LBL-18967
c.2

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE
BERKELEY LABORATORY
OCT 16 1985
LIBRARY AND
DOCUMENTS SECTION

Accelerator & Fusion Research Division

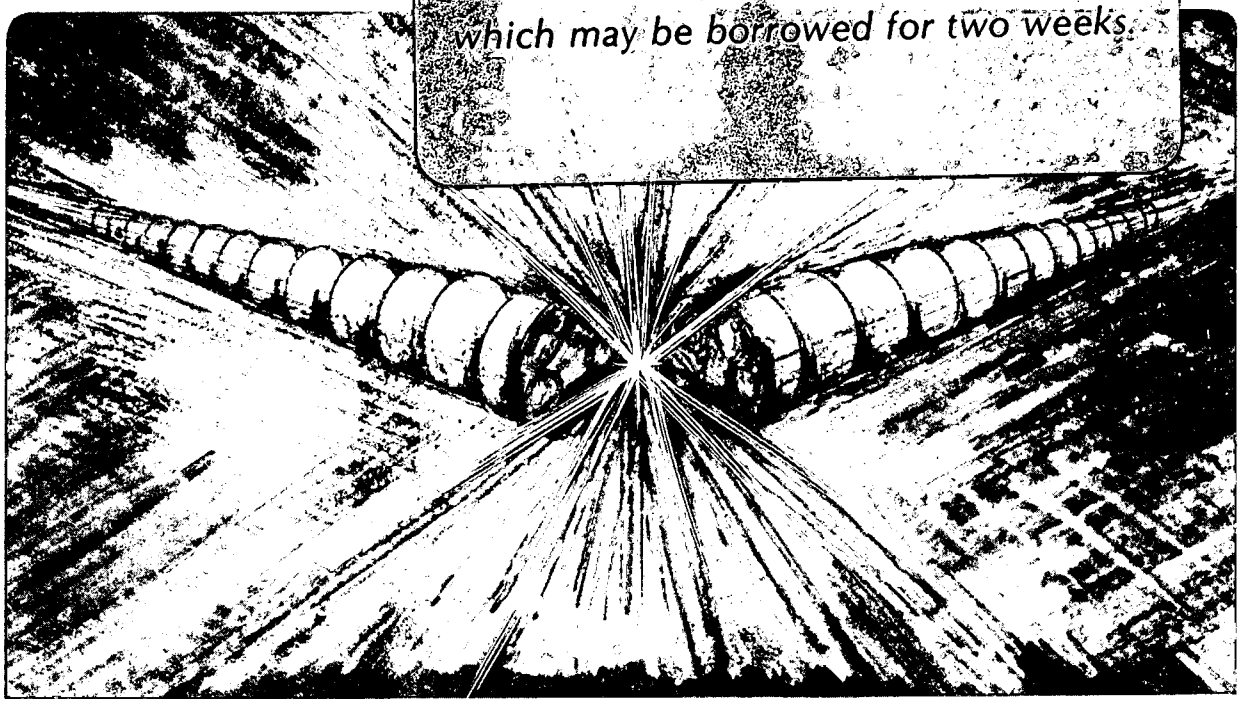
Presented at the 1985 Particle Accelerator Conference,
TRIUMF, Vancouver, B.C., Canada, May 13-16, 1985

INITIAL OPERATION OF THE NEW BEVATRON LOCAL INJECTOR

J. Staples, R. Dwinell, R. Gough, J. Halliwell,
D. Howard, J. Lax, S. Lundgren, R. Richter,
G. Stover, and J. Tanabe

May 1985

TWO-WEEK LOAN COPY
This is a Library Circulating Copy
which may be borrowed for two weeks.



LBL-18967
c.2

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-18967

Initial Operation of the New Bevatron Local Injector

J. Staples, R. Dwinell, R. Gough, J. Halliwell,
D. Howard, J. Lax, S. Lundgren, R. Richter,
G. Stover, and J. Tanabe

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

May 1985

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Science Division, U.S. Department of Energy, under Contract Number DE-AC03-76SF00098.

