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**Authors**

Brodzik, D.
Lancaster, H.
Lou, K.H.
et al.

**Publication Date**

1973-03-01

Presented at the Particle Accelerator
Conference, San Francisco, CA,
March 5-7, 1973

LBL-1397
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D. Brodzik, H. Lancaster, K. H. Lou, R. M. Richter,
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March 1973

Prepared for the U.S. Atomic Energy Commission
under Contract W-7405-ENG-48

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# THE 50-MeV BEVATRON INJECTION LINAC*

D. Brodzik, H. Lancaster, K. H. Lou, R. M. Richter,
J. W. Staples, J. T. Tanabe, F. Voelker,
and E. Zajec

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

## Summary

The BNL 50-MeV injection linac has been installed as a new injector for the Bevatron. The preinjector, linac modifications, and beam transfer lines are described. The linac and modulator have been modified to permit longer pulse operation at a higher peak current. Most support equipment was already on hand and modified for use.

## Introduction

Recent improvements in Bevatron performance have made it desirable and practical to increase its intensity by increasing the injection energy and current. The Bevatron intensity increase by a factor of 2 to 3 makes practical low cross-section experiments that were previously impractical. The new stopped K-beam now under construction requires a large primary proton flux. Accelerator physics will benefit by having available large circulating currents for the study of coherent effects.

## Cockcroft-Walton

The power supply for the preinjector is a 21-deck Cockcroft-Walton. The bottom 12-deck 455-kV unit, powered by an 800-Hz generator, was a spare for the 20-MeV injector. The nine upper decks, supplied by a 400-Hz generator in the terminal, provide an additional 345 kV, giving a total of 800 kV.

All parameters in the high-voltage terminal are controlled by a small digital processor over a fiber-optics two-way communications link.[1] Five intermediate points along the column are returned to corresponding voltage points along the 21 decks, requiring that the 455-kV unit and the 345-kV unit outputs be proportional to each other. A digital reference signal is sent to both units and each is regulated individually. The maximum peak current is expected to be about 200 mA and the average drain about 750μA.

A plate mounted near the ceiling of the Cockcroft-Walton room provides a capacitive divider signal to control the bouncer which compensates for the sag in the terminal voltage during injection loading. The bouncer output stage is composed of two 4PR250 tubes in parallel driven by a light-link and low-level transistor amplifiers. This closed loop regulator has a bandwidth of 100 kHz and will reduce output perturbations in the ripple frequency band by a factor of 100.

To date the Cockcroft-Walton has been operated to 800 kV without the column and to 760 kV with column.

The dimensions of the high-voltage terminal were dictated by economic and voltage-holding considerations. The terminal room size permitted a seven-foot clearance between terminal and room walls. Complete service access to the high-voltage terminal, whose size was restricted to 6×7×7 feet high, is handled by a room-size floor elevator.

## Ion Source and Column

The 50-MeV injector source is a BNL MK-II duoplasmatron proton source[2] with an anode aperture 1.0 mm in diameter. The intermediate electrode is isolated from the anode by an alumina insulator fixed into position by an epoxy cement. Adequate cooling is maintained by circulating freon around the source magnet coil.

Initial tests of the source were made in the low-energy test facility, using a simple einzel lens to transport the beam to a Faraday cup. The filament used was a hairpin of tantalum 1 mil in diameter. Conversion to a barium-strontium oxide mesh-type cathode will take place soon.

The use of a dual arc supply permitted independent control of the filament and intermediate electrode voltage which in turn led to longer filament lifetime. The typical lifetime of the filament is now about 350 hours. The source has been run to 150 mA, but no beam quality tests have been performed yet.

The high-gradient column is a basic copy of the BNL design with some minor modifications. There are six basic modules consisting of three ceramic insulators epoxied to circular plates. The modules are bolted together to form the complete column of 18 insulators. The column is supported rigidly at the wall end and by a polypropolene rope at the high-voltage end. Total column weight is approximately 2500 pounds.

The ion source and column are pumped through a large drum-type manifold with two 1500-liter/sec ion pumps and a 650 liter/sec turbo-molecular pump.

