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THE SUPERHILAC HEAVY ION INTENSITY UPGRADE*

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Summary

A high current MEtal Vapor Vacuum Arc (MEVVA) ion source[1] is to be installed in the third injector (Abel) at the SuperHILAC, representing the first accelerator use of this novel ion source. The MEVVA source has produced over 1 A of uranium in all charge states, with more than 100 electrical mA (emA) of U^{5+}. Transport of the space-charge dominated beam through the charge-state analysis dipole will be enhanced by a 100 kV extractor voltage and neutralization by secondary electrons. In addition to the MEVVA source, other improvements already in place include a lower pressure in the Low Energy Beam Transport line (15.8 keV/AMU) to reduce charge exchange for the heavy elements, and the addition of a second 23 MHz buncher upstream of the Wideroe linac and two 70 MHz bunchers between the 23 MHz Wideroe and the 70 MHz Alvarez linacs. The project is expected to result in a five-fold increase in beam delivered to Bevatron experiments, increasing the extracted uranium beam to 5×10^7 ions/pulse.

Introduction

The SuperHILAC serves as an injector for the Bevatron, injecting ions as heavy as uranium at energies up to 8.5 MeV/AMU. The Bevatron then further accelerates the ions to 2.1 GeV/AMU for the lighter ions or 1 GeV/AMU for uranium. This combination of accelerators, called the Bevalac, is the only facility in the world capable of accelerating the heaviest nuclei to relativistic energies.

The Bevalac now produces beams of low-Z ions such as neon at intensities up to 1×10^{10} ions/pulse, and 960 MeV/AMU uranium beams have been delivered to experimenters at up to 1×10^6 ions/pulse. In addition, uranium of somewhat lower energy can be produced at intensities of 1×10^7 ions/pulse.

Increasing the beam intensity by a factor of five will open to exploration wide fields of atomic physics research. One notable example would be the measurement of the Lamb shift in Li-like uranium. Such measurements would be of considerable interest to quantum field theorists because one cannot use perturbation theory to accurately calculate the Lamb shift of such high-Z ions. Thus, measuring the Lamb shift of highly ionized uranium would almost certainly stimulate theoretical activity in nonperturbative quantum field theory. The present intensity permits measurements of the Lamb shift to an accuracy of 12%,[2] while the upgrade will allow the accuracy to be increased to about 0.5%.[3]

The recent development of the MEVVA ion source provides the basis for the SuperHILAC upgrade.[1] Figure 1 shows the SuperHILAC accelerator. Since the object of the upgrade is to increase the beam intensity, the chief concerns of the project are the production and transport of low energy, high current, heavy ion beams. Transporting this increased beam intensity to the Wideroe linac of the Abel injector will enable better use of the 10 emA output capacity of the Wideroe. In addition, improving the longitudinal phase matching between the Wideroe and the Alvarez linacs will further increase the beam intensity.

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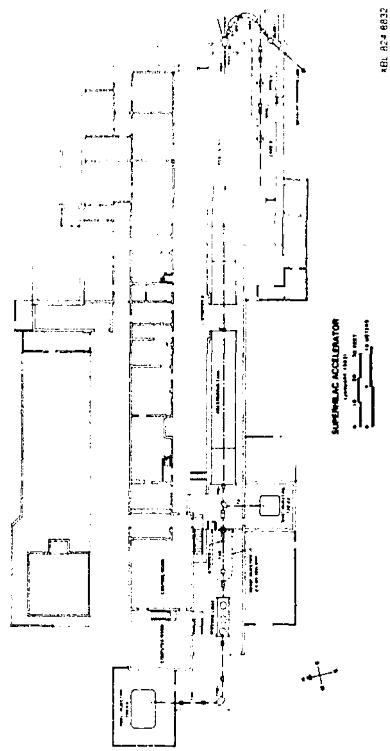

Figure 1 - The SuperHILAC accelerator. The upgrade involves modifications to the Abel injector, both upstream and downstream of the Wideroe linac.

MEVVA Ion Source

The source uses a metal vapor vacuum arc discharge as the plasma medium from which the ions are extracted. The metal plasma is created simply and efficiently directly from the solid by means of an arc discharge between two metallic electrodes in vacuum, and no carrier gas is required. Beams have been produced from metallic elements spanning the periodic table from lithium through uranium, at extraction voltages from 10 to 100 kV and with beam currents as high as 1.1 Amperes (electrical current in all charge states).

A characteristic of the metal vapor vacuum arc is the formation of many 'cathode spots' on the surface of the cathode. These are minute regions of intense current concentration (many megamps/cm^2 at micron-size spots) where the metal plasma is generated from the solid surface. The quasi-neutral plasma plumes away from the cathode toward the anode and persists for the duration of the arc current drive. The anode of the discharge is located on axis with respect to the cylindrical cathode and has a central hole in it through which a part of the plasma plume streams; it is this component of the plasma that forms the medium from which the ions are extracted. The plasma plume drifts through the post-anode region to the set of grids that comprise the extractor - a three-grid, accel-decel, multi-aperture design. A small magnetic field, up to about 100 gauss, helps to duct the plasma plume in the forward direction but is not essential.

