Ion Source Development and Operation

P. Spädtké, J. Bossler, M. Galonska, F. Heymach, R. Hollinger, R. Iannucci, R. Lang, K.D. Leible, K. Ochs, K. Tinschert

ECR Ion Source (ECRIS)

Regular operation at the High Charge State Injector (HLI) was performed for: $^7\text{Li}^+$ (6 d), $^{12}\text{C}^{2+}$ (97 d), $^{20}\text{Mg}^{5+}$ (21 d), $^{48}\text{Ca}^{7+}$ (74 d), $^{54}\text{Cr}^{7+}$ (34 d), $^{124}\text{Sn}^{16+}$ (8 d), and $^{136}\text{Xe}^{18+}$ (7 d). For $^{48}\text{Ca}^{10+}$ a long run of 67 days could be provided characterized by exceptional stability at high intensity level. The lifetime of the oven exceeded 1500 hours while 3 fillings of the crucible were consumed. Taking into account the amount of material recovered from condensation a consumption of only 0.2 mg/h has been achieved which corresponds to an efficiency never reached before. Initiated by a request of a SHIP experiment for a $^{30}\text{Si}$ beam tests were performed at the ECR injector setup (EIS) using natural $\text{SiO}$ to produce a $^{28}\text{Si}^{5+}$ beam by evaporation from the GSI standard oven (STO). $\text{SiO}$ appeared to be the only choice, because the vapor pressure of $\text{Si}$ and $\text{SiO}_2$ are by far too low. An appropriate source setting could be found to provide a stable beam of $\text{Si}^{5+}$ at moderate intensity level for more than 20 hours.

Beam diagnostic tools have to be adapted to the specific requirements of an ECR ion source. To measure the beam emittance a pepper pot device has been reactivated. The pepper pot has a spatial resolution of 5 mm only, but provides information which is not available from a standard slit grid device. The difference between both measurements is that the pepper pot gives a two dimensional subspace of the transverse phase space, whereas the slit grid method is a two dimensional projection of the four dimensional phase space. As an example, the emittance of a singly charged helium beam, directly behind the extraction system is shown in Fig. 1. The ion source has been tuned to a low current mode. Even in that case the characteristic shape of an ion beam extracted from an ECR source can be seen.

Penning Ion Source (PIG)

Regular operation was performed for: $^{20}\text{Ne}^{3+}$ (4 d), $^{22}\text{Ne}^+$ (4 d), $^{27}\text{Al}^+$ (18 d), $^{40}\text{Ca}^+$ (13 d), $^{40}\text{Ar}^+$ (2 d), $^{40}\text{Ar}^{2+}$ (11 d), $^{52}\text{Ca}^{2+}$ (12 d), $^{58}\text{Ni}^{2+}$ (13 d), $^{58}\text{Ni}^{3+}$ (6 d), $^{152}\text{Sm}^{3+}$ (22 d), $^{197}\text{Au}^{8+}$ (14 d), $^{208}\text{pb}^{4+}$ (7 d), $^{238}\text{U}^{10+}$ (8 d), and $^{238}\text{U}^{14+}$ (52 d). The attempt to create a neodymium beam without previous experience failed, indicating the necessity to develop new beams at the test bench before offering them for the regular beam time schedule. Theoretical, experimental, and technical investigations to increase the available ion currents resulted in the design of an accelerated beam extraction system [3].

High Current Ion Sources

Regular operation was performed for: $^{1}\text{H}^+$ (14 d, 1 mA), $^{2}\text{D}^+$ (20 d, 2 mA), $^{14}\text{N}^+$ (3 d, 4 mA), $^{40}\text{Ar}^+$ (6 d, 20 mA), $^{40}\text{Ar}^{2+}$ (23 d, 0.1 mA), $^{40}\text{Ca}^+$ (6 d, 5 mA), $^{58}\text{Ni}^{2+}$ (12 d, 6 mA), $^{70}\text{Kr}^{2+}$ (9 d, 6 mA), $^{86}\text{Kr}^{2+}$ (22 d, 10 mA), $^{106}\text{Mo}^{2+}$ (9 d, 0.5 mA), $^{132}\text{Xe}^{3+}$ (12 d, 0.2 mA), $^{136}\text{Xe}^{3+}$ (16 d, 0.8 mA), $^{142}\text{Nd}^{3+}$ (10 d, 1.5 mA), $^{181}\text{Ta}^{3+}$ (7 d, 7 mA), and $^{238}\text{U}^{14+}$ (2 d, 5 mA). Ion beam current measured in front of the RFQ. In order to study and to compare the beam quality produced by the gaseous ion source CHORDIS and the vacuum arc ion source VARIS transversal beam emittance measurements were carried out with a slit-grid device at the high current test bench. Both ion sources were equipped with the same extraction system. The effective emittance using a multi-aperture system is approximated by a parallelogram that surrounds all single emittance ellipses. The emittance is then given by
\[ \epsilon_{\text{eff}} = 4R\phi/\pi + \epsilon_1. \]