## Low-Energy Beam Transport

A peak current of 150 mA with an emittance of 2.55π cm-mr is to be transported 6.9 meters from the ground end of the accelerating column to the middle of the first drift tube of the linac. The beam leaves the quasi-Pierce accelerating column and passes through five triplets with an average center-to-center spacing of 1.5 meters, with the gradients of each triplet reversed. The triplet strengths were calculated by using TRANSPORT, which simulates space charge by thin defocusing lenses, and also by numerically integrating a beam envelope equation with space charge forces. Both methods agree. The beam is well within the quadrupole aperture to minimize phase space distortion.

The beam is matched to the calculated acceptance of the linac both transversely and longitudinally. The longitudinal matching is accomplished with a single-gap fundamental-frequency buncher 1.2 meters upstream from the center of the first accelerating gap.

The design of the beam line is highly modular, consisting of triplets alternating with boxes containing various types of diagnostic devices. The entire beam line is mounted on an optical bench and all components are self-aligning.

## Linac

The linac consists of a single tank, 22 wavelengths long, containing 124 drift tubes with quadrupoles. There are 64 ball tuners, 64 sensing loops, and three RF drive ports at the 1/6, 1/2, and 5/6 points.

Calculations of the linac beam dynamics have been carried out by using the PARMILA program modified for space charge effects with a macroparticle procedure.[3] These calculations agree with those of Benton et al.[4] Parameters investigated are input matching, tank amplitude and tilt, quadruple tuning law and space charge effects. These calculations were carried out with a constant stable phase law throughout the tank. Recent calculations by Batchelor et al.[5] show that a synchronous phase space law results in improved transmittance and longitudinal phase space values, although we cannot achieve the required degree of tilt in our single tank. This inherent deficiency of the ball tuners also does not allow us to raise the field for the first few drift tubes the 25% required to compensate for the lower-than-expected transit time factors in those drift tubes.

In spite of this difficulty, it is still possible to achieve an output current of 60 mA or so with an input current of 150 mA. Computer runs show that for a bunch 120° long and emittances in both planes of $3\pi$ cm-mr and a focusing sequence -++-- , that we can achieve an output emittance of $2\pi$ cm-mr in each plane at an energy of 51 MeV with a spread of ±120 keV and phase spread of ±3° with an input current of 150 mA. Turning the last drift tube quadrupole off, resulting in a focusing sequence of --+0, produces a round beam at the exit.

The quadrupoles are driven in pairs by solid-state pulsers, which provide a flat-top during the beam pulse. Failure of any pulser during a pulse results in a beam abort. The pumping system consists of seven 1500-liter/sec Varian ion pumps and an 800-liter/sec Hg diffusion pump.

## RF System

The linac tank length of 22 wavelengths poses several RF problems. First, since the operating mode is at the edge of a pass band, the group velocity is low, and with heavy beam-loading the RF fields will deviate from an optimum distribution. This can be partially remedied by having multiple drive ports along the linac to reduce the distance from any part of the linac to the nearest source of RF energy.

A second difficulty arises because the operating $TM_{010}$ mode at 201 MHz is separated from the $TM_{011}$ mode by only 30 kHz. The RF sidebands produced by beam-loading compensation will excite many modes simultaneously if the amplitude is increased too rapidly.

The LBL group devised a solution to both of these problems by driving the tank at the 1/6, 1/2, and 5/6 positions along the cavity with a RF manifold system.[6] This particular system will supply energy to the $TM_{010}$ mode, but will not excite the five nearest TM modes, provided each loop supplies an equal amount of energy. The manifold between the three loops and the final RF amplifiers insures uniform distribution of RF energy. The end loops are connected to the center loop with 8-in. coaxial transmission lines which are an integral number of wavelengths long. Similarly, the final amplifiers are tied to the RF manifold at points which are an integral number of wavelengths from the drive ports. The power delivered to the cavity by each loop will be a function of the total power delivered to the manifold and of the relative coupling of each loop, but not a function of the relative power delivered by each amplifier. The effect of the manifold on the tank dispersion curve has been investigated qualitatively with a coupled-oscillator model and shows that the modes nearest to the operating mode are moved away from the operating mode.