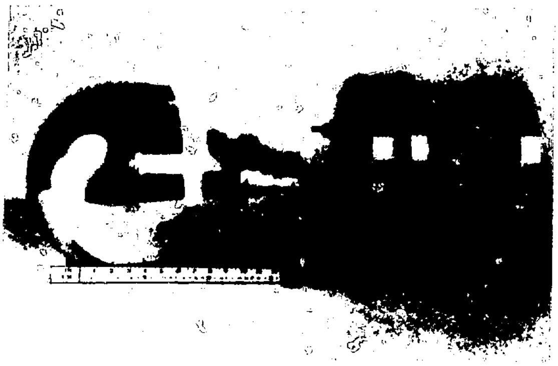

Figure 2 - Photograph of the MEVVA IV ion source. Note the rotatable cathode assembly.

A photograph of the MEVVA IV source is shown in Figure 2. A new feature of this source is the rotatable cathode assembly, which allows the cathode to be changed while maintaining the source vacuum. This enables one to use multiple cathodes of the same material, or to use cathodes of different materials. For the first case the source can last 16 times as long between changes of the cathode assembly, or, for the second case one can make rapid changes in the ion species. Each cathode will last for over 100,000 pulses, assuming a pulse duration of one millisecond. For the usual repetition rate of 2 Hz, this translates into a source lifetime of nine days if all cathodes are made of the same material.

The emittance has been measured with a pepper pot diagnostic. Typically half the beam current resides within a normalized emittance of from 0.2 to 0.5 pi mm mrad. The charge state spectrum of uranium is peaked at U^{5+} and extends from U^{2+} to U^{7+}. The distribution can be varied to a small extent via the arc current, but this effect is small. (As the arc current is increased more cathode spots form to participate in the arc, but the physics of each spot is not greatly changed.) The spectrum is clean, showingno contamination from the stainless steel trigger, the alumina trigger/cathode insulator, or other components of the source, presumably reflecting the fact that the origin of the plasma is indeed the cathode spots, which form only on the cathode.

Terminal Modifications

At present the ions are produced in the source magnet using a PIG source. This source is capable of producing about 5 emA of U^{6+} at the entrance of the accelerating column. The MEVVA source will be mounted outside of the source magnet, since it cannot operate within the strong magnetic field. The installation of the MEVVA source in no way interferes with the operation of the PIG source, so that either source can be used as required, the PIG source for high duty-cycle SuperHILAC beams and the MEVVA source for high intensity Bevalac beams.

Between the ion source and the source magnet a quadrupole triplet and a pair of steering magnets will provide the necessary optical elements to transport the beam into the magnet. The source magnet will then be used to separate the charge states produced by the MEVVA source. Aluminum plates will be positioned inside the dipole to provide a source of secondary electrons. Primary particles striking the plates at glancing angles produce secondaries which can serve to neutralize the space-charge forces and increase beam transport. This technique has been used successfully for transport of the PIG beam, and tests with the MEVVA source have shown that it is useful in that case, also. An existing quadrupole triplet will transport the analyzed beam to the entrance of the present medium gradient column.

Computer calculations using a beam envelope code show that up to 50 emA of U^{5+} can be transported through the present column. Modifications are needed to the Cockcroft-Walton power supply to handle the increased current of the MEVVA beam. A small bouncer has been installed to maintain the voltage regulation of the terminal at $\pm0.1\%$ under the increased loading of the high current beam.

Low Energy Beam Transport Modifications

Vacuum improvements have been made to decrease the residual gas pressure from an average pressure of 10^{-6} Torr to 2×10^{-7} Torr. This decrease in pressure is expected to increase the transmission of uranium from about 60% to greater than 90% by decreasing the charge exchange losses. The vacuum in the LEBT line has been improved by modifying the line to allow low-temperature baking and replacing diffusion pumps with cryopumps. Since an average pressure of 2×10^{-7} Torr is sufficient, it is not necessary to rebuild the line with ultrahigh vacuum components.

The outgassing has been reduced by providing and maintaining a clean system. Several improvements were made to achieve this. All removable beamline components were vacuum baked and the remaining components (mainly magnets) were degreased. The prime contaminant in the vacuum system was air, which entered when the Faraday cups were activated. The Wilson seals, therefore, have been replaced with bellows seals, which eliminated slight air leaks when the seals were activated. All neoprene "o-rings" have been replaced with Viton, and all epoxy and lucite has been removed from the system to allow low-temperature (100° C) baking.

