TESTS FOR PULSED HIGH-CURRENT HEAVY-ION
SYNCHROTRON INJECTION WITH AN MP-TANDEM VAN DE GRAAFF

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SUMMARY

The new MARK VII high-current, negative-heavy-ion source designed by R. Middleton¹ was operated in a pulsed mode to provide 100-200 μ A negative-ion currents in 230- μ sec square pulses, 10/sec. These pulses, 50-100 times more intense than normal DC beams, were then accelerated by the MP7 Tandem Van de Graaff accelerator while operating at 14 MV. After charge-state analysis, the emittance of the pulsed beam was also measured. The very stable accelerator behavior indicated that even higher currents are possible. Values for ^{16}O are: 115 μ A $^{16}\text{O}^-$ injected, 100-MeV $^{16}\text{O}^{6+}$, 250 μ A (43.3 pua) 1.8 mm-mr; and for ^{32}S are: 170 μ A $^{32}\text{S}^-$ injected, 140-MeV $^{32}\text{S}^{9+}$, 240 μ A (26.7 pua) 0.51 mm-mr. The high intensity and low emittance of these ion beams make them ideal for injection into a synchrotron like the AGS 30-GeV proton accelerator at BNL.

Introduction

The Brookhaven Tandem Van de Graaff facility² has provided a large variety of heavy ion beams for many years. The list of available projectiles has been steadily increasing and, to date, 65 different isotopes have been accelerated, in support of a wide ranging research program including atomic, molecular, and solid state physics with an emphasis on heavy-ion nuclear physics. Also, the energies have increased over the years, thanks to many large and small accelerator improvements, the last of which have led to reliable operation at terminal voltages in excess of 16 MV for the main accelerator. Ion beams from a negative terminal machine operated at -11 MV can be used to inject the main MP Tandem accelerator and this combination is now roughly equivalent to a single 19 MV tandem. A few such very large single electrostatic machines exist elsewhere, but none of them has yet achieved reliable operation at these levels.

Now, plans are being made for accelerating heavy ions to much higher energies. A booster cyclotron has been designed,³ based on a large existing room-temperature magnet. This cyclotron would multiply the tandem energies by approximately a factor of 20. To get relativistic heavy ions, there is a proposal⁴ to inject the beams from this cyclotron into the AGS, which could accept heavy ions up to iodine without any vacuum improvements. Some of the lighter ion beams such as oxygen or sulphur could actually be injected directly from the tandems.

The purpose of the tests described here was to determine whether beam intensities available from the tandem will be satisfactory for injection and acceleration in the AGS.

DC versus Pulsed Beams in
Tandem Van de Graaff Accelerators

Tandem Van de Graaff accelerators are well known for their excellent DC beam quality and stability, but also for the fact that intensities are low compared to beams usually injected into high energy accelerators by linacs. These synchrotrons

accept injected current only for a small fraction of the acceleration period: the AGS, for instance, typically accepts the input beam during 200 μ sec out of a 2 sec period, or 1 part in 10^4 of the time. In principle, it should be possible to make use of this fact by accelerating short, high intensity beam bursts through the tandem without exceeding its average beam capabilities. The capacitance of the accelerator structure should tend to preserve the voltages sufficiently during short times, even when the charging and voltage distribution systems would be totally incapable of sustaining them for a DC beam of the same intensity. Of course, there could well be other problems when very large beam bursts traverse the acceleration tubes, operated close to their maximum voltage gradients. For instance, it is easy to imagine how breakdowns or instabilities could be triggered.

Until recently there was no good way to find out what the problems might be because the available negative ion sources were all matched to the limited current DC beam capabilities of the Tandems. This situation changed dramatically with the development by Roy Middleton (University of Pennsylvania) of his MARK VII sputter ion source¹ which provides over 200 μ A of a variety of negative ions; an increase of more than one order of magnitude over older sources.

Figure 1. Simplified schematic diagram of the ion source system for the MARK VII Middleton sputter ion source. The indicated voltages are typical and can be adjusted for optimum performance. The energy of the negative ions is determined exclusively by the extraction supply and therefore does not vary during the pulse. The 1.5 kV DC voltage in series with the high voltage pulser provides a low intensity DC beam used for tuning the accelerator and beam transport.

