THE BEVALAC BEAM TRANSPORT SYSTEM*

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R. Avery, G. Behrsing, R. Morgado, D. Rondeau
W. Salsig, F. Selph, J. Staples, R. Yourd
Lawrence Berkeley Laboratory
University of California
Berkeley, California

Abstract

The Bevalac consists of, in part, a 200 meter long transfer line between the SuperHILAC and the Bevatron, which are at differing elevation. Unique features in the construction of the transfer line are described. The line, located largely outside, must cope with a natural environment. Part of the line passes through a hillside, requiring some unique support and alignment techniques. The dipoles are of the tape-wound variety and the steering magnets use printed circuit conductors. The vacuum system and an inexpensive and effective destructive monitoring system are described.

Introduction

Recent interest in relativistic heavy ion reactions has increased considerably. At the Bevatron, low intensity relativistic beams of ions as heavy as Neon have been available since August 1971, using the 20 MeV proton injector as a heavy ion source at an energy of 5 MeV/A in the 2βλ mode. The close proximity of the SuperHILAC led to the suggestion that it might be used as an alternate ion source for the Bevatron, providing higher intensity and mass numbers. The marriage of the SuperHILAC and Bevatron--the Bevalac--was accomplished with a beam transport system linking both machines, with appropriate modifications to each machine to render them mutually compatible.[1]

Several unique features have been incorporated into the Bevalac. A computer-controlled time multiplex of the SuperHILAC beams allows highly efficient use of the SuperHILAC, since the Bevatron requires a low duty-factor injection pulse. Tape wound and printed-circuit magnet coils are used at several locations to save weight and cost.

Optics

The beam line transports the 8.5 MeV/A beam from the SuperHILAC beam switchyard to the existing 50 MeV proton transfer line. The BEVALAC line is 170 meters long and descends 45 meters in elevation. The 50 MeV transfer line adds 89 meters more to the overall length.

The SuperHILAC beam has the following parameters:

Kinetic Energy	8.5 MeV/A
Relative e/m	.40 - .50
Rigidity	10.5 kGauss-m
Emittance	2π cm-mr
Momentum spread	±.5%

Ions accelerated in the poststripper tank of the SuperHILAC must have a charge-to-mass ratio greater than .16, but are usually not fully stripped, necessitating the use of a stripper at the exit of the poststripper tank. Neon and lighter ions are fully stripped by a carbon foil. Heavier ions are stripped with progressively less efficiency, with a yield of 60% for 18+ Argon and 5% for 36+ Krypton.[2]

The first part of system, shown in Fig. 1 begins inside the last tank of the poststripper with a pair of matching quadrupoles located in drift tubes 74 and 75, followed by a 1° switching magnet PM4. This magnet diverts the beam into the south channel of the 3-channel septum magnet M1, the first of a series of bending magnets which bend the beam through an additional 130° before entering the transfer line. Because of space limitations the magnets are placed very close together. The two quadrupoles, QS2 and QS3 are used for focusing and to control dispersion.

The beam is then bent downward 23° by an achromatic bend and enters the 45 meter long tunnel through the hillside. At the end of the tunnel is an 8" doublet and another 45 meter drift length. A 66° achromatic bend and several quadrupoles match the beam into the 50 MeV transfer line. The emittance is preserved in the compound bend into the 50 MeV line by focusing the beam to a round waist.

The 50 MeV transport line, described previously, transports the beam to the electrostatic inflector septum of the Bevatron.[3] No changes were required in this section of the system except for the installation of monitors similar to those found in the Bevalac transfer line. Any one of the three injectors for the Bevatron, the 20 and 50 MeV proton injectors, and the SuperHILAC, can be selected with an hour's time required for the changeover.

Fig. 2 shows the horizontal and vertical beam envelope for the entire line and Fig. 3 the overall beam line arrangement.

Hardware

Five of the bending magnets in the transfer line use edge-cooled tape coils. These magnets are considerably smaller, lighter and require less power than magnets using conventional hollow conductor coils. The magnets are wound using 5-in. x 0.020-in. copper strip, with 0.003-in. polyester weave paper insulation saturated with epoxy during the wet-winding process. Electrically insulated water cooled plates are compressed against both coil edges using a thermally conductive heat sink compound. Hall probes are bound to one pole in each magnet as a field reference.

The magnetic fields range from 4.5 to 6 kGauss, with clear gaps of 5 to 6 cm and aperture widths of 6 to 10 cm. The design current for the magnets is 250 amps with voltage drops of 12 to 25 volts.