The characteristics of the individual cells have been calculated with the LALA program: in particular, the transit time coefficients, the ratio of axial accelerating field to wall induction field, and the sensitivity of the ball tuners has been determined.

RF energy is generated by three final amplifiers, using Thomson-CSF TH 515 tubes capable of 3 MW peak power each. These have a relatively low gain so a fourth TH 515 is used to supply drive power to the final amplifiers. An RCA 4616 delivers 300 kW to the driver. Plate supply power to the four TH 515's is provided from a single 18-MW hard-tube modulator using two Westinghouse WL 8641 tubes in its final. The modulator has been redesigned to eliminate parasitics and to accommodate a longer RF pulse. The rebuilt modulator delivers 30 kV at 600 A to our dummy load with a bandwidth of 100 kHz.

Since the amplifiers have a common plate supply and a common drive amplifier, there is no way to regulate the relative amount of power from each amplifier during the pulse. The average power from each amplifier is controlled by varying the self-bias developed across a rheostat in the cathode return, making the amplifiers share the load.

To date the modulator is complete and has been used both on its dummy load and to supply plate voltage to one TH 515. The energy storage system has not yet been doubled to handle the longer RF pulse. The low-level RF system is completed and RF has been provided to the first TH 515. This stage has not been operated at full level because its 820-kW RF water dummy load sparks when its rating is exceeded. The 8-in. transmission line between drive loops and the final amplifiers is being installed at this time and should be complete soon.

## High-Energy Beam Transport

The high-energy beam transport (HEBT) carries beams from the 50-MeV injector, the present 20-MeV injector, and from the SuperHILAC to the Bevatron. The HEBT consists of three parts: an achromatic bend following the linac, a long straight section to the Bevatron area, and an achromatic inflection system into the Bevatron ring. The HEBT can transport a 50-MeV proton beam at an 80-mA peak intensity with an emittance of $2\pi$ to $3\pi$ cm-mr and a momentum spread of less than ±2.0% over a distance of 108 meters.

The first part of the HEBT, 19 meters long, contains a conventional achromatic bend with two magnets and a focusing scheme to match the betatron wavelength of the linac to that of the beam line. A kicker magnet can route linac pulses not injected into the Bevatron to a magnetic spectrometer and emittancemeasuring device. A single-gap debuncher is located 18 meters from the linac exit. Beam monitoring consists primarily of slits and viewing screens, emittance devices, toroids, and RF pickoffs.

The middle part of the HEBT, 61 meters long, consists of four equi-spaced doublets with a unit transfer matrix. Earth's field compensation is provided by four parallel current-carrying wires.

The final part of the HEBT, 28 meters long, consists of four bends which guide the beam around the Bevatron guide field magnet return yoke and translate it laterally 0.7 meter. The 20-MeV proton beam from the presently used injector is multiplexed with the 50-MeV beam in this area, and momentum analysis and emittance measurement provided both beams.

The electrostatic inflector design is conservative and retains the 87-kV/in. gradients which exist for the present 20-MeV inflector. In order to get a large enough bending angle to avoid the magnet-septum design problem, the electrostatic inflector length was increased 50% over the present 20-MeV design.

Steering and sensing elements consist of beam transformers, nondestructive RF vertical and horizontal beam position monitors, and vertical and horizontal steering magnets to trim the beam direction.

Emittance and beam-quality measurements are made in boxes scattered along the considerable length of the low-energy and high-energy beam transport lines. These boxes are standardized so that the apparatus used to measure the beam characteristics can be mounted on cover plates which fit any box along the beam line providing maximum access and flexibility.

Six bending magnets of five different designs are in various stages of design and construction. Magnetic uniformities ranging from 0.07 to 0.1% of the line integral field were attained by two-dimensional computer models for each magnet cross section. In two cases, MIRT, a two-dimensional interactive pole-shaping computer program, generated trapezoidal pole shims to bring the two-dimensional model within specifications. In both these cases, mechanical access and fabrication considerations required the use of an "H" type magnet with "pancake" coils mounted off the horizontal beamline.