Initial Operation of the New Bevatron Local Injector*

LBL-18967

J. Staples, R. Dwinell, R. Gough, J. Halliwell, D. Howard, J. Lax, S. Lundgren, R. Richter, G. Stover, J. Tanabe

Lawrence Berkeley Laboratory, Berkeley, California 94720, USA

Abstract

Initial operational characteristics of a new Bevatron injector system are described. It is capable of providing an independent source of ions to the Bevatron through mass 40. The new injector consists of a sputter ion PIG source, operating on a 60 kV DC platform, an RFQ linac, and two Alvarez linacs, all operating at 199 MHz. Beams with $q/A \geq 0.14$ are accelerated to 200 keV/n in the RFQ and to 800 keV/n in the first Alvarez tank. Each Alvarez operates in the $2\beta\lambda$ mode, and each is followed by a foil stripper. Beams with a $q/A \geq 0.32$ are accelerated through the second Alvarez to 5 MeV/n, fully stripped, and injected into the Bevatron. Because the Bevatron can be efficiently switched between this injector and the SuperHILAC injector, a more efficient operations schedule is made possible to meet the increasingly diverse needs of the Biomedical and Nuclear Science research programs.

Introduction

Since 1971 ions more massive than protons have been accelerated in the Bevatron. The first heavy ions, up through ^{20}Ne were accelerated in the 20 MeV proton injector operated in the $2\beta\lambda$ mode and fitted with a PIG ion source. The available neon intensity in this mode was in the microamp range. Later on, improvement programs resulted in the installation of a beam transfer line to bring ions generated at the SuperHILAC to the Bevatron (creating the Bevalac), resulting in a high intensity capability up to ^{56}Fe. Later, the installation of a 10^{-10} torr vacuum system in the Bevatron extended the mass capability all the way to ^{238}U.

An extensive biomedical program developed, treating patients during the day shift, and remains a prime user of ions up through ^{40}A. The actual beam time required for treatment is typically 2 minutes out of 30, most of the time is used for patient set-up. To efficiently use the facility, the Bevalac was improved to allow rapid ion and energy switching, so the physics program could be interlaced with the biomedical program. The SuperHILAC is a less flexible machine to switch between ions, but has been used this way to improve the operational efficiency. In addition, the SuperHILAC has its own set of users, all of which must compete with the Bevalac for beam time. To remedy the injector availability problem, the 20 MeV proton linac was extensively modified to a high intensity heavy ion injector with mass capability through ^{40}A. An important goal was to minimize the cost of this conversion and to have no interruption of Bevalac operation during the rebuilding of the linac.

Linac Configuration

To improve the efficiency of both the SuperHILAC and the Bevatron operation, the 20 MeV proton linac underwent extensive modification[1] to convert it to a series of three linacs, optimized for the ion range of ^{2}He to ^{40}A. The system is now up and running. The injector consists of a PIG ion source, operating on a 60 kV platform (instead of the original 500 kV Cockcroft-Walton platform) injecting a heavy ion RFQ[2]. The RFQ accelerates the charge-to-mass $(q/A) \geq 0.14$ ion to 200 keV/n. The beam is injected directly into the first (prestripper) Alvarez linac, 3.5 m long, which accelerates it to 800 keV/n in the $2\beta\lambda$ mode. A stripper raises $q/A \geq 0.32$ and the second tank, the last 51 cells of the original 74 cell Alvarez linac, further raises the energy to 5 MeV/n in the $2\beta\lambda$ mode. A final stripping foil raises the charge state of the ion, if necessary.

The beam from the sputter PIG ion source is analyzed 120° by a magnet and focused by an einzel lens to the 60 keV single accelerating gap. The sputter electrode allows production of metallic ions. The design $q/A \geq 0.14$ of the RFQ and first Alvarez requires the +4 charge state of silicon and the +6 charge state of argon. The source has already produced 433 pμA of neon, 133 of silicon, and 33 of argon, all in the required charge state, inside a 95% normalized emittance contour of 0.07 to 0.08π cm-mrad. The beam is transported to the RFQ through a beam line that includes a second analysis magnet, which doubles as a switching magnet for a future second ion source.

