To meet the FAIR requirements for future ion operation it is necessary to increase the uranium beam intensity from the ion source as well as the duty factor for synchrotron injection. For RFQ injection the uranium beam intensity should be 30 mA for four fold ions within an emittance of 250π mm mrad which is an increase of the beam brilliance by a factor of 2. The repetition rate has to be increased by a factor of 4 (4 Hz). The ion source is able to deliver the requested beam intensity but we have to optimize the dc-post acceleration system to increase the beam brilliance and to reduce the beam losses in the LEBT. Therefore, it is foreseen to build up a new terminal (terminal west) between the two others with a direct two-solenoid injection scheme. To analyze the beam properties and to optimize the transport section the test injector HOSTI was build up. First experiments with a superconducting solenoid and a new compact dc post acceleration system were performed. The analyzed emittances are in the range of 250-350π mm mrad which seems to be sufficient for direct injection into the RFQ. Fig. 2 shows a possible injection scheme scenario for the future uranium injector at the test bench including the ion source, dc-post acceleration system and superconducting solenoid. A slit-grid emittance meter, Faraday cups and beam transformers are installed to analyze the beam quality.

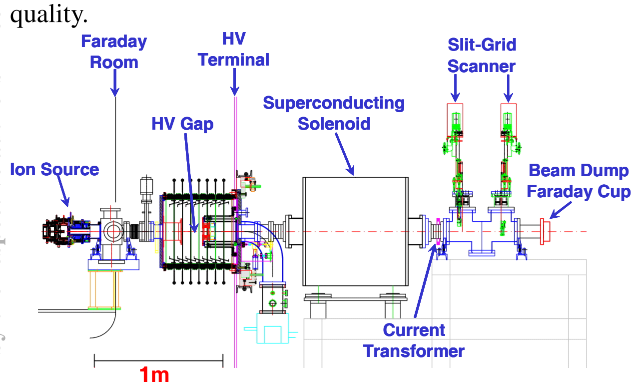

Figure 2: Injection scheme for high current uranium production

Proton Linac (p-LINAC)

The future proton LINAC is a low duty cycle machine which will serve exclusively the synchrotron SIS18. The beam energy is 70 MeV with a desired beam current at the entrance of the SIS18 of 70 mA. The pulse length is 36 µs with a repetition rate of 4 Hz. Over all the p-LINAC has a length of 33 m and working at a frequency of 325 MHz. Many collaboration partners in France (CEA, CNRS, GANIL), Slovenia (ITEC), and Germany (IAP) have their contribution to this project. For the ion source and LEBT CEA-Saclay in France take part to 100 %. The well known SILHI microwave source at CEA Saclay will be reproduced and optimized for pulse operation. For injection into the RFQ a very compact two-solenoid focussing system is foreseen. Table 3 gives an overview of the most important parameter of the ion source and LEBT.

Table 3: Ion source parameter for the p-LINAC

ion source	ECR, 3 GHz
full beam current	<130 mA @ 95keV
proton current	100 mA
proton fraction	>85 %
emittance (rms, n)	<0.3π mm mrad
duty cycle	4 Hz / ~500 µs
extraction system	single hole pentode
availability	>99 %
life time	several months

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