## Mechanical Considerations

The dissassembly and transportation of the linac was accomplished is approximately eight weeks with the use of eight transport trucks. Eleven tank sections comprising a total assembled length of 110 feet were placed on pedestal supports and aligned to an approximate bore center line of ± 0.005 inch. Entrance and exit dummy lead optical target holders were installed and aligned to the projected beam center line within ± 0.002 inch. These two targets would then constitute the absolute beam center line from which floor targets were installed for alignment of the beam transport system. To match the Bevatron beam height, the injection system beam center line is 82 in. above the floor.

Optical alignment bore scopes were set up at both ends of the linac and each of the 123 drift tubes were installed and aligned to ± 0.002 inch. In order to maintain as much accuracy as possible, drift tubes were positioned from each end of the linac, sighting only a maximum one-half of the machine length. A linear steel tape in conjunction with a bore scope and a pentaprism were used to position drift tubes down the tank length.

To maintain the machine at a constant temperature of 70°F a closed circuit water system was installed, maintaining tank walls and drift tubes to ± 1/4 °F. A surplus cooling tower ($4.8 \times 10^6$ BTU - 300 GPM) is presently being installed and will provide a water supply independent of fluctuating experimental demands. Most of the shielding, a humidity-controlled air conditioner (10 tons) for the preinjector, and much of the control room were already on hand.

Drilled caissons support the transport magnet stations to isolate the elements from the load imposed by the 12-in.-thick concrete shielding enclosing the vacuum channel.

## Footnote and References

*Work done under the auspices of the U. S. Atomic Energy Commission.

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4. A. Benton, R. Chasman, C. Agritellis, 1967 Particle Accelerator Conference, NS-14, p. 577.

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6. Ferd Voelker, Theory of the RF Manifold and Measurements on a Model Manifold System, Lawrence Radiation Laboratory Report UCRL-17308, April 1967.

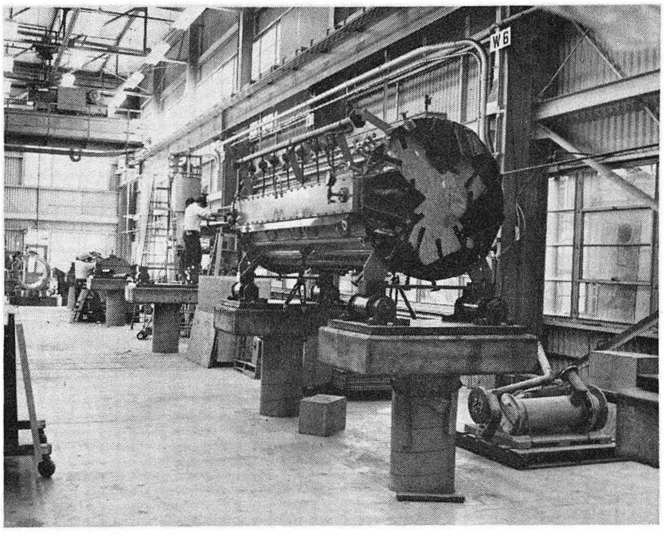

Fig. 1. Linac tank section resting on support caissons.

