SYSTEM FOR TRANSPORT AND ANALYSIS OF 200 MEV LINAC BEAM*

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ABSTRACT

The 200 MeV beam from the NAL linac will be steered along either of two beam lines. One beam line will be used to transport the beam from the linac to the inflector of the booster synchrotron. This line will be 65m long. It includes a vertical translation from the linac elevation to the booster elevation and quadrupoles for matching the beam to the booster acceptance. The other beam line will be used for analysis of the linac beam. Emittance will be measured with three beam profile monitors located in a line straight ahead from the end of the linac. Momentum spread will be monitored by deflecting the beam 40° with a magnet and measuring the width of the dispersed beam. Switching the beam between the transport and the analysis lines will be done with a pulsed electrostatic deflector followed by a septum magnet in order to permit selecting the duration of the beam pulse transmitted to the booster over the range from 1 μsec to 100 μsec. Linac beam not transmitted to the booster will be stopped in a beam dump in the analysis system.

Introduction

The 200 MeV proton beam from the NAL injector linac can be steered into either of two beam lines. One beam line leads to the system for measuring the emittance and the momentum spread of the linac beam. The other beam line transports the beam from the linac to the inflector of the booster synchrotron. A layout of the area occupied by the two systems in shown in figure 1.

The beam line leading to the equipment for analysing the linac beam proceeds straight ahead from the end of the linac to a 40° spectrometer magnet. The momentum spread is determined by bending the beam with the 40° magnet and measuring the beam profile at the image. The beam used for emittance measurements proceeds in a straight line through a hole in the yoke of the spectrometer magnet. Thus, there is no dispersion in the beam used for emittance measurements. The emittance is determined by three beam profile measurements along this line. Beam dumps are located at the ends of both the emittance and momentum analysis systems. An enlarged view of the area used for analysis of the linac beam is shown in figure 2.

The beam to be injected into the booster synchrotron is bent immediately after leaving the linac by an electrostatic deflector and a septum magnet. The beam leaves the linac analysis area and proceeds to the booster tunnel through a narrow duct 40 feet long. It then proceeds along the booster tunnel near the outside wall for 70 feet before being injected into the synchrotron. With this arrangement, it is expected that installation and maintenance work can be done in the booster tunnel while the linac is operating and the beam is stopped in one of the beam dumps located at the end of the analysis area.

Chopper

Most of the deflection which separates the beam line for the beam going to the booster from the beam line going straight ahead to the linac analysis area is produced by a 9.7 deg. septum magnet. The beam is switched from one side of the 0.2 inch thick septum to the other by a pulsed electrostatic kicker located just after the last cavity of the linac.

To reduce the voltage required on the plates of the kicker in order to switch the beam from one side of the septum to the other, the beam is focused in the horizontal phase plane to a 0.5 cm wide waist at the leading edge of the septum. Since there is room for only one focusing magnet between the last cavity of the linac and the septum, this focusing must be done with quadrupole magnets inside the drift tubes of the linac. Therefore, the strengths of the last four quadrupoles in the linac are adjustable independently. A trim steering magnet at the exit of the linac is adjusted so that the 0.5 cm wide beam skims past the outside edge of the septum when the kicker voltage is off. The focusing and steering of the beam at the leading edge of the septum are monitored with the beam profile detector W-1.

The electrostatic kicker is designed to select the segment of the linac beam pulse with the best quality and send it to the booster synchrotron while the remainder of the linac beam pulse goes into one of the beam dumps at the end of the linac analysis area. The length of the segment selected can be adjusted from 1 μsec to 100 μsec. For the nominal 4 turn injection planned for the booster, a 12 μsec segment will be sent to the booster. Shorter pulses will be available for booster tune up and diagnostic work.

The kicker consists of two 80 cm long plates separated by 1 inch. Both plates are charged to 75 kV in between linac pulses. The leading part of the linac pulse goes straight ahead to a beam dump beyond the linac analysis area. To deflect the beam to the booster, one plate is crobared with a thyratron in one μsec. At the end of the booster injection interval, the other plate is crobared and the remainder of the beam goes to the beam dump.

