REDESIGN OF THE LOW ENERGY SECTION OF THE FERMILAB LINAC TO IMPROVE BEAM BRIGHTNESS

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Abstract

The critical parameters which limit the luminosity of the Fermilab Tevatron Collider are the beam emittances, both longitudinal and transverse, at each stage in the acceleration sequence. Improvements to reduce invariant emittance growth at earlier acceleration stages necessarily encourage improvements in all downstream stages. Recent advances in linac technology should permit a significant increase in the beam brightness of the Fermilab linac. A redesign of the low energy section of the linac is envisioned to include a circular aperture H^- source, a short 30-keV transport line (solenoids, Gabor lenses or einzel lenses) for matching to a radio frequency quadrupole linac (RFQ), and injection at approximately 2 MeV into a new 200 MHz Alvarez linac tank for acceleration to 10 MeV.

Introduction

The Fermilab linac will be undergoing a major revision to boost the output energy from 200 MeV to 400 MeV.[1] Increasing the energy could improve the brightness of the beam in the Booster and the rest of the machine by reducing the space-charge tune shift and the resulting beam blow-up during injection into the Booster. At the same time plans are being developed and studied to improve the emittance of the linac beam which could lead to a further increase in the beam brightness and hence to the luminosity in the collision region.

In the present linac, beam is injected into tank one at an energy of 750 keV with a 90% normalized emittance of 2 π mmmr. By the end of tank one the normalized emittance has grown to 4 to 5 π mmmr. It is thought that the increase occurs mostly in the low energy end of the tank due to space charge and construction misalignments. Similarly in the transport line from the Cockcroft-Walton accelerator where the ion source resides to the linac the beam emittance grows by a factor of two (1 to 2 π mmmr).

The plan for improving the low energy end of the linac (fig. 1) calls for replacing tank one of the Alvarez linac with a tank that accelerates the beam from about 2 MeV to the present output energy of 10.42 MeV. By injecting well above 750 keV, 2 MeV or greater, the problems associated with injection at very low energy are reduced and the new tank becomes somewhat shorter (six meters long) and relatively easy to construct.

The injector to the linac will be a RFQ. It is envisioned that the RFQ will operate from 30 keV to 2 MeV or greater and accelerate a beam current of 50 mA.

The source will continue to be an H^- magnetron source as presently used at Fermilab with perhaps a circular aperture and a modified bending magnet providing 55 mA of H^- ions at 30 keV. The transport line from the source to the RFQ will have two focusing elements (solenoids, plasma lenses or electrostatic lenses) to match into the RFQ.

Ion Source

Operation with an H^- magnetron source has been very good at Fermilab providing beam currents of 50 mA with a lifetime of typically four to six months.[2] Presently the source has a slit aperture of 1 mm by 10 mm so the beam is rather unsymmetrical in the transverse planes. Changing to a circular aperture and a gradient bending magnet with index n=1/2 as studied at Brookhaven[3] should correct this problem. The ions will be extracted from the source at 30 kV or at a lower voltage (17 to 20 kV) with an acceleration to 30 kV following the extraction electrode or after the bending magnet. Obtaining a 55 mA-30 keV H^- beam at 90% normalized emittance of 1 π mmmr should be possible.

Transport

The transport line between the source and the RFQ must be short to prevent significant emittance growth of the space-charge dominated beam.[4] In order to match to the RFQ, two focusing elements will be desirable. With lenses of 20 cm length and short drift spaces the transport line would be approximately 70 cm

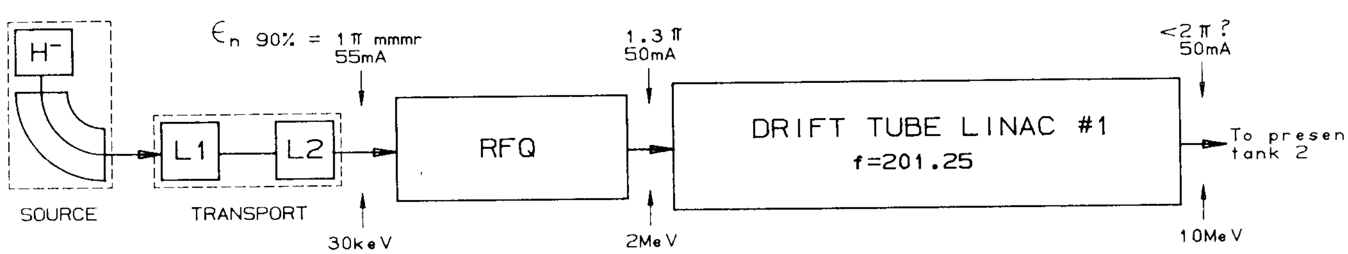

Figure 1. Anticipated low energy improvement for the Fermilab linac.

