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HIGH CURRENT METAL ION BEAM INJECTION EXPERIMENTS

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Abstract

High current beams of metal ions have been efficiently transported through the injector beam line of the UNILAC heavy ion linear accelerator. Using a MEVVA high current metal ion source, a beam current of 20 emA of titanium (all charge states, Q = 1, 2, and 3) was accelerated to an energy of 280Q keV through a single gap accelerating structure, and a current of over 5 emA of Ti²⁺ was measured at the Wideroe entrance some 13 meters downstream. The beam pulses were flat and reproducible. In this paper we describe the source configuration used and the results of the injection experiments.

Introduction

The GSI accelerator complex is presently being upgraded by the construction of a large heavy ion synchrotron, SIS (Schwerionen Synchrotron) [1,2], and storage ring, ESR (Experimenteller Speicher Ring) [3,4]. It is a goal of the GSI program to provide energetic, high current beams of metal ions as well as gaseous ion species from these low duty cycle accelerators, and this is the reason for our interest in the experiments reported on here.

A high current metal ion source has been developed at LBL [5-8], with which beam currents of several hundreds of milliamperes can be produced from a wide range of metals spanning the Periodic Table. We would like to use this unique ion source for the injection of high current metal ion beams into the GSI UNILAC heavy ion accelerator [9-10]. Thus the present work addresses the concern of adapting the MEVVA source to the GSI UNILAC heavy ion accelerator. Previous work on the application of the MEVVA ion source to the GSI accelerator facilities has been reported by Brown et al. [11], Keller et al. [12], and Mueller et al. [13]. In this paper we describe the use of the MEVVA ion source and the results of the most recent series of experiments to adapt the MEVVA to the UNILAC.

Ion Source

The ability of the MEVVA ion source to produce high current beams of metal ions has been well established, but some of the typical beam characteristics have needed improvement for accelerator injector application. Thus, for example, it has often been the case that the beam pulse shape has lacked reproducibility from shot to shot, often with missing pulses. The pulse shape within a single beam pulse has also needed improvement. Finally, the beam noise (fractional beam current fluctuation level) has been seen to vary quite significantly depending on the precise operating conditions; this has given cause for concern both about possible beam loss due to inadequate space charge neutralization, as well as about accelerator RF regulation problems due to the fast changes in beam loading during the pulse.

As well as the original MEVVA II ion source [5,6], we also tried a new source configuration in which the MEVVA cathode stem was attached to an anode chamber of the CHORDIS ion source [14], with a permanent magnet (samarium cobalt) multipole structure incorporated within the plasma region between anode and extractor; the possibility of this hybrid providing an interesting configuration was suggested by Keller and Emig [15]. More details of the MEVVA ion source, including detailed measurements of source performance and ion beam charge state distributions, can be found in the references cited above. The source was tested on a high current beam line test stand that has been described previously [11]. The line is 5 m in length and contains a quadrupole triplet and a dipole analysis magnet, with current transformers and suppressed Faraday cups to monitor the beam transport. The pressure in the beam line was typically in the 10^{-6} Torr range. The ion source was operated in a pulsed mode with 1 pps repetition rate; pulse length was varied in the range 100 µs to 2 ms. In earlier work, an L-C pulse forming network had been used as the arc current power supply and the pulse length was fixed by the L-C configuration. For the work described here a transistor-switched dc power supply allowed the pulse length to be simply controlled.

UNILAC Injection Beam Line

The beam transport line between the ion source within the high voltage terminal and the entrance of the Wideroe pre-accelerator is shown schematically in Figure 1. The elements of the beam line are the high voltage accelerating gap, focussing quadrupole triplets and doublets, and two separate dipole bending magnets. Faraday cups to measure the beam current, and an emittance measuring diagnostic [16], are located along the beam line as indicated. The total length of the beam line is 13 meters.



Fig.1 UNILAC injector beam line.

To inject the beam into the Wideroe accelerator, a particle energy of 11 .7 keV/amu is needed, corresponding to a potential drop of 280 kV for Ti^{2+} . It is convenient for this total voltage to be shared between the ion source extraction voltage and the terminal accelerating gap voltage. A typical voltage split is 25 kV extraction voltage and 255 kV gap voltage. The ion source extractor and the acceleration gap are connected by a drift section of 1 meter. A high gradient single gap accelerator column is used, with gap width 180 mm and aperture diameters 40 mm and 50 mm. This acceleration geometry was designed and has been tested for high current Ne+ experiments [17]; in these experiments up to 40 mA of Ne+ were measured. Behind the acceleration gap a negative screening electrode preserves the space charge neutralization of the beam; a very high degree of space charge neutralization can be inferred from the necessary settings of the beam focussing lenses (magnetic quadrupoles). The pressure along the beam line varies from 5 x 10^{-7} Torr near the terminal to 1 x 10^{-7} Torr near the Wideroe. In these injection experiments, as for the experiments on the test stand beam line, the source was operated at 1 pps repetition rate and 100 µs to 2 ms pulse length.

