UPGRADE AND OPERATION OF THE BNL TANDEMS FOR RHIC INJECTION*

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Abstract

One of the tandem Van de Graaffs (MP7) at Brookhaven National Laboratory (BNL) has successfully completed its first year as an injector for the Relativistic Heavy Ion Collider (RHIC). The tandem provided pulsed beam of Au^{+32} (peak intensity 80 eμA, 500μs) with only 17 hours of downtime during a 5 month run. Improvements are being made to further increase the intensity of the gold beam for the experimental run starting in 2001. A second tandem Van de Graaff (MP6) has been extensively upgraded and can now reach a terminal voltage of over 14MV. A beamline has been constructed to transport the MP6 beam around MP7 and then connect to the existing MP7 beamlines. This has allowed MP6 to deliver beam to local target rooms for an outside user program, while MP7 has simultaneously injected RHIC. MP6 can also be used as an injector for RHIC.

1 INTRODUCTION

The acceleration scheme for the Relativistic Heavy Ion Collider (RHIC) is shown in figure 1. Negative gold ions are produced by a cesium sputter source operated in the pulsed beam mode [1]. The ions are accelerated to the terminal of the tandem, which is operated at +14MV. At the terminal, the negative ions pass through a 2μg/cm^2 carbon stripping foil. This results in a distribution of positive ions with approximately 15% in the desired +12 charge state. The gold ions are accelerated back to ground potential and then pass through another carbon stripping foil, which has a thickness of 15μg/cm^2. Again there is a charge distribution with approximately 15% of the incoming +12 ions leaving in the +32 charge state. The Booster will accept only a specific charge state combination. The gold ions are transported to the Booster through an 850 m long Tandem to Booster (TtB) transfer line with an energy of 0.92MeV/nucleon. After multi-turn injection in the Booster, the beam is accelerated and then further stripped to the +77 charge state before injection into the Alternating Gradient Synchrotron (AGS). After acceleration in the AGS the last two electron are removed so that bare gold nuclei are injected into the two counter-rotating rings of RHIC.

Pulsing the ion source allows several hundred microamps of Au- to be injected into the tandem without damaging the accelerator. The pulse length of the beam can be as long as 2msec but is usually set to between 500μsec and 700μsec. The acceleration cycle calls for the tandem to deliver 4 pulses to the Booster every AGS cycle. The pulses are approximately 200 msec apart and an entire AGS cycle is approximately 3.5 sec. The AGS fills RHIC with four bunches every AGS cycle so each tandem pulse corresponds to one RHIC bunch. Each RHIC ring can be filled in approximately one minute. After RHIC has been filled, the time until the next request for beam from the tandem can be as long as 10 hours [2].

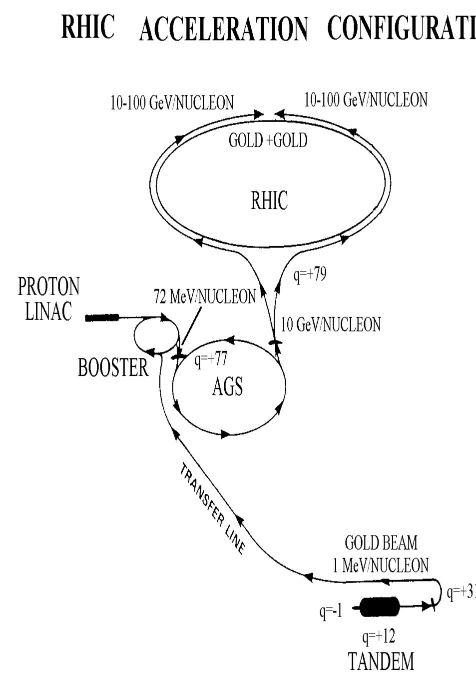

Figure 1: RHIC acceleration scheme.

2 YEAR 2000 PERFORMANCE

The MP7 tandem operated very reliably for the 2000 RHIC experimental program. The experimental run lasted from mid March to the beginning of September. During this 5 month period only 11 hours was lost due to tandem problems and an additional 6 hours were lost due to faults in the TtB transfer line.

2.1 Ion Source Performance

The PSX-120 [3] cesium sputter sources operated reliably during the run. Over the entire run, the ion source delivered over 10 million pulses without any lost time due

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to ion source problems. The maximum current observed at the beginning of the transfer line was 80eμA of Au^{+32}, which corresponds to $7.2x10^9$ particles in a single pulse. To get the maximum current, 287μA of Au- was injected into the tandem and 1300μA of all charge states was measured after the tandem. The typical run values were 150μA of Au- being injected, 600μA after acceleration, and 25-35μA at the start of the transfer line.

