FERMILAB LINAC INJECTOR, REVISITED

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Abstract

The Fermilab linac has been operating at 200 MeV since 1971 and was upgraded to 400 MeV in 1993 with a peak current of ~ 35 mA. The injector consists of a Haefely Cockcroft-Walton, H^- source, an high gradient accelerating column (750 kV), 4 and 10 meter long transfer lines and a single gap 201.24 MHz cavity. The performance of the injector has been very gratifying although some tuning must be done approximately daily. The purpose of this report is to present representative experimental data and numerical simulations that are used as a guide for improvements to the Fermilab Linac. Today, the Fermilab Linac delivers a 400 MeV H^- beam with a peak current over 45 mA.

I. INTRODUCTION

The Fermilab Linac Upgrade increased the energy of the H^- linac from 201 to 401.5 MeV[1]. This was achieved by replacing the last four 201.24 MHz drift-tube linac cavities with seven 804.96 MHz side-coupled cavity modules. The energy increase has improved the brightness of the beam in the Booster and the rest of the Fermilab accelerator complex. In the past few months a further increase in the peak beam current has lead to a further increase in the beam brightness and hence an increase in luminosity for collisions. The increase in the H^- peak current to 45 mA or higher at the end of the linac is a result of work done on the injector area. The ion source work is described in the next section. Section 3 presents modeling results of the transport line using TRACE3D and section 4 presents experimental data and PARMILA modeling of the buncher cavity effects on the beam from Tank 2. Figure 1 shows the injector area, transfer line from the source to the buncher cavity and Tank 1.

II. ION SOURCE

For twenty years Fermilab has been using a H^- magnetron source. Until last May the source typically provided a beam current of 50-55 mA with a lifetime of four to six months. This source has a slit aperture of 1 by 10 mm^2 and is at a potential of -750 kV. The ions are extracted from the source at 18 to 20 kV. To compensate for the large asymmetry in the two planes and obtain a nearly circular beam, a 90^o bending magnet with a radius of 8 cm and an index n=1 is used after the extractor. Following the bending magnet beam enters the accelerating column and is accelerated to 750 keV. For the source to work in an acceptable regime, with a lifetime of several months, there are about ten parameters that must be adjusted carefully[2]. An extensive search of that parameter space has been done which resulted in:

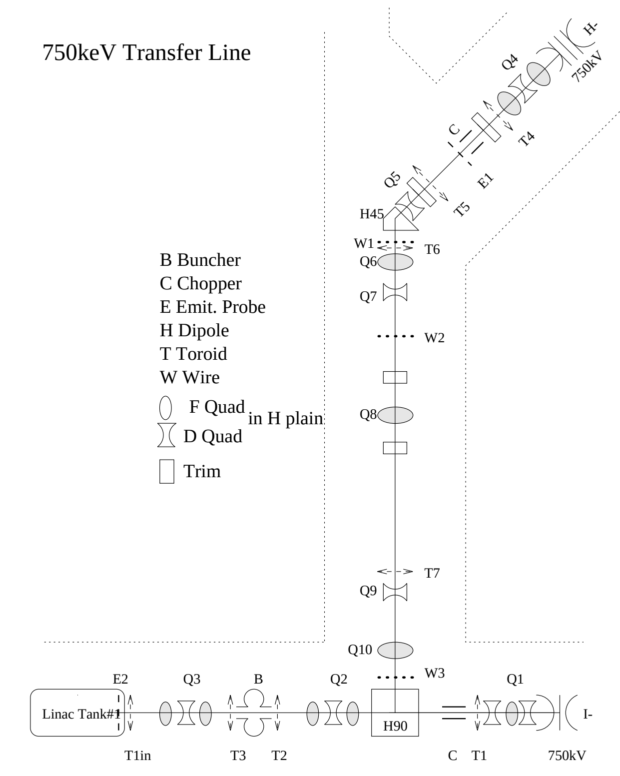

Figure 1. H^- Source and 750 keV transfer line.

1. an increase of the extraction voltage,
2. an increase of the cathode temperature,
3. a decrease of the hydrogen gas usage, and
4. adjustment of the hydrogen gas timing,

to give more then 65 mA peak current with a lifetime longer than four months. Figure 2 displays the output current as a function of the pulsed hydrogen valve on and off times. It shows that the output current depends strongly on timing and hydrogen usage.