<u>Results</u>

Triggering reliability of the ion source was improved by an upgrade of the triggering system; a step-up pulse transformer, located close to the ion source, was used to provide a pulse of several kilovolts to the trigger of the MEVVA. We also changed the arc current power supply. For earlier work, an L-C pulse line of pulse length a few hundred microseconds and of impedance about 1 Ohm had been used; such a system provides a simple means of producing the pulsed high current (typically 100 to 200 Amps) needed to drive the MEVVA arc, but the pulse shape shows considerable overshoot because of unavoidable mismatches in the line and load. Thus we replaced the L-C system with the system used for the CHORDIS discharge - a high current dc power supply in series with a transistor switching unit. In this new configuration the arc voltage is switched on some 50 - 100 μ s prior to application of the trigger pulse; when the trigger pulse is applied, the arc current rises in a few tens of microseconds to a steady value determined by a series resistor (1 Ohm), with no noticeable overshoot. The pulse is terminated by switching off the transistor switch. The beam pulses produced with this system were very flat and highly repeatable.

Beam transport was investigated at the high current test bench. The beam current was measured by a Faraday cup in the diagnostic chamber 50 cm downstream from the extraction system of the source. The total (all charge states) titanium ion beam current was 25 mA. Beam current was measured after the dipole charge state analysis magnet using a shielded Faraday cup with an entrance slit of $15 \times 50 \text{ mm}^2$. The total transported beam (the sum of all charge states) was equal to 35% of the metal beam directly after the source. The measured charge state distribution is shown in Figure 2. The Ti^{2+} beam current measured by the Faraday cup was 2.5 mA. Note that the lenses in the beam line were optimized for the Ti^{2+} peak. In Figure 2, the peaks identified as $Ti^{3+->2+}$ and Ti^{2+ -> 1+} refer to ions that are created and extracted in the higher charge state but are charge-exchanged down to lower charge state by collisions with residual gas atoms in the beam line. Thus particles have a velocity corresponding to the higher charge but a charge (at the analysis magnet) corresponding to the lower charge state.





We have found in MEVVA work at LBL that the ion beam current tends to be less noisy when the source is operated at an arc current higher than the minimum at which it is possible to operate. Thus although the source will still work (the arc will ignite) for arc current as low as a few tens of Amperes (for the case of a titanium cathode), beam quiescence optimizes at an arc current considerably higher. In this case however, the plasma density is higher and the extractor geometry and voltage must be appropriately matched. In the new source version investigated here (MEVVA attached to CHORDIS multipole structure) the arc current could be run at a higher level than previously while still allowing good beam extraction, since then the cathode at which the plasma is generated is located some distance from the extractor. The beam noise observed with this new configuration was significantly better than with the earlier version. We plan to carry out further experiments to clarify this aspect of the MEVVA beam behavior.

After making these improvements, the source was installed within the UNILAC injector terminal. A beam current of 20 mA of titanium ions was accelerated through the terminal gap and measured at the first Faraday cup (FC1), located 1.8 m from the source. The ion source extractor was set at 26 kV and the gap voltage was 251 kV. Of the 20 mA thus introduced into the beam transport line a current of 8 mA was measured after the first bending magnet (FC3); at this point charge state selection has been done, and the measured current is in the $\tilde{Q} = 2$ + charge state. A beam current of 5-6 mA was measured at the last cup before entering the Wideroe structure (FC4). Oscillograms of typical beam pulses measured just after the acceleration gap and at the Wideroe entrance are shown in Figure 3. The beam emittance was measured at the location in the beam line indicated in Figure 1; at a beam current of up to about 3 mA of Ti²⁺, the measured emittance was $\varepsilon = 50$ mm mrad. Since the acceptance of the beam line is 80 mm mrad, all of the measured beam is expected to be accepted by the Wideroe structure.



Fig. 3 Beam current pulses of titanium ions in the UNILAC injector beam line.

Upper oscillogram: Just after the 250 kV accelerating gap, 1.8 m from the ion source; 10 mA/cm. (XBB 888-7422) Lower oscillogram: Just before the beam enters the Wideroe; 1 mA/cm. (Charge state selected, Ti^{2+}). Sweep speed: 50 µs/cm. (XBB 888-7421) (The stepped decrease at the end of the pulse is due to a defect in the transistor switch controlling the arc current).

Conclusions

The MEVVA beam characteristics were improved in a number of ways important to accelerator injection application, including the beam repeatability, pulse shape, and quiescence. A titanium beam of some 20 mA was transported through the 250 kV accelerating gap and injected into the 13-meter long UNILAC injector beam line. The Ti^{2+} charge state was selected from the beam by the dipole analysis magnet, and over 5 emA of beam was transported to the end of the injector beam line and the Wideroe entrance. The measured beam transport efficiency compares well with that using other more conventional ion sources (e.g. PIG), and is a characteristic of the beam line itself. We conclude that the MEVVA titanium ion beam is well coupled to the Wideroe, with a Ti^{2+} current intensity (pulsed beam current) greater than that obtained using conventional sources by an order of magnitude.

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