Site visit to Brookhaven National Laboratory

February 14-15, 2006
Report by
Doug Moehs

During our BNL site visit Henryk Piekarz and I discussed magnetron operations with Jim Alessi and Tim Lehn. We also had the opportunity to look at the front end of the BNL Linac and to do some quick tests with their online magnetron ion source.

Topics for Discussion

Availability of documentation or drawings:

- Mechanical: Collected
- Vacuum interfacing: Collected
- RFQ interface: No comment
- Arc Power Supply design: Collected
- Extractor Power Supply design: tube design similar to ours

Possibility of testing a 3 ms pulse at BNL and measuring emittance:

- We tested up to a 1.6 ms pulse on the fly see figure 1
- What would be required to do a 3 ms test?
  - A test stand would need to be reassembled and the arc supply PFN would need to be modified to provide a longer pulse.
    - It appears that we will be faster in testing a 3 ms pulse at Fermilab.
- Would it then be possible to measure the emittance through the pulse? Yes

For higher DF (1 or 1.2%):

- Is additional source cooling necessary? Probable not
- Material used to thermally isolate ion source?
  - The ceramic could be replace with stainless steel (or another thermally conducting none magnetic material)
- Do you use an external source heater? No
- For a 3 ms pulse do you expect Cs sputtering to effect output current? No

Extraction considerations for 50 kV recommendations?

- Try single gap 50 kV first.
  - We will have to check to make sure that the extractor can handle the power associated with beam losses; however for 12 mA from a reduced aperture source we expect roughly a factor of 4 reduction in power as compared to BNL operations. Therefore this is probable not a problem, but it still should be investigated further.

Jim told us that it is important to use a tungsten extractor tip rather than a molybdenum one because tungsten has better erosion properties. Tantalum might be another possibility.

Note: The BNL source magnetic field does not bend out electrons as well as the Fermilab system does, thus there may be issues with 50 kV X-rays associated with electrons being dumped on the extractor!

Staged Accel-Accel extraction design? This is possible

The BNL magnetron emittance is 0.4 π mm mrad norm. RMS for 100 mA. (D. P. Moehs, J. Peters, and J. Sherman, IEEE Trans. Plasma Sci., v. 33, p. 1786, Dec. 2005 0.4) Where was this measured in relation to the source? Right after source

Paradigm Note: The BNL source puts out much more beam than they need, typically around 80-100 mA. Much of the excess beam is scraped away in the LEBT or does not meet the RFQ's acceptance. In this mode of operation the RFQ defines the beam emittance. Jim Alessi also indicated that this mode of operation provides added stability by decoupling the ion source output from the beam out of the RFQ.

Transmission of Magnetic LEBT?

Expected to be 100% at 12 mA-45 mA, but this should be investigated since the BNL LEBT uses 4 inch diameter pipe and larger bore magnets and our LEBT currently has a 2 inch diameter pipe. The smaller pipe size may reduce pumping speeds in this region and lead to scrapping if the beam spot is too large.

What are the disadvantages of a Magnetic LEBT?

Cannot do chopping in the LEBT in order to shorten the distance from the RFQ to first Linac cavity! See: J.G. Alessi, J. M. Brennan, and A. Kponou, *H- source and low energy transport for an RFQ preinjector*, Rev. Sci. instrum. v. 61, p. 625, January 1990.

I have plotted normalized RMS emittance verses current for all readily available magnetron data. I then fit the data assume a linear relationship, see figure 2 (assumption is based on H. Zhang, Ion Sources, Science Press, pg 64, 1999). Does this seem reasonable?

Jim reminded me that for a circular aperture, theoretically the emittance goes as the radius and the current goes as the area. This means that the theoretically emittance should scale with the square root of the current. I have added the square root curve to figure 2 but do not believe it gives better insight.

Do you see emittance changes during the pulse?

Yes but not after the space charge neutralization stabilizes. The neutralization time depends on the background pressure, typically 10-100 microseconds, see figure 3. At BNL chopping is used to remove the unstable portion of the beam.

General requirements: Very similar to our own

Power: Roughly the same as our magnetron

Water: Permanent magnets are used; there is no solenoid to cool at the source

Other discussion topics:

Are spare source magnets available at BNL: (NO) Jim Alessi will provide us with the field strength at the surface and the size of the magnets. They use SmCo magnets which handle H_2 atmospheres better than NdFeB.

Extraction aperture and spacing:

What needs to be done in order to have the same extractor voltage gradient as BNL does at 35 kV, but achieve a LEBT beam energy of 50 keV?

Since the voltage gradient scales linearly with distance our extractor needs to be 5.71 mm from the anode aperture, 143% the spacing of the BNL extractor which is 4 mm.

What size anode aperture would we use for the Proton driver to produce 12-15 mA rather than the 80-100 mA measured at BNL for a 1.4 mm aperture?