The 3 kG field in the septum magnet is produced by a 1000 A direct current in an 8 turn water cooled coil. The septum is made of a single layer of 1/8 inch square hollow conductors insulated with glass tape and epoxy.

Linac Beam Analysis System

Emittance Measurement

For emittance measurements the beam in the straight ahead line is focused to a waist inside the straight through pipe in the yoke of the momentum analysis magnet with quadrupole magnets Q2 and Q3. The emittance of the beam is determined by measurements of the beam profile at, at least, three locations.

The beam profiles are measured by intercepting a small fraction of the beam on a 0.001 inch diameter wire which is stepped across the beam aperture. The wire is moved in steps, one step in each interval between beam pulses. Thus, several beam pulses are required to obtain one complete beam profile, and the beam properties must be steady from pulse to pulse. The use of this method for measuring the emittance of the 66

MeV beam from the first three cavities of the NAL linac has already been described at this conference by R.W. Goodwin, et. al.[1] The wire profile scanners labeled W-1 through W-5 in figure 2 are available for determining the emittance.

Should it become desirable later on to measure a complete beam profile during one beam pulse or if the residual radioactivity from intercepting part of the beam by the wire becomes undesirable on a long term basis, it is possible to replace the wire scanners with ionization type profile detectors.[2] For the initial operation of the accelerator, the wire scanners have the advantage of providing larger signals, thereby allowing detection of small beam currents without interference from noise. The ultimate resolution is higher than that of an ionization detector, and the resolution and the aperture covered can be changed easily.

Momentum Analysis

The 40° spectrometer magnet was built to measure the energy spread in the beam from the linac. During the recent tests with beam from the first six cavities of the linac, it also proved useful for monitoring changes in the mean energy of the beam. The calibration was known well enough to verify that the absolute value of the beam energy was 139 MeV to within about 2%.

The small horizontal waist at the entrance to the chopper septum magnet serves as the object for the spectrometer. The width of the beam at the object point is monitored with the wire profile detector W-1. Instead of defining the emittance with slits, in the customary way, it is measured with the profile detectors in the straight through beam line. This eliminates the problem of residual radioactivity on the slits. The momentum spread is determined by measuring the width of the beam at the object of spectrometer with the wire profile scanner W-6.

The pole faces of the spectrometer magnet are flat and parallel to each other. The ends of the poles were shimmed to make $\int (B/\rho) ds$ along beam trajectories constant to within 0.05% inside the good field width of 10 cm. Vertical focusing is provided by quadrupoles Q3 and Q4.

The quadrupoles Q4 and Q5 may be adjusted to produce as small a horizontal waist and as large a dispersion as possible at the profile detector W-6 as well as to spread the beam satisfactorily further on in the beam dump. The resolution is improved by adjusting Q2 and Q3 to make the beam nearly fill the horizontal good field width of the 40° magnet. The dispersion at W-6 can be made as large as 8 mm per 0.1% in $\Delta p/p$, and the calculated resolution is better than 0.1% for the design linac emittance of 8 πmm - mrad.

Beam Dumps

The beam dumps are buried in the dirt outside the room used for analysis of the linac beam. They are re-entrant steel castings approximately 3 feet in diameter. The beam enters through a hole along the axis. It is stopped on one side wall of the hole, which slopes at an angle of 3° with respect to the beam direction in order to spread out the area that the beam hits.

The steel castings serve as the vacuum chambers for the dumps which are open into the beam pipes in the analysis system. They provide fast neutron shielding and shielding for the residual radioactivity. Slow neutron shielding is provided by a layer of concrete about 1½ feet thick which was cast in place around the steel casting. Additional shielding is provided by earth fill over the top and sides of the beam dumps.

The heat generated inside the dumps is conducted through the steel and concrete to the earth where it is dissipated. It is estimated that the 15 ton, 9-ft long steel casting for the beam dump at the end of the momentum analysis line will dissipate from 3 to 10 kW. The steel casting for the dump at the end of the emittance line is only 6 feet long, and the dissipation is expected to be in the range of 0.3 to 1 kW. The maximum temperature rise during a beam pulse is expected to be less than 10° C provided the beam is spread out with a cross section 4 cm.