R is denoting the outer hole circle of the apertures, \( \phi \) the beam divergence, and \( \epsilon_1 \) the emittance of one of the apertures. According to this relation the emittance is a function of the beam divergence only if the extraction geometry is given. Fig. 3 (left) shows the emittance pattern of a matched Argon beam (80\% \( \text{Ar}^+ \), 20\% \( \text{Ar}^{2+} \)) at 18 kV extraction voltage, screening voltage is -1.4 kV using the CHORDIS ion source with the multi aperture system. The azimuthal position of the extraction system with respect to the measurement device is such that seven single ellipses are visible in Fig. 3. The ion beam current measured in a Faraday cup is 60 mA. The perveance is 0.0604 \( mA/(kV)^{1.5} \) for a single aperture.

The emittance (90\%, 4rms) is given as black ellipse. It amounts to 320 mm mrad, 0.32 mm mrad normalized. The effective emittance, only influenced by the beam divergence of 45 mrad, is 500 nm mrad. Fig. 3 (right) shows the emittance pattern of a nickel ion beam produced by the VARIS (74\% \( \text{Ni}^{2+} \)). Extraction voltage is 18 kV, screening voltage is -1.2 kV using the same extraction system as the CHORDIS. The ion beam current is 60 mA and thus the perveance is the same as for the argon beam. The emittance (90\%, 4rms) amounts to 645 mm mrad, 0.77 mm mrad normalized. The effective emittance (beam divergence of 90 mrad) is 1000 mm mrad. The different orientation of the emittance patterns is due to the different distance between the extraction system and the measurement device because of the different geometries of the ion sources. Transforming the emittance pattern of argon back to the position where the nickel emittance has been measured is yielding an emittance pattern with the same orientation. The small argon beam divergence of 45 mrad and therefore small effective emittance reflects the cold plasma which is produced by the CHORDIS. The ion temperature for the gaseous ion source is typically in the range of tenth of electron volts. Due to the ion generation process in a vacuum arc plasma the ion temperature is in the order of a few electron volts leading to a larger beam divergence of 90 mrad and therefore to a larger effective emittance which is two times higher as in the case of argon. The large beam divergence is intensified by the high transversal energy of ions in a vacuum arc ion source. The single ellipses of the argon beam are broader as the an in the nickel case. On the one hand this is due to the fact that these are a superposition of two ellipses produced by the ion beam and by the coexisting neutral particle beam. The neutral particles are generated within the extraction system in the first gap between plasma and screening electrode by charge exchange. These ellipses have a slightly different orientation because the ion beam experiences the defocusing effect of the screening electrode while the neutral particle beam remains unaffected by this. This is responsible for a broadening of the single emittance pattern. The measured fraction of these neutral particles may be as high as 20\% of the extracted beam.

Heidelberg Ion Therapy (HIT)

A proton beam has been provided for a period of 19 days for commissioning measurements of the RFQ, forseen for the Heidelberg therapy accelerator. This beam has been provided by a MUCIS ion source at a temporarily build test bench. The dedicated ion sources (Supermanogan ECR ion sources) for this accelerator have been delivered by Pantechnik [5] to the accelerator site of HIT and are ready for assembly at the low energy beam lines.

Uranium Material for the Ion Sources

Future supply of uranium cathodes turned out to be a problem. For the PIG ion source as well as for the MEVVA ion source depleted, metallic uranium (\( \leq 0.3\% \text{ U}^{235} \)) is required. Whereas we simply could buy these kind of electrodes on the market up to 2001, we are now faced with the fact, that the available uranium material is either sintered material or is such as sensitive to atmosphere, that it is unusable within the ion source. Both, sintered materials, and the newly delivered material tends to become dusty during operation, finally the electrode becomes brittle and unusable. In addition, the ion source itself, imposed to the uranium dust become unusable. One problem is, that we are not allowed to machine uranium in our workshop, which makes any modification of the available material impossible. This problem is unsolved in the moment for the MEVVA ion source, but it will become a problem for the PIG source also as soon as all old electrodes have been used.

References

[2] KOBRA3-1NP, INP, Junkernstrasse 99, 65205 Wiesbaden, Germany
[5] Pantechnik S. A.; 12, rue Alfred Kastler, Caen France