Pulsed Operation of the MARK VII Middleton Sputter Ion Source

Prior to these tests this ion source had only been used in the DC mode. In this mode, positive cesium ions are accelerated through a potential difference of 3 to 5 kV and focussed onto a sputter target from which the negative ions originate. These negative ions are accelerated by the same 3 to 5 kV and then further accelerated by an additional extraction voltage of about 20 kV.

In the pulse mode developed here (see Fig. 1), the total negative ion acceleration voltage is kept constant so as to preserve a constant beam energy independent of any pulse shape imperfections. Only the cesium acceleration voltage is pulsed from a DC base level of about 1.5 kV to a maximum intensity level of about 4.5 kV. The lower value is adjusted so as to generate a low intensity DC beam used for tuning the accelerator and the beam transport. The pulse amplitude is adjusted to obtain maximum beam pulse intensity and the optimum amplitude varies with the sputter target material.

The pulsed beam intensities observed are similar to beam intensities obtained for DC operation. Beam pulse rise times between 2 and 10 μsec were observed while the applied high voltage pulse had a rise time less than 1 μsec .

Acceleration of High Intensity Heavy Ion Beam Pulses

The pulse length for these tests was adjusted to 230 μsec and ten pulses per second were injected into the accelerator. Examples of pulse shapes for ^{16}O and ^{32}S beams can be seen in Fig. 2.

For instance, in the case of ^{32}S a 170 μA negative ion beam was injected and the total instantaneous accelerator output current was 900 μA , of which 240 μA (27 particle μA) was in the most abundant charge state. The operation of the accelerator was completely normal, even though instantaneous intensities were over two orders of magnitude larger than conventional DC beams.

Figure 2. Test results for high current pulsed heavy ion beams obtained by injecting ^{32}S and ^{16}O beams from a MARK VII Middleton ion source into the Brookhaven MP7 Tandem Van de Graaff accelerator. The oscilloscope traces show a) the injected negative beam currents, b) the total beams containing all charge states at the exit of the accelerator, and c) the analyzed most abundant charge state components. These analyzed beams were 43 particle μA of 100 MeV $^{16}\text{O}^{6+}$ and 27 particle μA of 140 MeV $^{32}\text{S}^{9+}$. The emittances were also measured for both beams and were found to be about 18 mm mrad MeV $^{1/2}$ in the worst case. This excellent emittance and the pulsed beam intensities two orders of magnitude larger than normal DC tandem beams assure that the beam intensities for AGS operation quoted in the text can be reached with large safety margins.

Figure 3. Simplified diagram of currents entering and leaving the high voltage terminal. The relative magnitudes of the currents are indicated by the length of the heavy arrows. During a beam pulse these currents are not balanced and charge must be supplied by the terminal-tank capacitance. The resulting total voltage droop for the present example is ~ 2 kV.

While DC beams must always be smaller than charging and voltage divider currents, these pulsed beams are in fact much larger (see Fig. 3). The terminal voltage is kept nearly constant by the terminal-tank capacitance. The total calculated voltage droop at the end of the pulse is ~ 2 kV and the deviation from the average is ± 1 kV or $\pm 7 \times 10^{-5}$ of the total voltage. The emittance of the analyzed beam was approximately determined by adjusting a set of slits located at a focal point so as to transmit 80% of the beam and by probing the beam profile with a beam scanner located 4 meters beyond the slits. The values obtained for oxygen and sulphur are 18 and 6 mm mrad MeV^{1/2}, respectively.

Conclusions

In spite of the very large instantaneous beam intensities, the operation of the accelerator was completely normal, and the measured beam quality was excellent. From these results one can conclude that if necessary, even higher intensities could be obtained. The very good beam quality would allow many more turns to be injected into the AGS than is customary with linac injection. This, together with the now demonstrated heavy-ion intensities from the tandems, provides a large safety margin to assure that oxygen intensities of 4×10^{10} particles per pulse can be reached. For iodine beams, which require the cyclotron booster, the intensity would be 10^9 particles per pulse.

Beyond AGS injection and beams at 15 GeV/AMU, considerations have been made of possible injection of heavy ions into the future Colliding Beam Accelerator proposed for Brookhaven.⁶ There appear to be no technical problems in accepting AGS Heavy

Ion Beams - passage of heavy ion beams through transition during acceleration can be accommodated by all presently considered CBA designs. The range of heavy ion beams with reasonable luminosities that would become available is truly impressive - involving center of mass energies of order 10^5 GeV.

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