Transport To The Booster

In order to make beam line to the booster achromatic, the bend which separates this beam line from the linac analysis line is divided into two parts. The chopper kicker and septum magnet are the first part of the bend and the 5.9^{o} horizontal bending magnet makes the second part. Momentum recombination is done with Q6. Vertical focusing for this part of the system is provided by Q1.

As shown in the elevation view in the lower part of figure 1, two 12.8^{o} vertical bending magnets produce the vertical translation required to get the beam from the linac level down to the level of the booster synchrotron. Quadrupoles Q9 to Q12 are used to make the vertical translation achromatic and to provide focusing in this part of the beam line. The quadrupole magnets Q7 and Q8 are used for matching between the bending system in the linac analysis area and the vertical translation.

To increase the drift distance available for debunching, the beam goes along the outer wall of the booster tunnel for 18 m before being bent across the tunnel to the inflector. The total drift distance from the linac to a debuncher located just ahead of Q16 would be 45 m.

The multiturn injection system planned for the booster synchrotron is similar in principle to the one in use in the AGS at Brookhaven. The beam is injected on the outside of the purturbed closed orbit by 0.7^{o} electrostatic inflector with a 0.002" thick wire septum. The inflection bend is increased to 9^{o} by a magnet with an 0.2" thick septum. Both elements operate dc. The quadrupole magnets Q20, Q21, and Q22 together with the inflection bend and the 24.6^{o} bending magnet at the outside of the tunnel form a system which can be tuned either to be achromatic or to give momentum matching. The quadrupole magnets Q13 to Q19 are used to match the beam to the transverse acceptance of the booster and to provide focusing in the long drift space.

During the 139 MeV tests, the beam intensity was monitored at several points along the transport system with current transformers.

Several of the transformers have split windings so they can be used to detect the beam position in the future. Air core trim magnets are used to correct steering errors.

Space Change Affects

The detailed design calculations for the transport system have been done with the SLAC computer program transport and do not take space charge affects into account.[3] S. Ohnuma has estimated that, for 100 mA beam currents, transverse space charge forces will increase the beam size by a factor of approximately 4/3 if the low intensity tuning of the system is not changed.[4] However, for transmission of a high intensity beam it should be possible to reduce the beam cross section by increasing the strength of the quadrupoles. The affect of space charge on the achromatic properties of the system has yet to be determined.

The effect of space charge on the longitudinal rf bunch structure of the beam has been studied by L. Smith[5] and by A. Benton.[6] These studies indicated that, with 100 mA, the width in phase of the 200 MHz bunches will increase from a nominal value of approximately $\pm 4^\circ$ at the end of the linac to approximately $\pm 35^\circ$ after a 50 m drift. At the same time the momentum spread increases by a factor of 3 to 4 from the nominal value of 0.1% at the end of the linac. Space charge forces change the beam very little as it drifts beyond 50 m.

The longitudinal spreading of the rf bunches helps to reduce space charge affects in the booster synchrotron. However, the increase in momentum spread increases the rf voltage required in the synchrotron accelerating cavities in order to trap the beam. For this reason the design of the transport system includes provision for the future installation of a debuncher to reduce the momentum spread. The calculated phase width of the bunches and the dependence of the energy deviation on phase indicate that a conventional first harmonic debuncher should be satisfactory.

Acknowledgements

The design and construction of this system has been under the overall direction of A. VanSteenbergen, P.J. Reardon, and R. Billinge. They determined the main features of the system. L.A. Klaisner and J.M. Stephenson were responsible for the power supplies and the controls. A large number of other people in the Booster Section made very important contributions to the project especially L. Mapalo in mechanical design, T.A. Topolski in alignment, and E. Stitts in installation.

