A POSSIBLE FNAL 750 keV LINAC INJECTOR UPGRADE *

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Abstract

The present FNAL linac H⁻ injector has been operational since 1978 and consists of a magnetron H⁻ source and a 750 keV Cockcroft-Walton Accelerator. The proposed upgrade to this injector is to replace the present magnetron source having a rectangular aperture with a circular aperture, and to replace the Cockcroft-Walton with a 200 MHz RFQ. Operational experience at other laboratories has shown that the upgraded source and RFQ will be more reliable and require less manpower than the present system.

INTRODUCTION

The present FNAL injector has been operational since 1978 and has been a reliable source of H⁻ beams for the Fermilab program. At present there are two Cockcroft-Walton pre-injectors, each with a magnetron H⁻ source[1]. Only one source and Cockcroft-Walton is operational at any one time, with the other on stand by and ready to take over if there is a failure. With this operation the combined injector has a reliability of better than 97%. However, issues with maintenance, equipment obsolescence, and retirement of critical personnel, have become difficult obstacles for the continued reliable running of the H⁻ injector. With these problems looming on the horizon, a new 750 keV injector has been proposed to replace the present system. The proposed system will be very similar to the one at BNL (Brookhaven National Laboratory) which has a similar magnetron source and a 200 MHz RFQ. This combination has been shown to be extremely reliable operationally[2].

LEBT

Magnetron H⁻ Source

The source is a modification of the magnetron H⁻ ion source used at Fermilab for thirty years but with a circular rather than a long rectangular aperature[1]. The circular aperature, shown in Figure 2 makes more efficient use of the cathode surface, on which H⁻ ions are created and produces a cylindrically symmetrical beam suitable for transport through solenoids and injection into the RFQ as shown
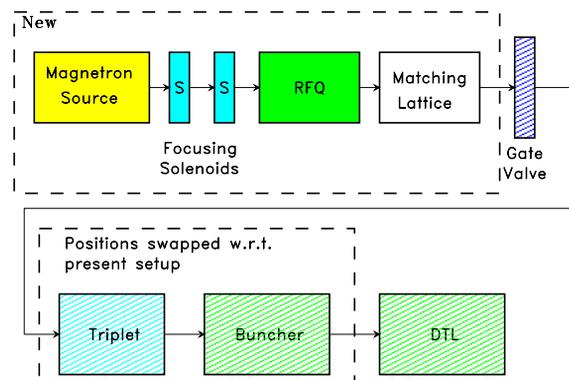
Figure 1: The plan is to remove every element before the gate valve and replace them with a magnetron source, RFQ and elements to match the beam to the DTL. A possible matching lattice with the buncher and triplet swapped is shown in Figure 6.

by BNL[2]. Its duty-factor is low compared to some H⁻ sources however it is more than adequate for the linac requirements. See Table 1.

The reliability of the BNL source is in part contributed by better vacuum near the source[3]. The BNL source vacuum chamber has one 3000 L/s turbo pump that maintains on the order of 3×10^{-6} torr at the source while operating[4]. The FNAL operational source, on the other hand, has one turbo pump with no provisions for additional pumping and has a vacuum on the order of 2×10^{-5} torr. The improved vacuum chamber will have three ports where turbo pumps can be mounted.

The BNL magnetron has a dimple on the cathode surface which provides spherical focusing from the cathode to the circular aperture. With this focusing, the BNL source only requires 10 A of arc current[2] while the present FNAL slit source requires 50 A. The lower arc current has improved both the efficiency and reliability of the BNL source.

Currently the source and vacuum chamber are being tested for use in the HINS project[5]. See Figure 2. The operational experience gained from testing plus the BNL experience will be valuable for the design of the proposed upgrade.

Solenoid Matching

The plan is to use two solenoids to match the beam from the source to the entrance of the RFQ[6]. Trace2D has shown that similar Twiss parameters used at BNL are suit-
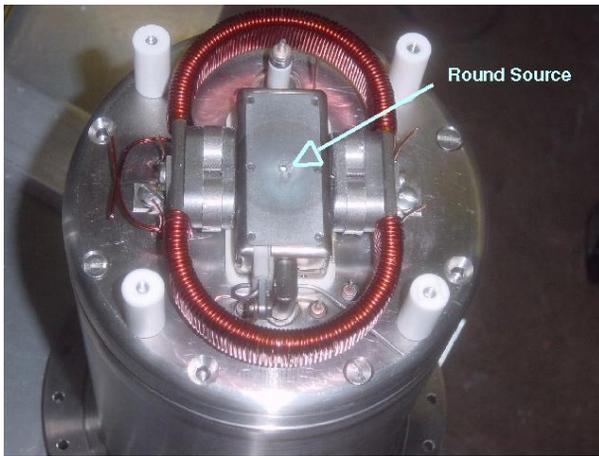
Figure 2: Modified source with circular aperature.