To increase the beam intensity from the tandem, a new ion source (figure 2) with an extra acceleration gap was purchased. This will allow the extraction voltage to be increased from the present 35kV to approximately 50kV. Initial testing has shown promise with a pulsed beam intensity of 96eμA of Au^{+32} being measured at the start of the transfer line for an extraction voltage of 45kV. Further testing is required to confirm that the ion source can reliably operate at these higher voltages.

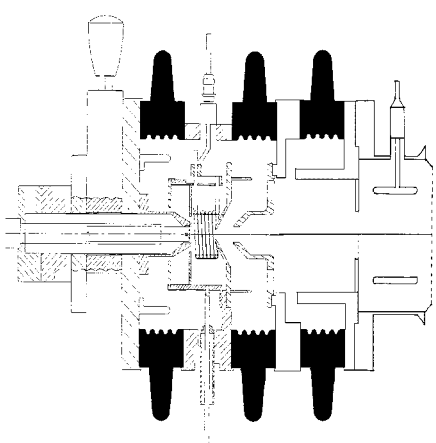

Figure 2: New PSX-120 Cesium Sputter source with additional acceleration gap.

2.2 Stripping Foils

The carbon stripping foils located in the central terminal and also the object point are critical in determining the intensity of the desired charge state combination. The stripping foils are manufactured by an arc discharge between two graphite rods and the thickness of the foils is measured using an optical densitometer. The performance of the stripping foils will degrade with beam use and must be periodically replaced. Therefore the terminal foils are mounted in two holders with each holder containing 300 foils. There are two varieties of terminal foils. Holder 1 contains foils that are mounted on a rectangular frame with an opening that measures 2.2cm by 1.0cm. The holder itself is mounted on a bellows and connected to a motor that oscillates the entire holder 1.25cm with a period of 1 minute. Because this exposes a greater area of the foil to the beam the usable lifetime of the foils is increased. Holder 2 contains carbon foils mounted on frames with a 0.95cm diameter hole and is stationary.

The carbon stripping foils at the object location have a thickness of $15\mu g/cm^2$ and are mounted on a frame with a 1.9cm diameter hole. The object foil holder contains 120 foils and is connected to a variable speed oscillator. Because of the higher beam energy the lifetime of the object foils is much longer.

Both the object and terminal foils were replaced during an extended shutdown between July 5-12. Table 1 contains the data for the foils used between March 17 and July 5 while table 2 contains the data for the foils used between July 12 and September 5. On average, three oscillating terminal foils were used a day while an object foil lasted approximately 2 days.

Table 1: Stripper Foil Data March 17-July 5

Foil Type	Foils Used	Pulses per foil
Oscillating Terminal	266	14,000
Stationary Terminal	137	8000
Object	62	79,000

Table 2: Stripper Foil Data July 12-Sept. 5

Foil Type	Foils Used	Pulses per foil
Oscillating Terminal	178	17,000
Object	14	96,000

3 MP6 UPGRADE AND BYPASS LINE

The second tandem Van de Graaff (MP6) has been upgraded to be similar to MP7 [4], which was upgraded in the early 1980's. The purpose of upgrading MP6 is to provide a spare injector for RHIC, to allow fast switching between ion species for the Booster Application Facility (BAF) and also to support an outside user program while MP7 is injecting RHIC. The upgrade consisted of installing longer accelerating tubes to increase the active length by 22%, installing 3 additional pelletron chains for charging, improved voltage grading resistors for the accelerator tubes and column, and increased vacuum pumping along the accelerator tubes. The net result is that now MP6 can comfortably operate with a terminal voltage over 14MV.

The bypass line that takes the MP6 beam around MP7 has also been commissioned. The beam line consists of four 25^o dipoles and one 90^o dipole as shown in figure 3. If the beam is required for RHIC injection, the first two 25^o dipoles (6DH1 and 7DH1) shift the beam off the tandem axis by approximately 3 m. There is then a 38 m run past MP7 before the beam is shifted back on axis by the third and fourth dipoles (8DH1 and 10DH1). A quadrupole doublet at the exit of MP6 is used to produce a double waist at slits located upstream of the first dipole. Another doublet at the exit of the second dipole is used to produce a double waist at the midpoint of the bypass line. The line is designed to be symmetric about this midpoint, so one then gets a double waist just downstream of the