Footnote and References

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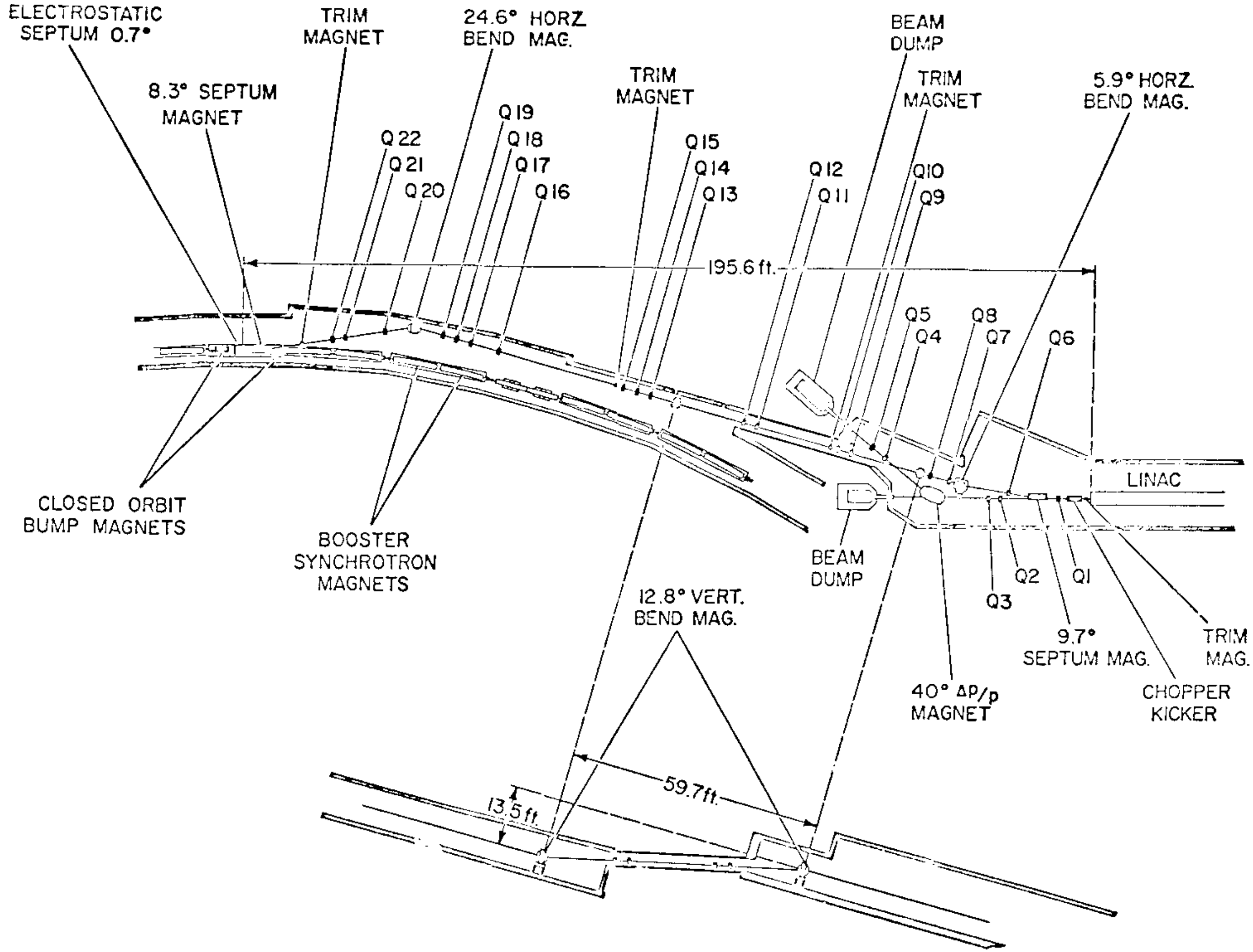

Fig. 1. Layout of the system for transporting the 200-MeV proton beam from the linac to the inflector of the booster synchrotron.