able for this matching[7]. See Figure 3. The solenoids will operate at a current of about 400 A to give the required field of about 3000 gauss. There is about 60 cm of space between the solenoids which should be enough for steerers, beam monitors and a chopper.
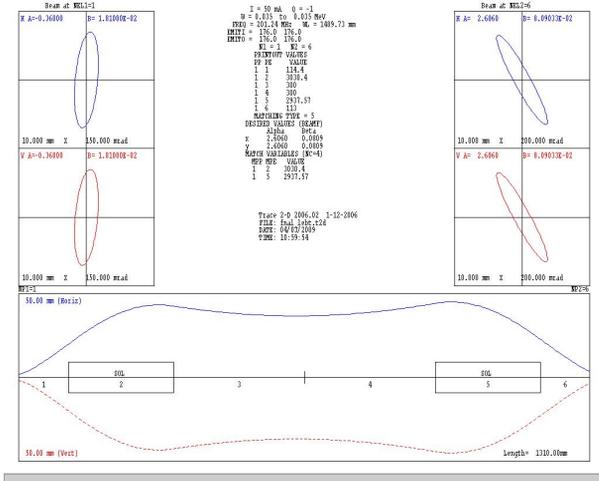
Figure 3: Two solenoids are used to match the beam from the magnetron source to the entrance of the RFQ.

RFQ

The proposed RFQ will be similar in design to the RFQ used at BNL. It has an input energy of 35 keV, output energy of 750 keV and RF frequency of 201 MHz which fit the Fermilab requirements.

In the $\mathrm{PARMTEQM}$ simulation, the RFQ model is 163 cm long and consists of 147 cells. Using the Twiss parameters and input emittances calculated with Trace2D (Figure 3) from the LEBT discussed above, the $\mathrm{PARMTEQM}$ simulation shows a 98% transmission efficiency for 50 mA H$^-$ beam. See Figure 4.
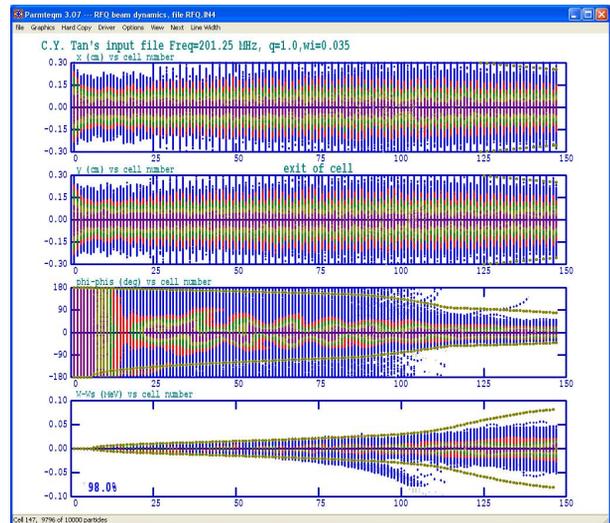
Figure 4: Tracking particles using $\mathrm{PARMTEQM}$ through the RFQ shows a 98% transmission efficiency.

MEBT

The MEBT will both focus and keep the 750 keV beam bunched before injecting it into the DTL. Traditionally, a FODO lattice has been used to match the beam from the RFQ to the DTL because they are both FODO devices. However, the spacing of the FODO lattice in this case is approximately $2 \times \beta\lambda = 12$ cm which is too small for reasonable sized quadrupoles, bunchers and instrumentation etc. and so a non FODO lattice has been used.

