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TRANSMISSION MEASUREMENTS FOR HEAVY ION BEAMS THROUGH THE ROCHESTER MP TANDEM

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Summary

The transmission efficiency for heavy ions through the MP Tandem Van de Graaff at the University of Rochester has been measured for ^{16}O, ^{32}S, ^{58}Ni, and ^{197}Au at terminal voltages of 8 MV, 10 MV and 10.5 MV using gas stripping and high-speed cryogenic terminal pumping. For oxygen the transmission was close to 100%; for ^{197}Au the transmission over the range of terminal voltage 8-10 MV was between 25 and 50%. No significant beam loading was measured when 4 μA of ^{197}Au were injected, and there was no indication of a current limit at this intensity level. A comparison of the data with theoretical charge state distributions show that multiple scattering losses in the terminal were not significant and that the vacuum in the high energy acceleration tubes was adequate.

Introduction

The present paper describes measurements of the heavy ion transmission of the MP Van de Graaff accelerator at the University of Rochester. The Rochester MP tandem has been upgraded to operate beyond the originally guaranteed maximum terminal voltage of 10 MV.[1] A major feature of the upgrading of this machine is the design of the acceleration tubes using spiral inclined field electrostatic suppression.[2,3] The transmission tests described here were undertaken to investigate the performance of these acceleration tubes using heavy ion beams throughout the periodic table and also using high intensity beam currents.

Except as noted below, a Hiconex Model 834 ion source was used for these measurements. This ion source was a refocused beam of positive cesium ions to produce a sputtered beam of negative ions for injection into the MP tandem.

These measurements were made by analyzing several charge states of each beam using a 70° port on the standard 90° analyzing magnet. Each of the charge states can then be compared to predicted gas stripper yields in order to arrive at an overall measurement of the transmission efficiency of the accelerator.

Experimental Arrangement

The standard MP beam transport system was used during these transmission measurements. In order to analyze the lower charge states of the heaviest ions, particularly ^{197}Au, a set of slits and a biased faraday cup were mounted on the 70° port of the analyzing magnet. The radius of curvature of this port is 65", and this allows beams up to a mass energy product divided by Q^2 ($M \times E/Q^2$) of about 300 to be analyzed. The standard object slits were opened wide and the HE quadrupole focused the beam through the magnet and into the faraday cup. This allowed the HE quadrupole to focus the beams with a longer image distance so that the measurements were not limited by the strength of this focusing lens. A schematic drawing of the heavy ion transmission test arrangement is given in Fig. 1. The beam defining aperture at the entrance to the accelerator is 4.75 mm diameter.

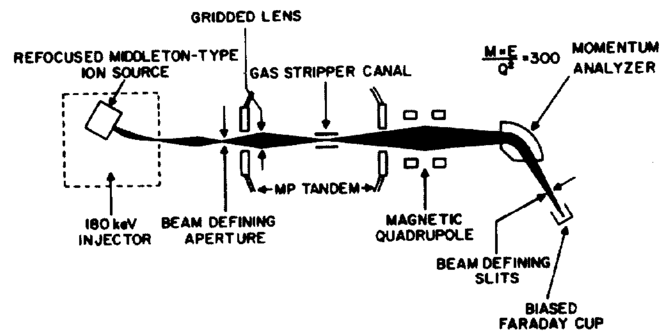

Fig. 1. Heavy Ion Transmission Test Arrangement.

Experimental Results

Transmission Efficiency

For each of the heavy ion beams, several charge states were measured as described in the previous section. Gas stripping in the terminal of the machine was used for all of these measurements. Each of the measured charge states were normalized to the injected beam current to obtain a particle ratio as follows:

$$\text{Particle Ratio} = \frac{I_{Q+}}{Q^{+} \times I_{LE}} \qquad (1)$$

where I_{Q+} is the measured current of a particular charge state, Q^+, and I_{LE} is the injected beam current measured at the low energy faraday cup (LEFC) which is located just behind the beam-defining aperture shown in Fig. 1.