Ten steering magnets are located along the Bevalac beam transport system, five steering horizontally and five vertically. These magnets consist of a piece of steel pipe inside of which are located printed-circuit windings.[4] The steel shell is 65 cm long with a 26.2 cm I.D. At 25 amperes the integrated field is 54 Gauss-meter with a .65% maximum field inhomogeniety at a 10 cm radius.

The underground portion of the BEVALAC beam transport line is located between the SuperHILAC parking lot and the steep scarp midway on the

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partially-wooded hillside slope. After studying the excavation alternate, it was decided to push a liner pipe through the earth from station 4 in the SuperHILAC parking lot. This method preserved the trees in the right-of-way of the line and produced a minimum disturbance of the hillside, a precarious terrain and former slide area which has been relatively stable for the last dozen years. Alignment of the liner pipe as it was proceeding through the hillside was checked periodically with previously surveyed benchmarks on the wooded platform.

The 8-inch vacuum pipe is supported inside the tunnel at the half and quarter points. Each pipe positioning support consists of two jacks installed at 45 degrees which can pivot at the pipe yoke and the jack base. The jack base rides on ball rollers and is restrained by stop bars from moving sideways. The jacks can be remotely operated by actuator rods which extend to the ends of the tunnel. Alignment of the pipe in the tunnel is done with targets bolted to the support yokes.

The Bevalac beam transport line is supported on steel towers and support platforms. Steel reinforced piles are installed into drilled holes at stations 2, 3 and 7 to depth of up to 20 feet. The support platforms and towers are welded to steel pipes, 6 and 8-inch diameter, which are embedded in the piles.

On the hillside below the steep scarp, 8-inch. diameter steel friction piles were driven to refusal into the bedrock under the old landslide slip plane to insure adequate bearing capacity. This construction, done with a pile driver on a long crane boom from the service road below, permitted minimum disturbance to the vegetation and stability of the soil.

Optical tooling equipment and procedures are used to align the Bevalac beam magnets and vacuum pipe with respect to both the SuperHILAC and the 50 MEV injector line junctions.

The quadrupole doublets and dipoles were aligned and surveyed at night to reduce thermal effects with an illuminated collimator target and an alignment telescope. These magnets have permanently mounted prepositioned tooling balls or cones which accept either the collimator or alignment telescope. By using an alignment collimator as a target, x, y, pitch and yaw can be determined on a single sighting.

The proper roll of these magnets around the beam axis is set with a stride level mounted on a roll bar which is installed on each magnet. The resulting alignment errors of all the magnets is well within the correction capability of the steering magnets.

The Bevalac vacuum line consists of 8-inch stainless steel tube sections between magnet stations and through BLQ-5 and 4-inch tube elsewhere. The vacuum line is a 10-inch pipe at a 40 foot span across the road at the SuperHILAC. Stainless steel bellows in the line accommodate expansion and some misalignment of the pipe sections. Aluminum gasket plates between flanges facilitate inspection and replacement of gaskets. All vacuum joints between line components are sealed with rubber O-rings.

The transfer line is divided into six sections separated by gate valves. The system has 4 vacuum pumping stations. Vac Ion pumps with a pumping speed of 435 ℓ/sec are located at stations 2, 4, and 7. A 650 ℓ/sec turbomolecular pump is located at station 5.

Ion and Hastings gauges are located at the pumping stations and approximately midway between pumps where the maximum point of the parabolic pressure curve occurs. The average vacuum in the line during the day, when the sun raises the temperature of the pipe and causes additonal outgassing from the walls, is about 1×10^{-5} Torr. The average vacuum at night has been observed to be 5×10^{-6} Torr.

Monitoring

Monitoring of the beam in the transfer line is accomplished primarily with segmented Faraday cups, several scintillator screens and a sensitive beam transformer. The SuperHILAC nominally produces 36 pulses per second, with every sixth pulse sent into the transfer line. The instantaneous particle current from the SuperHILAC ranges from less than 10^{10}/sec for Krypton to 10^{15}/sec for carbon, corresponding to $7 \cdot 10^{8}$ to $1.2 \cdot 10^{13}$ charges per 2 msec pulse. The Faraday cups have nine segmented electrodes in a 3 x 3 grid on approximately 1 cm centers. The sensitivity is sufficient to cover the above range, with a margin of almost two orders of magnitude on the low end. Crosstalk between the segments is minimized by a biased grid in front of the segments. DC offsets are eliminated by sampling the segment potential just before and just after the beam pulse and digitally subtracting the two values.