Figure 3 shows the beam current (h4tor) following the H^- source and 750 kV accelerating column. The lower curve is the beam current at the end of the linac (d7tor). From May to August 1994 the second source and accelerating column was in use. Since the beam is transported through the straight line this produces a gap in h4tor of figure 1. From the ratio of the two curves in figure 3 it is clear that the extracted current from the source and that the overall efficiency of the linac as a whole has increased.

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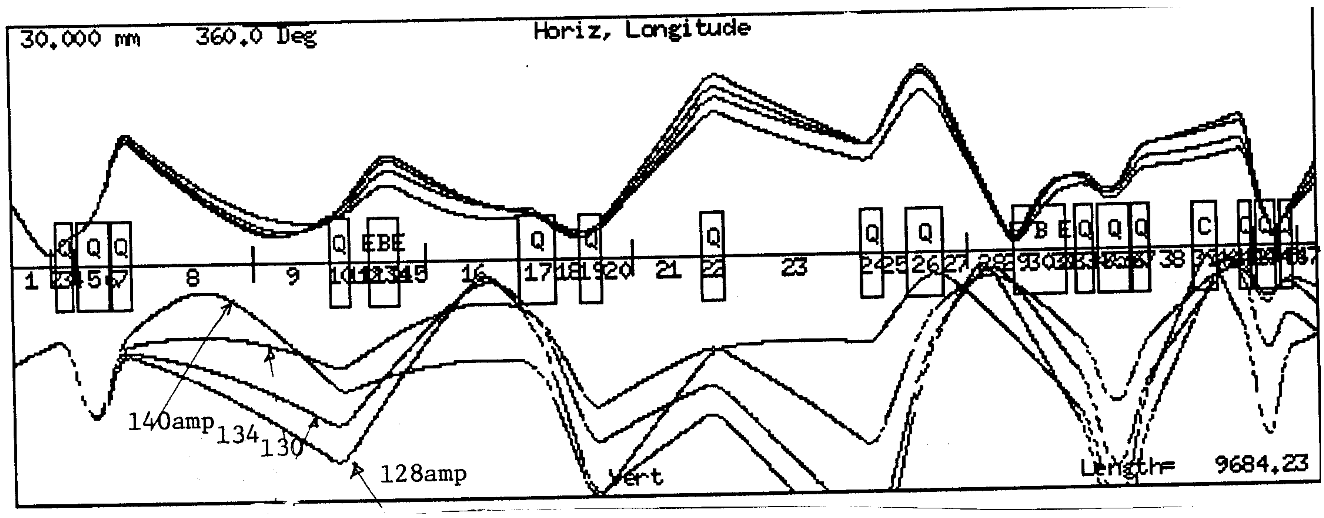

Figure 4. Search for the optimal setting of the first H^- quad.

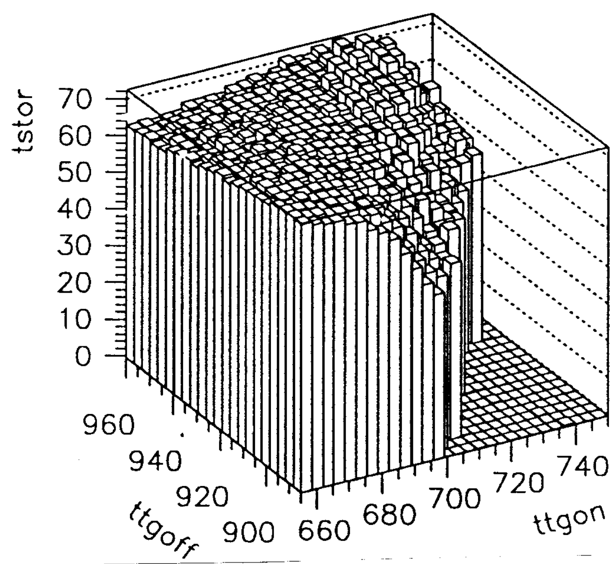

Figure 2. The horizontal axes are the gas valve times in $\mu\,\mathrm{sec}$. The vertical axis is beam current in mA.