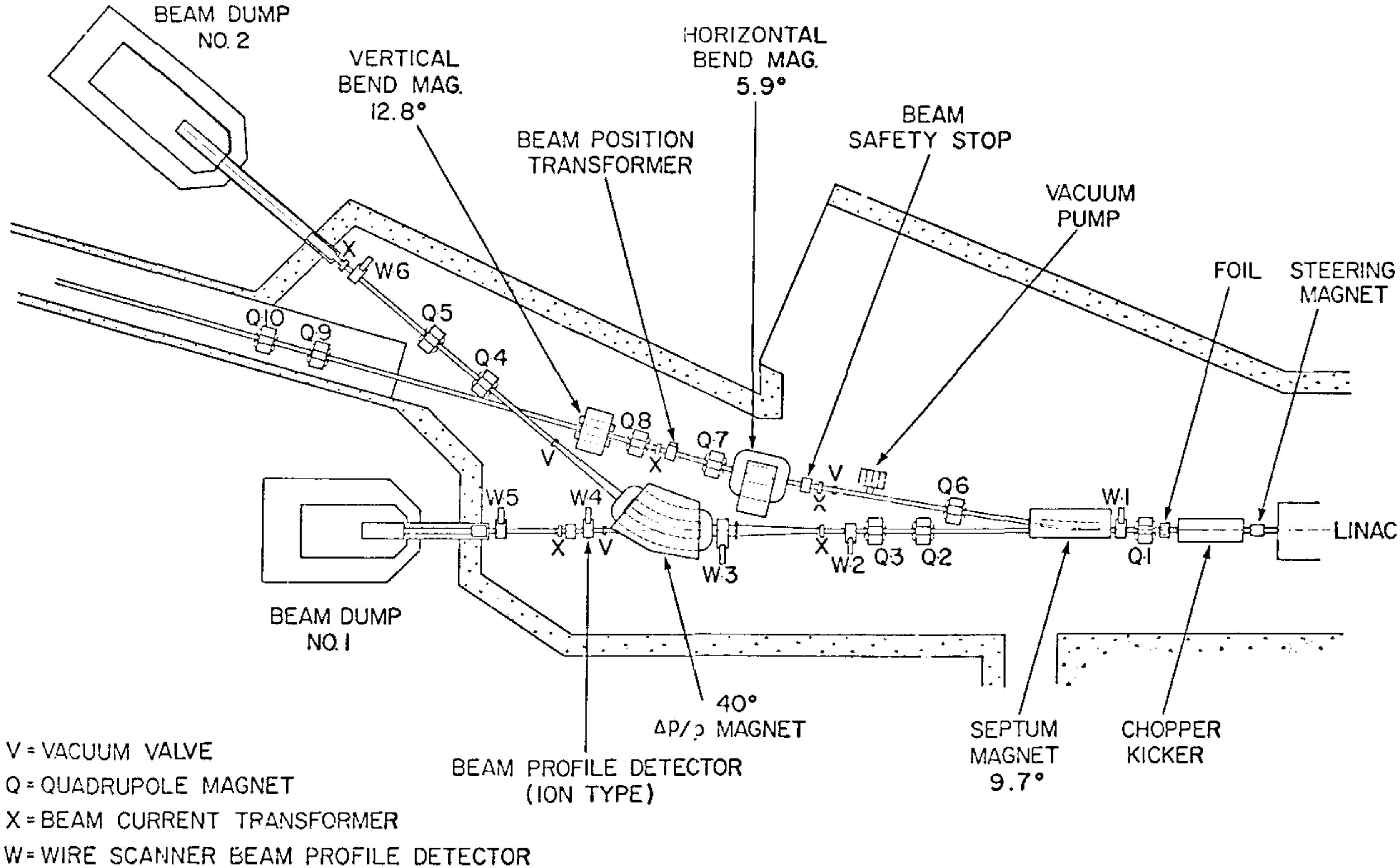

Fig. 2. Layout of the system for measuring the emittance and the momentum spread of the beam from the 200-MeV linac.

DISCUSSION

J. Claus (BNL): How do you define the direction of the beam upstream of the bending magnet in which you do the momentum analysis?

E. L. Hubbard (NAL): We use the wire profile detectors.