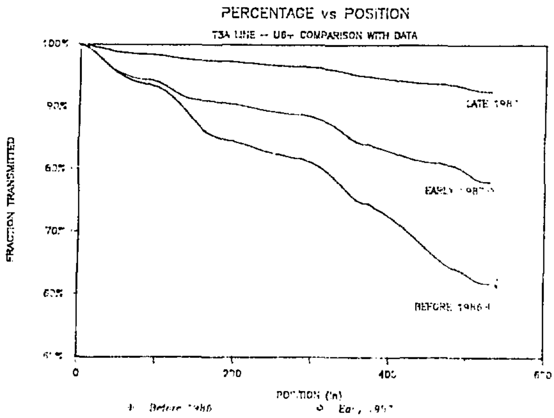

Figure 3 - Transmission of U^{6+} through the LEBT consideration charge exchange losses, both prior to and after the vacuum improvements. The lines represent predicted values, while the data points represent measured transmission.

These changes have resulted in a substantial pressure reduction. Eliminating the leaks and cleaning have resulted in the major contaminant being water instead of nitrogen. The average pressure is now 4×10^{-7} Torr, which has increased the transmission. When the line is baked the transmission is expected to further improve. Figure 3 shows the expected transmission based on the pressures measured at various points in the line, the aperture restrictions and pumping speeds, and cross sections for charge exchange from Muller and Salzborn.[4] The major contaminant for the pre-1986 calculation was assumed to be nitrogen, and for the most recent case, water. The increase in transmission is confirmed by the data points for U^{6+}, taken from the best runs prior to the vacuum improvements and from the most recent runs. The prediction for late 1987 assumes that the pressure is reduced to 2×10^{-7} Torr, resulting in over 90% transmission.

A further improvement to the LEBT was the addition of a second 23 MHz buncher upstream of the Wideroe linac. This buncher has increased the beam intensity transmitted through the linac by close to 50%. When the MEVVA source is installed, the buncher should increase the intensity by between 30% and 40%, depending on the degree of space-charge saturation of the Wideroe.

Medium Energy Beam Transport Modifications

The longitudinal bunch structure in the Medium Energy Beam Transport (MEBT) line was measured to determine the best way to improve the matching of the 23 MHz beam bunches produced by the Wideroe into the 70 MHz buckets of the prestripper. Measurements of the bunch width were made at three positions along the MEBT line using crystal detectors in a fast timing mode.

The measurements in the MEBT line showed that the amount of beam captured in the prestripper can be increased by bunching the beam at 70 MHz with two bunchers upstream of the prestripper, filling one out of every three prestripper buckets. The quantity of beam accepted by the prestripper can be increased by about a factor of three by this means. Since the first of the two bunchers was recently installed and resulted in a factor of two increase in intensity, it is expected that the calculated improvement will be realized.

Conclusions

The SuperHILAC Upgrade Project will increase the uranium output of the Bevalac heavy-ion facility from the currently available 10^7 ions/pulse to 5×10^7 ions/pulse. This upgrade will open to exploration wide fields of atomic physics research, such as enabling detailed Lamb shift measurements to be made in highly ionized uranium with important applications to nonperturbative quantum electrodynamics field theory.

This increase in ion intensity will be accomplished by the addition of a MEVVA source to the Abel terminal along with the appropriate focusing elements and by increasing the current handling capability of the Cockcroft-Walton power supply to accelerate up to 50 emA of beam through the existing medium gradient column. The LEBT line has been modified to improve the vacuum, reducing charge exchange losses. An additional 23 MHz buncher has been installed upstream of the Wideroe to improve the transmission. Finally, the phase matching between the beam exiting the 23 MHz Wideroe and entering the 70 MHz prestripper has been improved by the addition of one 70 MHz buncher upstream of the prestripper, with a second buncher about to be installed. These improvements should result in a factor of 5 improvement of beam intensity for the heaviest beams, such as uranium.

Acknowledgments

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References

1. I.G. Brown, J.E. Galvin, B.F. Gavin, and R.A. MacGill, Rev. Sci. Inst. 57, 1069 (1986).

2. C. Munger and H. Gould, "Lamb Shift in Heliumlike Uranium (U^{90+})," Phys. Rev. Lett., 57, 2927 (1986).

3. H. Gould, "New Experiments on Few-Electron Very Heavy Atoms," in Atomic Theory Workshop on Relativistic and QED Effects in Heavy Atoms, AIP Conf Proc 136, Edited by H.P. Kelly and Y.K. Kim, AIP, New York, 1985, p. 66.

4. A. Muller and E. Salzborn, "Scaling of Cross Sections for Multiple Electron Transfer to Highly Charged Ions Colliding with Atoms and Molecules," Phys. Lett., 62A, 391 (1977).