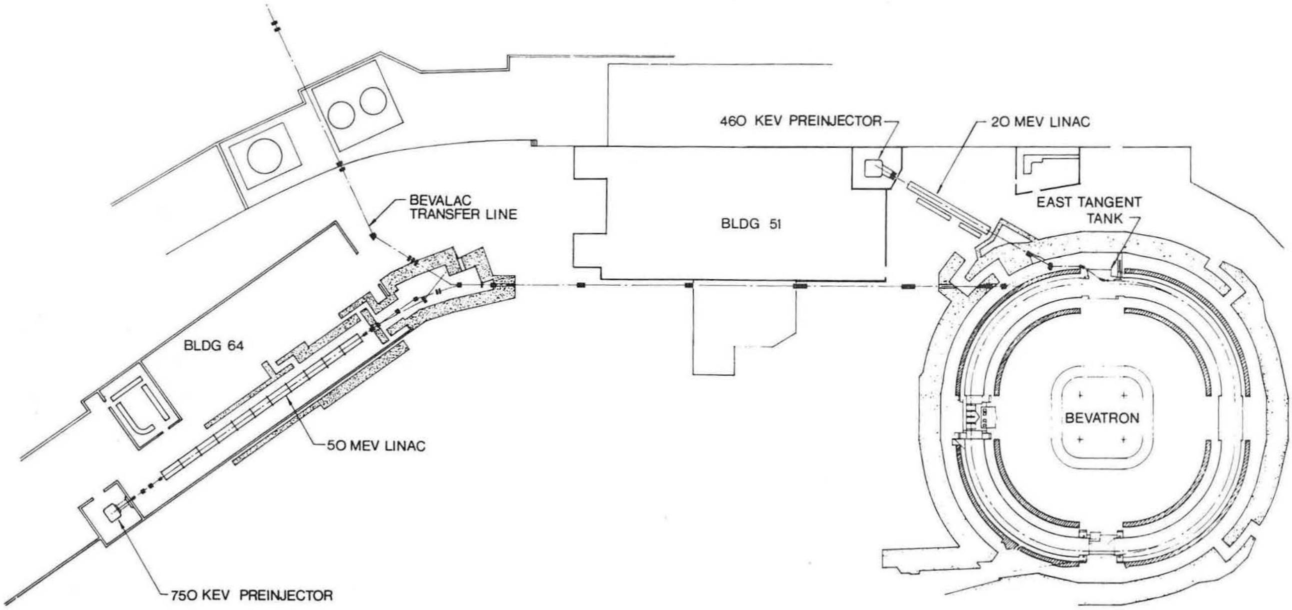

Fig. 2. Overall schematic of Bevatron injection lines. 50 MeV linac at lower left, 20 MeV linac at upper right, SuperHILAC off the page at upper left.

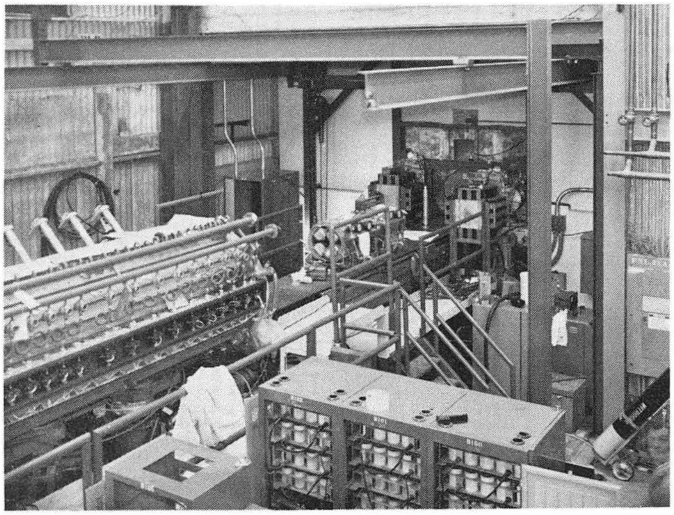

Fig. 3. (above) Low Energy Beam Transport area. Two triplets in view but not positioned.