Jim reminded us that magnetron currents roughly scales as $I \propto \frac{r^2}{d^2} V^{3/2}$, based on the "Child-Langmuir Law" (see Ion Sources by H. Zhang, pg 49, 1999) where r is the anode aperture radius, d is the distance between anode and extractor and V is the extractor voltage. For the Proton Driver we plan to use the BNL extractor voltage gradient [V/d] (see above), so the output current will roughly scale as $I = \frac{r^2}{V^{1/2}}$. Thus for 12 mA we would expect to need a 0.61 mm aperture. This may be a bit too small, so I would suggest starting with an aperture of ~0.70 mm a 50% reduction from the BNL anode aperture. Based on these changes the operating point should be about the same as the BNL system.

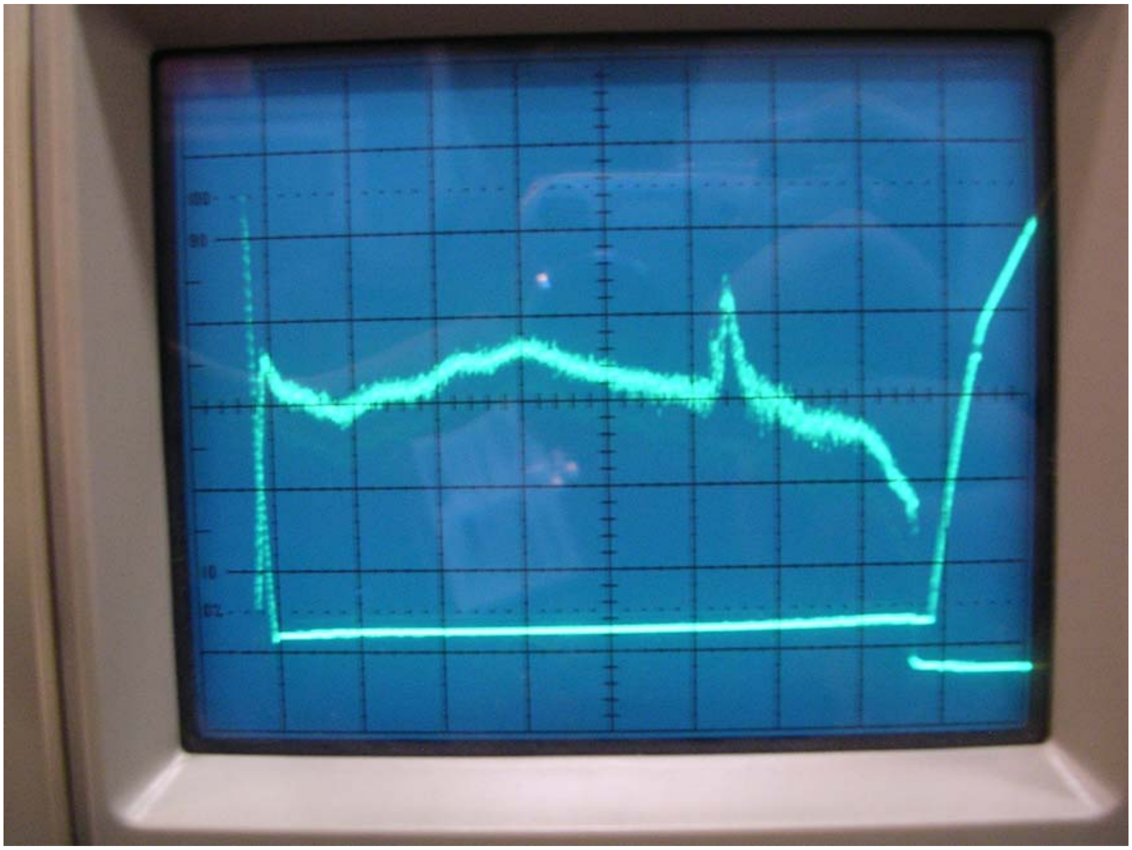


Figure 1: H^- beam from the BNL magnetron ion source, 20 mA/200 μs per division. The peak at 1.1 ms is artificial, and is due to the LEBT solenoids turning off. The droop in the beam is probable due to poor gas optimization and limits of the arc supply PFN. The second (downward) trace is the pulsed extractor voltage at 35 kV.