Because of the large aperture and the adequate steering and monitoring, normal beam losses are low. Hence, the losses during adjustment and abnormal operation define the radiation shielding needed. The assumed losses at any one location along the line shall be limited to the equivalent of one hour of full transmitted beam per 40-hour week. The beam intensity is assumed to be $3.6 \cdot 10^{12}$ charges per second, which includes the pulsed nature of the beam, and an adequate safety margin.

Access to large portions of the beam line is controlled by using an excluding fence located 15 feet from the line of the towers. The radiation level at the fence is held to less than 100 mrem per hour for less than one hour per week. To assure this, shielding equivalent to a few inches of concrete is placed at loss points on the line and neutron monitoring equipment is placed at ground level. In areas where personnel may come close to the line, up to 18 inches of concrete equivalent are provided.

The twelve segmented Faraday cups are designed to plunge sequentially into the beam on twelve successive pulses between the pulse eventually destined for Bevatron injection. Monitoring is thereby achieved between each injected pulse and steering and focussing errors can be detected and flagged for operator intervention. The cups, under computer control are pneumatically driven into the beam from the parked position in 150 ms. A dual bellows system was developed for this purpose and has been tested in excess of 10^{6} cycles without apparent fatigue. The relatively fast plunging requires that the mass of the cup assembly be minimized. An all-aluminum cup assembly is being fabricated to replace the more massive stainless steel assemblies presently used.

The Faraday cup and beam transformer data are presented on CRT consoles either as histograms or in numerical form.

For maximum sensitivity, the analog signals are digitally processed in the immediate environment of the cup. Since the transfer line is above ground and exposed to the weather, the associated electronics are environmentally controlled to maintain stability.

A sensitive beam transformer is provided for non-destructive monitoring. Over its bandwidth of 10 Hz to 10 kHz, the equivalent noise current is 25 nA peak-to-peak, allowing discrimination of a few 10^8 charges per pulse.

Alumina scintillators and TV cameras are provided at a few points along the transfer line, and providing sensitivity down to the 10^{10} particle range.

Computer Control System

The first seven months of Bevalac operation took place with the transfer line elements manually controlled, except for computer controlled and displayed Faraday cups. Subsequent operation, beginning in March 1975, will have all elements under computer control.

The BEVALAC Control System is a multi-processor system. The central processor is a Modular Computer Corporation Mod Comp IV Computer with 96K x 16-bit core memory, a 25 megaword disc, a 75-in. per second magnetic tape, a card reader and a high speed paper tape reader. A direct memory processor high speed serial link connects the central processor to the real-time processors. The real-time processor is a Mod Comp II computer with a 32K x 16-bit core memory.

Each operator station consists of a video display, a standard keyboard, a special function keyboard and four incremental encoded knobs.

The control of the magnet power supplies is provided in one of the real-time processors. The operators can monitor the interlock chain of a magnet power supply, turn the power supply on if the chain is complete, and control and monitor the magnet current.

The physical distribution of the magnet power supplies in the high noise environment was handled by placing the DAC's and ADC's close to the power supplies.

The control and monitor system is an 11-bit + sign system specified at 0.1% accuracy. The monitor system uses low-cost 100 millivolt shunts on power supplies up to 250 amps and a 10 volt dc transductor on power supplies from 250 amps to 2000 amps. A conditioning amplifier and a dual slope analog-to-digital converter provides 60 db of common mode noise rejection from dc to 1 kHz. Magnets requiring bipolar currents are run on a unipolar supply and are reversed using a relay.

The real-time processor algorithm monitors the magnet current every 100 ms keeping a running average of the magnet current and adjusting the control word to maintain the magnet current at the value desired by the operator. Values displayed for the operator are in engineering terms, while all DAC's and ADC's are scaled so the maximum binary value equals the maximum operating current plus 10%. Set-up parameters are stored on the disc for each ion at selected energy levels. An operator can request a particular ion and energy and if all power supply chains are complete, the central processor will turn on all needed power supplies and adjust the magnets to correct polarity and current via the real-time processor. The ability to automatically tune the line using the nine segment Faraday cups information exists in the hardware, but the correct algorithms and software have not been designed.

The synchronizing of the SuperHILAC and the Bevatron is accomplished with a complete handshaking method, where each interrogates and answers the other with status and timing information. The SuperHILAC basic rep rate is 36 pulses per second, and is synchronized to the 60 Hz line. The Bevatron basic rep rate is 10 pulses per minute and is synchronized to the large M.G.'s providing the current for the guide field with a basic turn-on window of ±3 ms. The transport system is run at six pulses per second for tuning purposes with ten of the pulses per minute synchronized to the Bevatron.