The predicted charge state distribution is based on a set of tables[4] which were calculated from a review article of Betz[5]. There is a known loss of beam at the gridded lens at the entrance to the acceleration tubes. This loss is nominally 10%, or conversely the transmission of the gridded lens is 90%. Since we are interested in the transmission efficiency of the accelerator, we have removed the loss due to the transmission of the gridded lens from the predicted ratios referred to above and calculated a transmission efficiency as follows:

$$\text{Transmission Efficiency} = \frac{\text{Particle Ratio}}{0.9 \times \text{Predicted Ratio}} \qquad (2)$$

The results of the various heavy ion beams have been tabulated in Table 1. The data for ^{16}O were taken using an off-axis direct extraction duoplasmatron. All of the other beams were produced from the Hiconex sputter ion source. During the measurements with ^{197}Au, the charge state did not change with and without

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this beam-defining aperture. The conclusion from this result is that the size of the beam, or the emittance of the beam from this sputter ion source, is well matched to the acceptance of the MP accelerator. In fact, the beam size could probably be increased without introducing appreciable loading or instability.

BEAM TYPE	CHARGE STATE Q^+	INJECTED CURRENT I_{LE} (μA)	ANALYZED CURRENT I_{Q^+} (μA)	PARTICLE RATIO	PREDICTED RATIO	PREDICTED RATIO AFTER ALLOWANCE FOR GRID	TRANSMISSION EFFICIENCY
^{16}O	+4	.500	.740	.370	.461	.415	.892
"	+5	.500	.820	.328	.377	.339	.968
^{32}S	+4	8.0	4.6	.1438	.2011	.1810	.794
"	+5	6.2	6.2	.2000	.3637	.3273	.611
"	+6	6.2	4.0	.1075	.2790	.2511	.417
"	+7	6.1	1.1	.0258	.0908	.0817	.316
"	+8	6.0	.32	.0067	.0125	.0113	.593
"	+9	7.8	.085	.0012	.0007	.0006	---
^{58}Ni	+4	.600	.300	.125	.2269	.2042	.622
"	+5	.700	.460	.131	.2788	.2509	.522
"	+6	.700	.360	.0857	.2099	.1889	.454
"	+7	.650	.220	.0483	.0968	.0871	.555
"	+8	.650	.130	.0230	.0274	.0247	.931
^{197}Au	+6	1.80	.300	.0277	.1346	.1214	.228
"	+7	2.30	.380	.0236	.0840	.0756	.312
"	+8	2.20	.175	.0099	.0424	.0382	.259
"	+9	2.17	.070	.00358	.0173	.0156	.229
"	+10	2.05	.020	.00097	.0057	.0051	.190
"	+11	1.90	.005	.00024	.0015	.0013	.185
		ADDITIONAL DATA WITH LE DEFINING APERTURE REMOVED					
	+7	4.00	.600	.0214	.0846	.0756	.283

TABLE 1 HEAVY ION TRANSMISSION DATA

Total Beam Measurements

Another aspect of the overall performance of the accelerator is the ability to accelerate high intensity, heavy ion beams throughout the periodic table. A series of measurements were made using different intensities of ^{12}C and ^{32}S at 8 MV terminal voltage. The high energy faraday cup current was measured as a function of the injected beam current for intensities up to 15 μa of negative beam injected. The data are plotted in Fig. 2. The beam transmission of the accelerator is constant, as evidenced by the straight line plot in Fig. 2, and beam loading is not occurring within the machine.

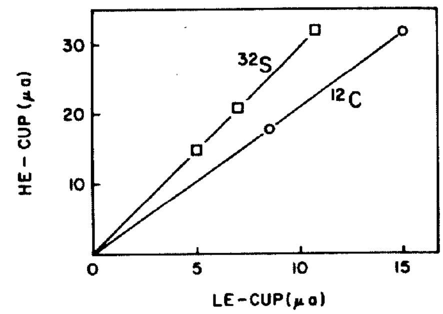

Fig. 2. Tandem Output Current Vs. Input Beam.

Conclusions

The present design of spiral inclined field acceleration tubes provides high transmission of heavy ion beams throughout the periodic table. A transmission efficiency of about 50% is a realistic number for the performance of the acceleration tubes. In addition, the accelerator is capable of accelerating high intensity beams (of at least 10 or 20 μa) without any significant loading. The emittance of the beam from a refocused sputter ion source is found to be adequately matched to the acceptance of the accelerator.

References

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