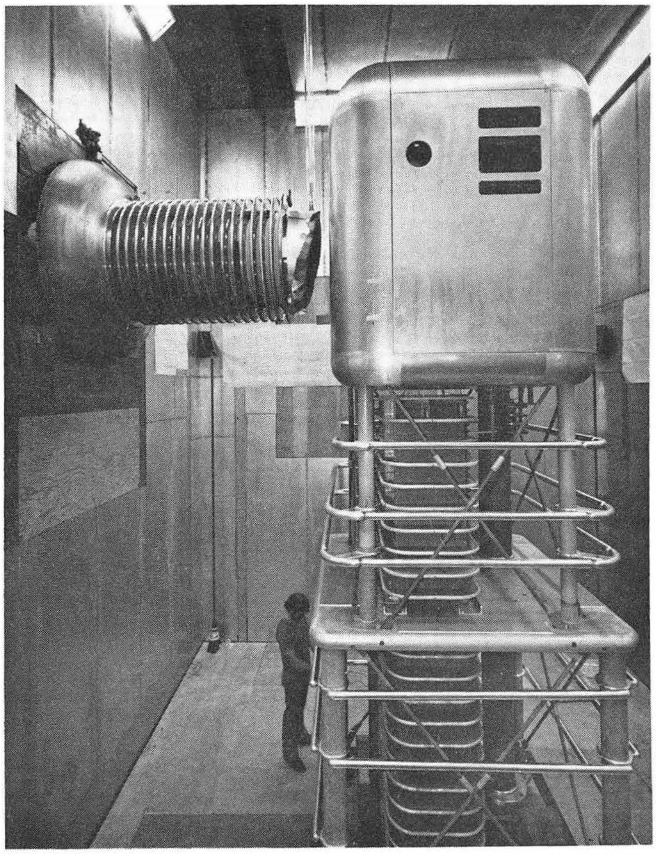

Fig. 4. (to the right) 750 keV Cockroft-Walton and high-gradient column.

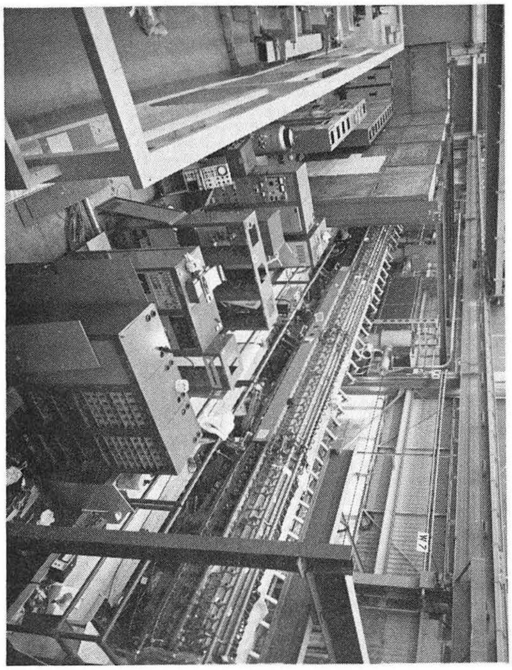

Fig. 5. Linac tank with shielding, low-level RF in the middle of the picture, quadrupole power supplies in the foreground.

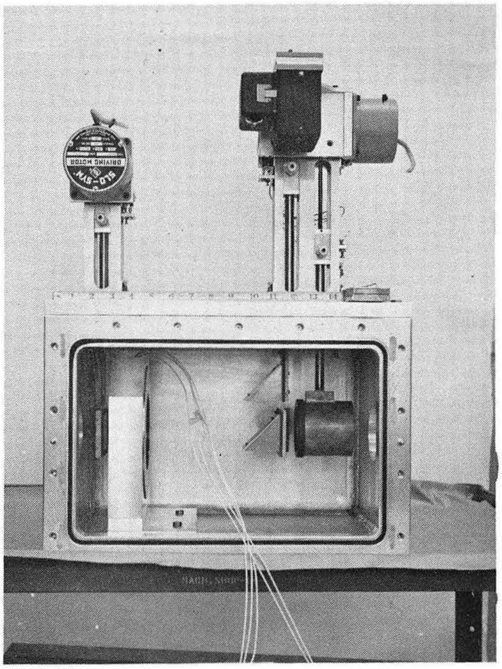

Fig. 6. A typical beam analysis station with two viewing screens and a traveling Faraday cup installed.

*TECHNICAL INFORMATION DIVISION*
*LAWRENCE BERKELEY LABORATORY*
*UNIVERSITY OF CALIFORNIA*
*BERKELEY, CALIFORNIA 94720*