The Bevalac is the work of many dedicated people. Particular thanks goes to G. Lambertson for suggestions on the design of the transfer system, to R. Mobley for assistance with the beam optical calculations, to A. Borden and T. Lauritzen for development of the mechanical alignment procedure, and to J. Cuperus for the design of the sensitive beam transformer.

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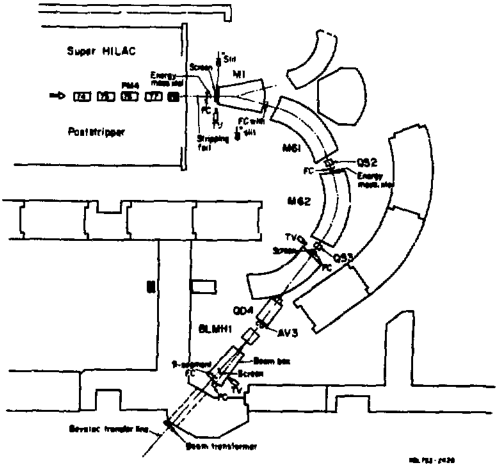
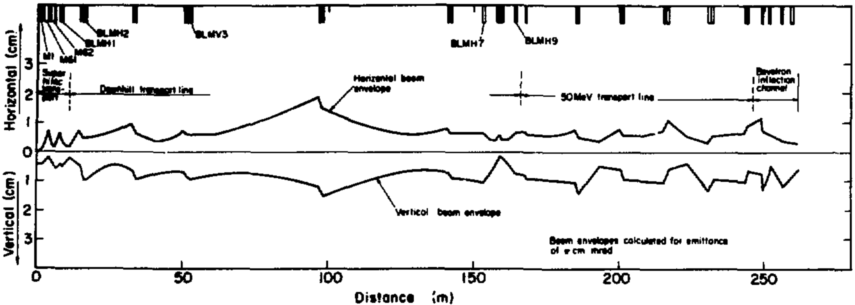


Bevalac Transfer Line in SuperHILAC Beam Switchyard.

Fig. 1



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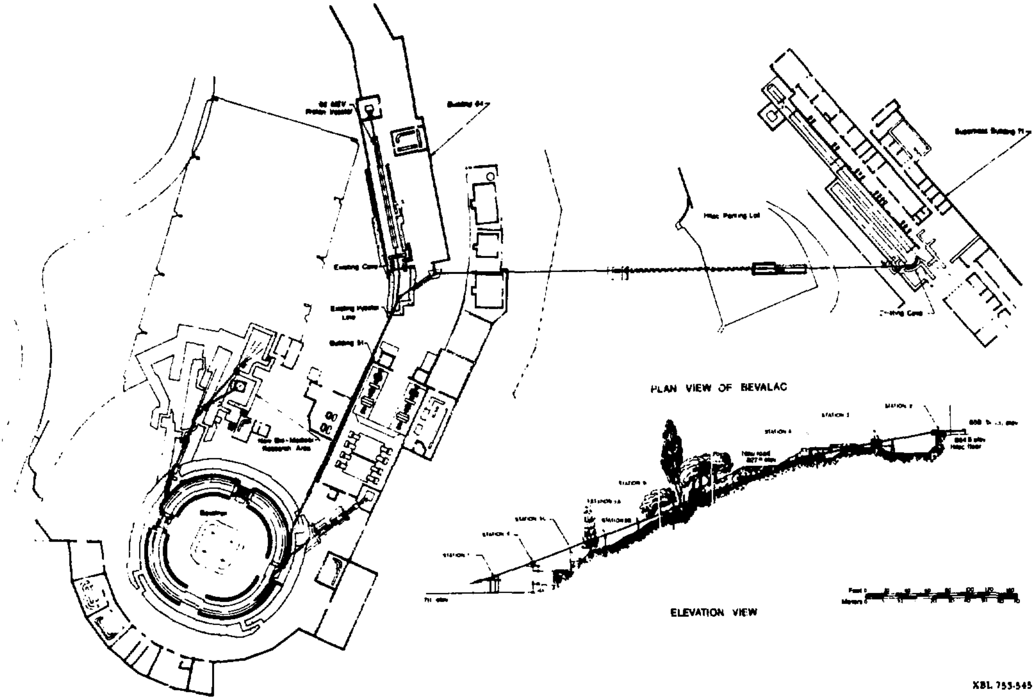
Horizontal an/ Vertical Beam Envelope

Fig. 2



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Plan and Elevation View of Bevalac Beam Line

Fig. 3