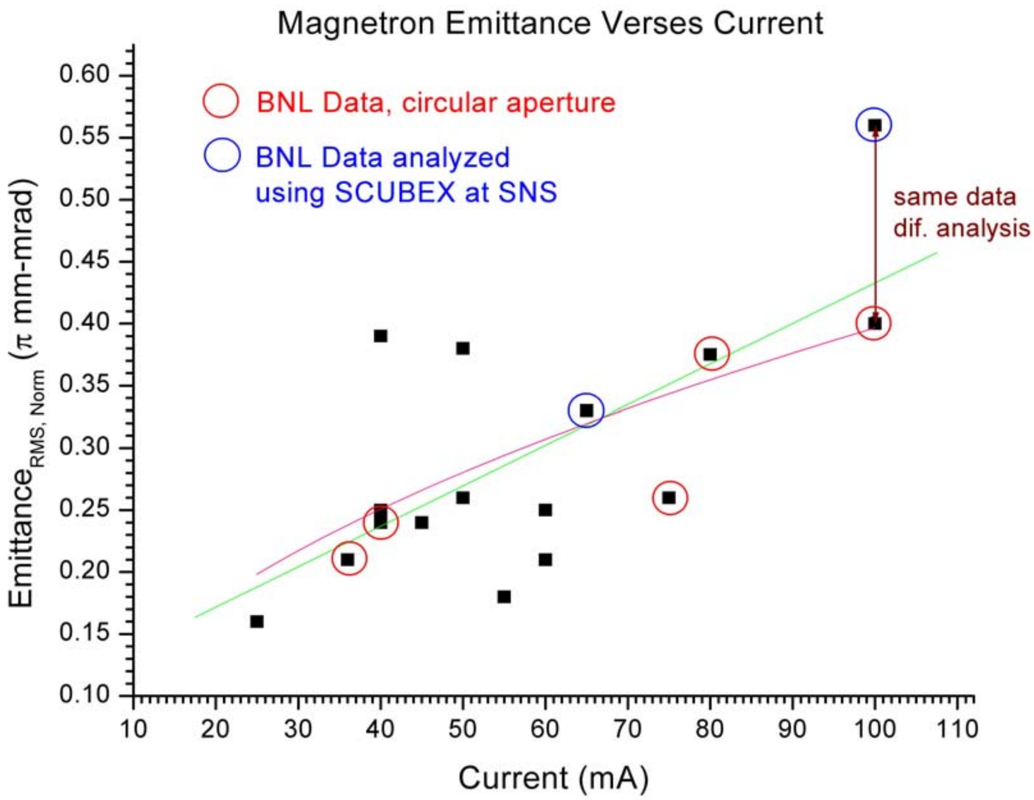


Figure 2. This figure shows the trend in emittance as a function of current for modern magnetron sources. No attempt has been made to normalize or separate out cathode, aperture or LEBT/pre-accelerator types. The green line is a linear fit to the data and the pink curve represents a square root fit to the data. The 2 data points at 100 mA represent 2 different analysises of the same raw data! Based on this plot alone it appears that we should be able to meet our emittance goal for both Proton Driver options using a magnetron ion source. **Better emittance measurements will be needed to verify this conclusion.** These emittance values were gleaned from the following reference:

Schmidt, PNNIB, p.123 (1977)
Alessi, PNNIB, AIP Conf. Proc. 158, 419 (1986)
Stipp, IEEE TNS, 30, 2743 (1983)
Smith, RSI 53, 405 (1982)
Alessi talk associated with, AIP Conf. Proc. 642, 279 (2002)
Criegee, Peters et al., RSI 62, 867 (1991)
Schmidt, PNNIB, AIP Conf. Proc. 158, 425 (1986)
Moehs, IEEE TPS, 33, 1786 (2005)
Peters RSI 71, 1073 (2000)
Welton, PNNIB, AIP Conf. Proc. 639, 160 (2002)

Space Charge Neutralization in LEBT

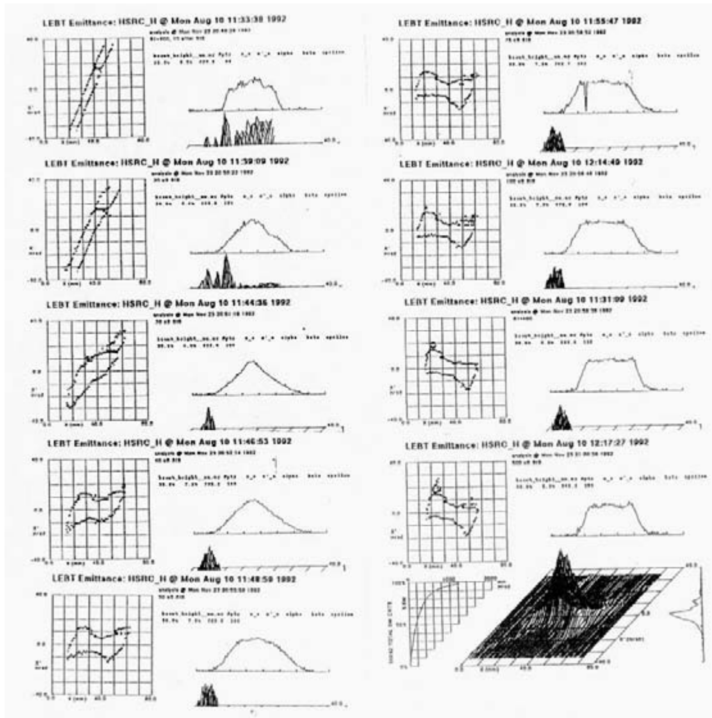
10 μs

20 μs

30 μs

40 μs

50 μs



75 μs

100 μs

300 μs

500 μs

Figure 3: Emittance evolution in the BNL LEBT, after 50-75 μs the emittance is more or less stable. For earlier times, positive (neutralizing) charge is building up in the beam. The figure was provided by Jim Alessi of BNL from a talk entitled, *Operation of the Brookhaven 200 MeV H- Linac,* 7th Workshop on HPPA Development and Utilization, October 9-12, 2003.