The MEBT line from the RFQ to the DTL has been designed to reuse the present elements downstream from the gate valve. See Figure 5. Elements before the gate valve will be replaced. Figure 6 shows the results of matching the ellipses at the output of the RFQ to upright ellipses at the centre of the first quadrupole in the DTL with Trace3D. The emittances used for the calculation come from the output of the $\mathrm{PARMTEQM}$ simulation shown in Figure 4. The position of the triplet and buncher after the gate valve have been swapped because the buncher needs to be closer to the DTL to keep the beam from debunching longitudinally. Two extra bunchers are also required between the RFQ and the gate valve to keep the beam bunched. In this design, smaller 45 mm long quadrupoles are used to focus the beam transversely before the triplet so that steerers and beam instrumentation can be inserted between the quadrupoles. Unfortunately, the optics shown here is still not quite ideal because according to $\mathrm{PARMILA}$, the transmission efficiency through the DTL is only 82% for 50 mA beam, although it is still an improvement over a simulation of the present injection line of 75%. However, other optics designs without the gate valve constraint shows better than 90% transmission to the end of the DTL.
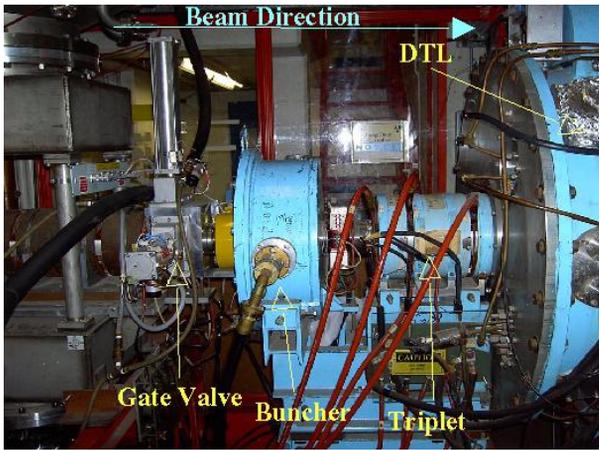
Figure 5: This picture shows part of the MEBT. In the proposal, everything before the gate valve will be removed and replaced.
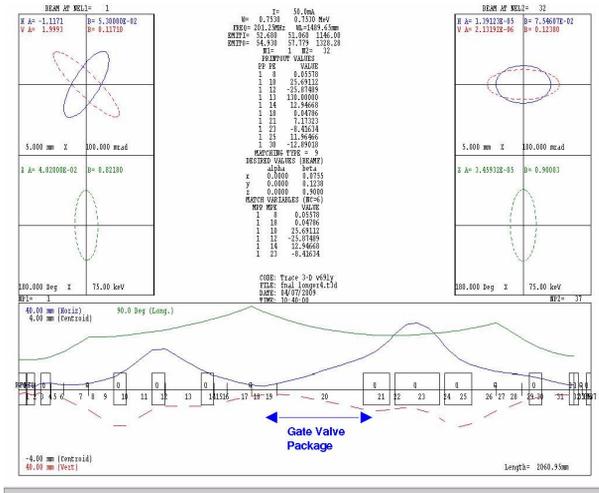
Figure 6: Matching the beam with TRACE3D from the RFQ to the first DTL. New elements have been added before the gate valve and existing elements have been kept after it.'

CONCLUSION

The proposed upgrade that is discussed in this paper uses existing technology that has been proven to work reliably at BNL. In fact, the BNL system is able to operate continuously with very little maintenance for up to 9 months with a single source[6]. In contrast, the present FNAL system uses two sources with each source operational for only 4 to 5 months and constant maintenance of the pre-injector is required.

There are three reasons for assuming higher reliability of the new injector:

- Circular aperture H$^-$ magnetron.

- Improved vacuum chamber which allows for greater pumping.

Table 1: Present Injector Parameters

H$^-$ current	50 – 60 mA
Repetition Rate	15 Hz
Pulse Width	70 μs
Duty Factor	0.11%

- Low maintenance RFQ.

Therefore, although the current FNAL pre-injector has provided reliable H$^-$ beam, it is going to be very difficult to continue the extensive maintenance and expertise to keep it running reliably. The proposed upgrade will allow FNAL to provide an H$^-$ beam reliably for many more years.

ACKNOWLEGEMENTS

REFERENCES

[1] C.W. Schmidt and C.D. Curtis, "A 50-mA Negative Hydrogen Ion Source", Proc. 1979 Part. Acc. Conf., IEEE Trans. Nucl. Sci., NS-26, 4120.

[2] J.G. Alessi, "Performance of the Magnetron H$^-$ Source on the BNL 200 MeV Linac", AIP Conf. Proc. Dec. 2, 2002 Vol. 642, pp. 279-286

[3] D.S. Bollinger et al. "Visit to BNL 17-19 Nov. 2008", Beams-doc-3265-v1

[4] J.G. Alessi, Private communication, 2008.

[5] C.W. Schmidt, R. Webber "H$^-$ Ion Source Spec for HINS and Considerations for Project X H$^-$ Ion Source", Beams-doc-3056-v1

[6] J.G. Alessi *et al*, "H$^-$ Source and Low Energy Transport for the BNL RFQ Preinjector", AIP Conf. Proc. No. 210, 1990, pp. 711-716 2007.

[7] D. Raparia, Private communication, 2009.

[8] H. Takeda, "Parmila", LA-UR-98-4478.

[9] K.R Crandall & D.P. Rusthoi, "Trace 3-D Documentation", LA-UR-98-4478.