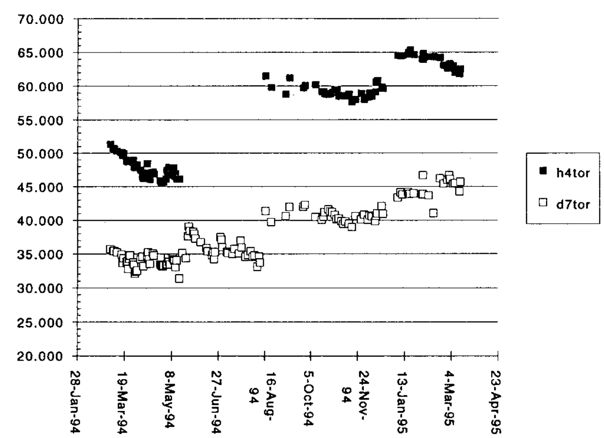

Figure 3. Upper points are current in mA at 750 keV. Lower boxes are beam current in mA out of the Linac, 400 MeV.

III. 750 keV TRANSPORT

The H^- transport line between the source and Tank 1 is about 10 meters long with limited diagnostic. The main diagnostic tools are six current transformers and four emittance probes. Two emittance probes (horizontal and vertical) are located after the first quadrupole triplet near the exit of the 750 kV column. The other two are just before the entrance of linac Tank 1. Each probe consists of a single slit, a drift space and a 20-segment target oriented with the segments parallel to the slit. Table 1 lists emittance values at these two locations for 50 and 65 mA beam currents.

Emittance measurements were used to reconstruct the beam ellipse orientation in phase space. These were used as beam input parameters for TRACE3D simulation of the 750 keV transport line. Figure 4 shows a search for the optimal current value for one of the quadrupoles. Simulations are interfaced with the control system so that currents in the magnets and quadrupoles are directly read by the program. There is good agreement between simulation and transfer efficiency along the line. This result is obtained for input parameters of the ellipses taken from measurements of the input beam. Measured ellipse orientations at the end of the line are not in full agreement with simulation possibly due to beam neutralization. According to the simulation the transfer line is "almost" achromatic. Operating with a completely achromatic condition as predicted by TRACE3D causes a degradation in the transmission efficiency.

Table I

Normalized emittances at the beginning and end of the 750 keV transport line. Units are $\pi mmmrad$.

Peak Current	50 mA	65 mA	
Emittance Probe H1	1.6	1.8	90 %
Emittance Probe V1	1.8	2.6	90 %
Emittance Probe H2		2.6	90 %
Emittance Probe V2		2.1	90 %

IV. BUNCHER

The low energy buncher cavity is located about 95 cm upstream of linac Tank 1. Experiments have been done changing the phase and rf amplitude in the bunching cavity and in the Tank 1. Figure 5 shows the best experimental as well as simulation data using PARMILA code[3]. Comparison of the beam entering the buncher with the beam at the end of Tank 5 shows a capture efficiency of about 75% of the 750 keV DC beam.

References

[1] E. McCrory, "The Commissioning and Initial Operation of the Fermilab 400 MeV Linac", Proceedings of the 1994 Linac Conf., pp. 36-40.

[2] C. W. Schmidt, "Review of Negative Hydrogen Ion Sources", Proceedings of the 1990 Linac Conf., pp. 259-263.

[3] M. Popovic, "Longitudinal Beam Dynamics of the 10 MeV Fermilab Linac", Bulletin of APS, Vol 40, No. 2, 1995, pp. 953.

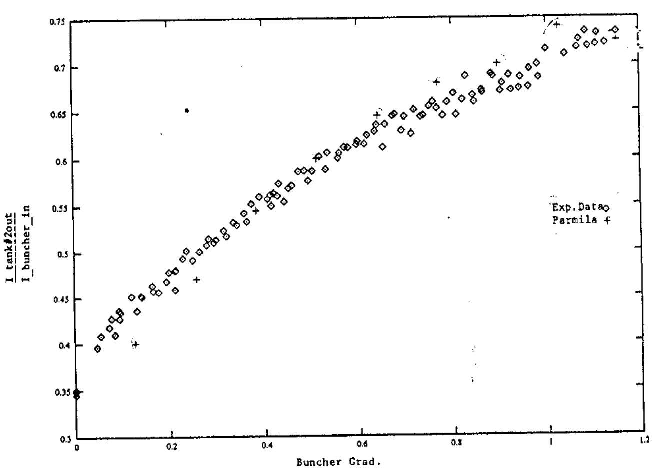

Figure 5. Linac capture versus buncher field.