The initial performance of the RFQ has been previously described by Staples[2]. It accelerates a $q/A \geq 0.14$ ion from 8.4 to 200 keV/n at 199 MHz. It is 2.24 m long and has a normalized transverse acceptance of 0.05π cm-mrad. The RFQ was built and tested in the summer of 1983 before the 20 MeV linac was disassembled for modification.

The original 20 MeV proton linac was rebuilt as a two tank heavy ion accelerator. Operated as a $2\beta\lambda$ injector before modification, it produced a 300 eμA carbon and a 1 eμA neon beam. The transit time factor of 0.19 at the entrance cell of the machine in the $2\beta\lambda$ mode required a gradient of 3.5 MV/m in the first few cells, which tapered to 3.0 MV/m at the high energy end of the tank, substantially greater than the 2.0 MV/m design gradient for protons in the $\beta\lambda$ mode. The installation of a new r.f. system several years ago permitted these very high gradients, which required long bake-in times.

The linac was modified by removing the first 24 drift tubes and placing a diaphgram at the last removed drift tube, a position corresponding to an energy of 800 keV/n in the $2\beta\lambda$ mode. A new prestripper Alvarez linac, also operating in the $2\beta\lambda$ mode was then installed upstream of the diaphragm which accelerates the $q/A \geq 0.14$ beam from 200 keV/n at the RFQ exit to 800 keV/n. A 20 μg/cm² carbon foil stripper at the diaphragm raises $q/A \geq 0.32$. A 50 μg/cm² aluminum stripper at the end of the linac (5 MeV/n) can be used to further raise the charge state.

The 38 drift tubes in the 3.5 m long prestripper linac have a uniform diameter of 14.5 cm in a 95 cm diameter tank. The g/L ratio ranges from 0.169 in the first cell to 0.202 in the last to maintain the individual cell frequency of 199 MHz. The tank gradient is tilted from 2.25 to 2.64 MV/m along the tank to keep the average gap field about 13 MV/m throughout the tank and to reduce the r.f. defocusing at the low energy end. The quadrupoles are divided into three groups, corresponding to the three aperture radii of 0.50, 0.65 and 0.80 cm, with maximum gradients of 12, 10 and 8 kG/cm over effective lengths of 3.8, 4.5 and 6.0 cm. Each drift tube is supported by two stems, with coolant circulated in one of them up to but not inside of the drift tube itself. Each quadrupole has its own power supply providing up to 35 amperes pulsed current. The r.f. and quadrupoles are pulsed twice a second.

The first gap in the Alvarez prestripper linac is located just 12 cm from the end of the RFQ vane. The ±15° phase spread of the beam from the RFQ increases to ±22° over this drift distance. In the 12 cm drift are located a vacuum valve, a Faraday cup, a quadrupole and the first half drift tube of the Alvarez.

The prestripper Alvarez linac is built in the part of the original linac tank vacated by the removal of the first 24 drift tubes, extended an additional 1.5 m by a new tank section. The original drift tube stem mounting holes in the tank wall were sealed shut, and a new set of stem mounting holes were bored at an angle rotated 22° from the location of the original holes. This azimuthally rotated stem configuration continues into the new extension tank. The double stem drift tubes in this section are right cylindrical with flat faces.

The diaphragm contains two half drift tubes with quadrupoles and the stripper cassette. The cassette holds five stripper foils, a Faraday cup, and two sets of 16-wire grids, one for each plane. The total length added to the regular cell structure of the linac by the diaphragm assembly is only 7 cm, or about one-half a cell length. No transverse or longitudinal beam manipulation is required across this transition.