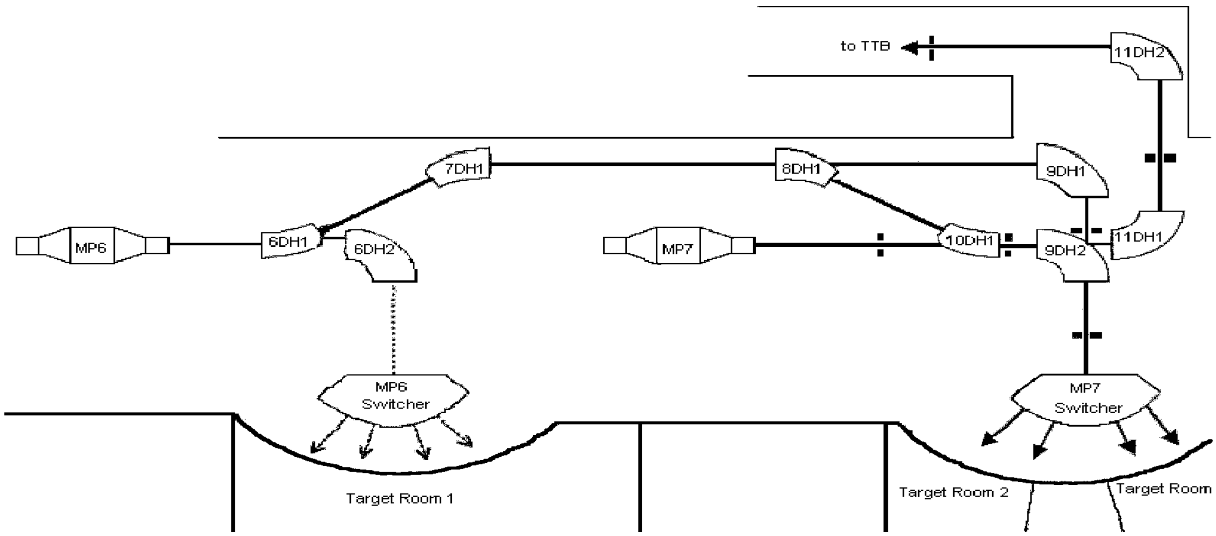

Figure 3: Layout of bypass line showing dipole magnets (not to scale).

last 25^o dipole (back on the tandem axis), where the object stripping foil is located. (A pair of quadrupoles near the midpoint are set so that the bypass line is achromatic). The total distance from MP6 to this foil is ~61 m. The beam at the object foil looks similar to that produced by MP7, where a quadrupole doublet at the exit of MP7 (identical to that on MP6) is used to also produce a double waist directly on this same object foil. There is an image point of the foil halfway between the 90^o dipoles 11DH1 and 11DH2, where a pair of horizontal "regulating" slits are located which feedback position (energy) information to regulate the voltage on either MP6 or MP7. This midpoint is then imaged at another set of slits after 11DH2, and is then matched into the long transport line to the Booster (quadrupole doublets, producing waists halfway between doublets). The bypass line has proved to be quite easy to set up (including making it an achromat), and transmission exceeds 95%. Diagnostics between MP6 and the object foil include 5 multiwire profile monitors, 4 Faraday cups, and 2 current transformers.

If the beam is required in the local target room to support the user program, 8DH1 is turned off and the 90^o magnet (9DH1) bends the beam into the existing image leg of MP7. The slits at the midpoint of the bypass line are then used to regulate the terminal voltage

MP6 has been used to provide ion beams to local target rooms to support the user program at the same time that MP7 was being used to inject RHIC. Recently MP6 beam has also been used to inject the Booster. By matching the energy of MP6 and MP7 the only changes that had to be made in the TtB transfer line were to a set of quadrupole magnets at the beginning of the line to carefully match the beam size of MP6 to that of MP7. Once this was done the beam from MP6 transported well in the TtB line and went into the Booster with little or no corrections at the end of the line. The Booster efficiency was similar to the injection efficiency from MP7. The switch from MP6 to MP7 can be accomplished in as little as 15 minutes if the beam has already been tuned through the accelerator.

4 CONCLUSION

The MP7 tandem Van de Graaff was a very reliable injector during the 2000 RHIC experimental run. During the 5 months of run time only 17 hours of down time was attributed to the tandem and TtB transfer line. Although the beam intensity was adequate, methods of increasing the beam current available to the Booster are being explored. The primary method being pursued is to increase the extraction voltage of the ion source.

The MP6 tandem Van de Graaff has been successfully upgraded and the bypass line has been commissioned. MP6 has been used to deliver beam to the Booster and has also been used to support the outside user program while MP7 has simultaneously delivered beam to RHIC.

6 REFERENCES

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7 ACKNOWLEDGEMENTS

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