*Operated by the Universities Research Association under contract with the U. S. Department of Energy.

long. Since the aperture of the RFQ will be 5 mm a strong lens will be necessary to produce a small strongly convergent beam. Three types of lenses are being considered: solenoids, Gabor plasma lenses and electrostatic lenses.

The solenoid appears to be the simplest lens requiring a field of 4 to 8 kG with a length of 10 cm. Unfortunately transient space-charge neutralization problems occur in such lines especially with H^- beams. At DESY such a line is used to transport a 40 mA-18 keV H^- beam to the RFQ.[5] Due to transient neutralization significant rotation of the phase space ellipse parameters at the RFQ entrance occur for the first 100 μs of the beam pulse. This would be unacceptable for Fermilab operation as it would reduce the source lifetime and possibly cause unwanted beam loss in the later part of the accelerator.

The neutralization time could possibly be reduced by placing cathodes into the transport line to emit electrons which ionize the background gas and creates a weak plasma through which the beam travels. When beam enters the plasma electrons will be expelled leaving positive ions to balance the charge of the H^- beam. Some transient effects at the start of the beam pulse could be chopped by placing a deaccelerating gap just before the RFQ to stop the unwanted beam.

A second choice is to use a Gabor plasma lens.[6] With this lens focusing is achieved by creating a radial plasma electric field. This produces an axisymmetric focus for matching into a RFQ. It is also believed that rapid neutralization or at least equilibrium of an H^- beam can be achieved by the plasma. The use of a plasma lens to focus and neutralize an H^- beam is under study on the Fermilab ion source test facility and is described in a separate paper.[7]

Thirdly, an electrostatic lens could be used. In this case the beam would be totally space charge dominated and very strong lenses would be required. Since the transport line is closely coupled to the source the line pressure will be 2 to 5 X 10^{-6} Torr which could cause sparking difficulties in the lenses and neutralization problems in the drift spaces. The large size of the lenses to reduce aberrations and the fields necessary to give sufficient focusing do not make this an attractive alternative.

RFQ

A RFQ will be used to accelerate the beam to 2 MeV or greater. This RFQ has not been designed but a four-rod RFQ built at Frankfurt University by A. Schempp[8] is on loan to Fermilab for study. This RFQ was successfully operated at DESY with 18 keV injection energy.[9] At present new rods are being built to accept 30 keV injection energy and accelerate to 750 keV. The basic parameters for this research RFQ are:

Design:	4-rod-$\lambda/2$ structure,
Beam in:	55mA H^- ions, 30 keV energy, 1 π mmmr normalized acceptance,
Beam out:	50 mA (90% transmission), 750 keV, <1.5 π mmmr normalized emittance for 90%,
Frequency:	201.25 MHz,
Aperture:	5 mm radius input,
Length:	118 cm,
Power:	~100 kW.

The rod design is being considered because of its simpler construction which allows a longer RFQ (2 meters) to be made more easily and cheaply. Studies of the beam dynamics through the 750 keV RFQ will be necessary to determine its quality.

Linac Tank 1

A new tank 1 with an injection energy of 2 MeV or greater is required for this project. It is not expected that much improvement in the linac emittance could be achieved unless the injection energy were increased and proper matching in longitudinal and transverse phase space were achieved. The new Alvarez drift tube tank will have the same parameters as the present tank except starting at a higher injection energy. The new tank will also include post couplers for field stabilization. (The present Fermilab tank 1 was a prototype built prior to post coupler development, only tanks 2 through 9 contain post couplers.) The frequency is 201.25 MHz and the field is tilted with a lower gradient in the first drift tubes. Adjustable quadrupoles will continue to be used to allow transverse matching into tank 2 and at injection. In order to achieve good longitudinal and transverse matching a RFQ is being studied with a post radial matching section.

Conclusion

The present linac has a 90% normalized emittance of 6 to 7 π mmmr at 200 MeV. By improving the low energy end it is hoped that the emittance can be reduced to 3 π mmmr or less. It is expected that an emittance of 1 π mmmr into the RFQ and 1.3 to 1.5 π mmmr out of the RFQ could be achieved. The question of whether 2 π mmmr out of tank 1 is achievable is still being studied along with what happens in the rest of the linac.

Equipment is being built and assembled to study the source and transport system and eventually connect it to an RFQ. This will become a prototype leading to the final design of an RFQ and a 10 MeV tank. The final assembly will be built and fully tested before installation on the operating linac.

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