The second Alvarez tank, the poststripper, consists of the last 51 cells of the original 20 MeV proton linac. In the $2\beta\lambda$ mode, the transit

* This work was sponsored by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Science Division, U.S. Department of Energy, under contract number DE-AC03-76500098.

time factor increases from 0.36 at the entrance to 0.53 at the exit. The ratio of transit time factors in the 2βλ mode to the βλ mode in these 51 cells varies from 0.5 to 0.6, requiring a small tilt to the accelerating field, starting at 3.1 MV/m at the entrance. This field is to be compared to the 3.4 MV/m attained with reasonable reliability in 2βλ operation before the conversion of the injector system, considerably greater than the proton design field of 2.0 MV/m. The drift tubes in this section have the football-like Christophilos surface shape.

The quadrupoles in the poststripper tank are hollow conductor solid polepiece magnets originally excited from d.c. power supplies. The gradients required for heavy ion operation in the 2βλ mode are up to 2.5 times the original proton design value. The quadrupole was found not to saturate at these higher excitations, which had less than 3.5 kGauss at the pole tip, but the cooling capacity was inadequate. It was found that the quadrupoles could be ramped to full required field in a few tens of milliseconds without apparent field distortion, so pulsed power supplies were substituted for the d.c. supplies, with 12 units in series per power supply. The ramp time of 100 milliseconds keeps the voltage to ground less than 50 volts on any unit. The one pulse per second operation has been completely reliable.

The 199 MHz r.f. system provides a 0.8 millisecond peak pulse power of 150 kW to the RFQ, 725 kW to the prestripper and 2.75 MW to the poststripper Alvarez tank twice a second. The low level electronics is discussed by Howard[3]. The RFQ is driven by a 300 kW RCA 4616 amplifier. Another chain consists of a 4616 exciting a Thompson Houston FTH-515 driver amplifier, which in turn drives two FTH-515 final amplifiers, one driving each Alvarez tank. The phase and amplitude balance between the two tanks is controlled by a high power trombone phase shifter and variable coupling loops at the FTH-515 driver output. The amplitude stabilization loop is closed on the prestripper Alvarez, with the poststripper running open loop. The frequency and phase tracking between the two tanks is accomplished by a continuously active tuner in the prestripper and by changing the master drive frequency. The RFQ is tracked independently. The amplitude variation in all three tanks is less than 1%. This system is a reconfiguration of available equipment and is a "zero cost" r.f. upgrade.

Linac Operation

The first unit of this system to operate was the RFQ, which was tested in the summer of 1983[2]. Immediately afterward, the 500 kV Cockcroft-Walton preinjector was disassembled and the first 24 drift tubes removed from the 20 MeV Alvarez linac. The new 60 kV ion source system and the RFQ were placed in the old preinjector room, the Alvarez tank extended 1.5 meters at the low energy end, and the diaphragm and 38 new drift tubes installed. Beam was first accelerated in February 1985.

The pre- and poststripper Alvarez tanks were tuned by monitoring the wall magnetic field with 6 and 17 pickups located along them, each loop at the location of an associated tuner. The tuners themselves are resonant loops which are rotated perpendicular to their axis, and are simpler than the customarily used piston tuners, as no high current wall joint is needed. The ratio of wall magnetic field to axial electric field is determined computationally: no bead pulling was used. The prestripper is given an 18% tilt, and the poststripper is almost flat. The 23 pickup signals are continuously displayed in a histogram format. The tuneup took only about a day for each tank.

The peak gradients of 2.64 and 3.1 MV/m in the pre- and poststripper are very high. Our previous experience with the original linac pressed into 2βλ operation with a peak gradient approaching 3.5 MV/m indicated that this gradient could be attained after about two weeks of conditioning. Most of the sparking occurred in the first few cells (the ones removed for this upgrade), resulting in a slow destruction of the drift tube face and an accumulation of copper "powder" at the bottom of the tank after 12 years of this mode of operation. At that time, two 3 MW amplifiers were used to drive the tank. During reconstruction, the tank was open to air and organic materials for over a year. The poststripper tank came up to full gradient in just a few days of conditioning with one 3 MW amplifier, requiring 2.75 MW, with the observed power agreeing with the predicted level. The X-ray levels are in the tens of millirad/hour range. The power level in the tank is determined by a wall magnetic pickup loop, calibrated against a standard level of power into the high level drive loop during a low power level test. A precision detector monitors the power from this calibrated pickup loop.

The prestripper, also with 3 MW of power available, shows a strong predilection to lock levels, probably due to the flat face drift tube design as well as an average X-ray level of about 3 rad/hour 1 meter from the tank at full gradient. The r.f. system must supply a rapidly rising pulse to break through the lock levels. The quadrupoles must be activated for reliable operation of the r.f. system, breaking up some of the electron orbits in the drift tube gaps.

The RFQ, thoroughly characterized in 1983, worked well when installed into the system. The previous testing was carried out at a temporary frequency of 202.4 MHz, as the final frequency of the Alvarez tanks was not yet known. The RFQ is fitted with two large frequency perturbation bars in each quadrant that are attached to the base of the vanes and run the full longitudinal distance of the machine. These bars were remachined after the final frequency of the Alvarez was known to be 198.96 MHz. The vane coupling rings[4] that tie opposing vanes in the RFQ together render the field distribution insensitive to small perturbations, allowing us to make these final trims easily. A loop tuner, inserted into one quadrant of the RFQ permits a ± 100 kHz variation of the resonant frequency without introducing a field variation in the structure. This is more than sufficient to track any variation in the Alvarez tanks, which has been at most a few kilohertz.

Beam Performance

The ion source has been in operation since the spring of 1984[5]. We have measured intensities of 430 pμA of Ne^{+3}, 130 pμA of Si^{+4}, and 33 pμA of A^{+6}. The emittance of these beams is presently about 50% larger than the 0.05π cm-mrad normalized acceptance of the RFQ, with most of the beam in the 0.05π cm-mrad core.

To date beams of helium and neon have been accelerated through the linac and Bevatron. The expected transmission through the LEBT, RFQ, prestripper and poststripper is expected to be 0.8 x 0.7 x 0.9 x 0.9 = 0.45. The stripper at 800 keV/n is expected to produce a 95% fraction of He^{+2}, and for neon a spectrum of 48% Ne^{+7}, 32% Ne^{+8}, and 7% Ne^{+9}. Our first acceleration attempt of He^{+1}, stripped to He^{+2} in the second Alvarez resulted in an overall particle transmission of 33%, which is 77% of the expected transmission. The emittance of the ion source is larger than the acceptance of the RFQ, so we expect that this is responsible for some of the losses.

A neon beam experiment showed a 25% overall particle transmission, to be compared to 22% – 37%, depending on the fraction of Ne^{+8} and Ne^{+9} picked up in addition to the normal Ne^{+7} accelerated in the poststripper. This indicates somewhere between 60 and 100% of expected particle transmission. The Ne^{+8} and Ne^{+9} components in the poststripper will emerge with a larger energy spread than the ±2% of the Ne^{+7} component.

The 95% beam emittance at the exit of the injector is 0.08π cm-mrad normalized. Based on these early experiments, it appears that the presently demonstrated intensities will be adequate to serve the objectives of the Bevalac research program.

References

1. J. Staples et al, "Heavy Ion Upgrade of the Bevatron Local Injector", 1984 Linear Accelerator Conference, Darmstadt, p. 377.
2. J. Staples et al, "Initial Operation of the LBL Heavy Ion RFQ", 12th International Conference on High Energy Accelerators, Fermilab, 1983, p. 516.
3. D. Howard, "A Versatile RF Controller", this conference.
4. H. Lancaster et al, "Vane Coupling Rings Simplify Tuning of the LBL RFQ Accelerator", 12th International Conference on High Energy Accelerators, Fermilab, 1983, p. 512.
5. G. Stover and E. Zajec, "Improved Bevatron Local Injector Ion Source Performance", this conference.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720