Reduction of Beam Current Noise in the FNAL Magnetron Ion Source

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Abstract. The new FNAL Injector Line with a circular dimple magnetron ion source has been operational since December of 2013. Since the new injector came on line there have been variations in the H- beam current flattop observed near the downstream end of the linac. Several different cathode geometries including a hollow cathode suggested by Dudnikov [1] were tried. Previous studies also showed that different mixtures of hydrogen and nitrogen had an affect on beam current noise [2]. We expanded on those studies by trying mixtures ranging from 0.25%N, 99.75%H to 3%N, 97%H. The results of these studies in our test stand will be presented in this paper.

INTRODUCTION

The new FNAL injector line has shown variations in the H- beam current flattop which shows up during one turn injection into the booster ring (multi-turn injection tends to wash out this variation). These single turn variations were not noticed during the time when the Cockcroft-Walton pre-accelerators were used. Since the source of the variations is not known, we decided to investigate the noise on the extraction beam current from the magnetron ion source. Initially the extractor pulser output was checked by pulsing into a dummy load as well as the arc modulator. Both pulser outputs had very small flattop fluctuations. Further studies that were done in our test stand, which has a 100MHz bandwidth toroid, were broken down into two parts. The first was testing various cathode geometries with the thought that the volume of plasma was not adequate. The second set of studies was testing various mixtures of hydrogen and nitrogen based on previous studies on penning sources [3] and on the FNAL magnetron. One thing to note is that the optics of the current test stand are inadequate to focus beam currents above 50mA so we were not able to take reliable data at the full extraction voltage of 35kV.

CATHODE GEOMETRY STUDIES

In previous experiments, Alessi and Sluyters [4] indicated that increasing the cathode-anode spacing on the back side of a magnetron produced a more stable discharge at a lower pressure than the normal grooved magnetron and the emission current density (A/cm^2) increased. It was also suggested by Wiesemann [5] that an asymmetric magnetron with a large gap on the back of the source will have a larger plasma volume that will stream to the front of the source, due to EXB drift, to the extraction region where H- ions will be formed. Since the magnetron relies on EXB drift Fig. (1) of the plasma from the back side of the cathode to the front increasing the total plasma volume

could lead to a more stable discharge and the increase in emission current density may reduce the noise seen in the extracted beam current. For the present experiments several cathode geometries were studied. Initial studies were carried out by incrementally increasing the plasma volume of the source on the back side of the cathode. Figure (2) shows the cathode geometries that were tried and Table (1) gives a description of each cathode geometry. Finally a "hollow cathode" geometry was tried.

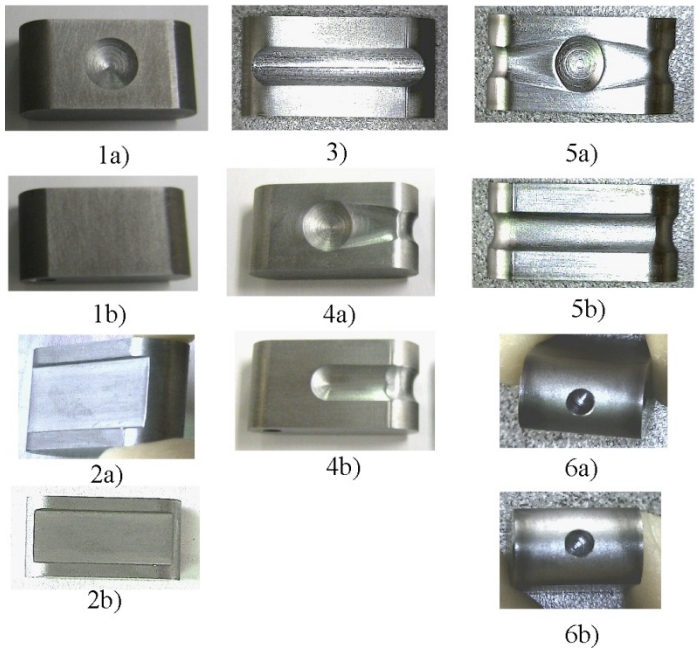


FIGURE 2. Pictures of different cathode geometries studies. Initial studies involved incrementally increasing the size of the groove on the back of the cathode**.** All cathodes used the spherical dimple on the front of the cathode for focusing the H- ions to the anode aperture**.** Table 1 has a description of each of the cathodes**.**

Data was taken on 6 different cathodes including the one that has been in operation since the FNAL injector upgrade. In order to reduce the amount of material used and machine shop effort the same cathode "blank" was used for cathodes 1,4,5 and 2,3 with increasing volume on both the back and front of the cathode.

TABLE 1 Description of cathodes studied. The cathode number and Picture a) and b) are shown in Fig. (xx)

Cathode number	Picture a)	Picture b)	notes
1	Front	Back	Normal operational cathode
2	Back	Back	9.2mm x 2.52mm x 1mm groove on back only
3	Back	X	Small groove on back of cathode only
4	Front	Back	Groove ½ way around front and back
5	Front	Back	Fully grooved on front and back
6	Side	Side	Hollow cathode

Cathode 2 had the largest increase of plasma volume of XXXXX%. This increase in volume also required a higher overall gas pressure to maintain a stable arc. As can be seen in Fig. 5a, this cathode had the lowest noise of any cathode at higher pressures. However, it is unclear if the higher gas pressure would work in the operational

system since we rely on a small pressure range in the LEBT for neutralization. The orifice between the ion source vacuum chamber and the LEBT beam pipe is on the order of the beam pipe diameter (about 4 inches) it is unclear if there would be enough pumping speed in the LEBT turbos to overcome the increased pressure.

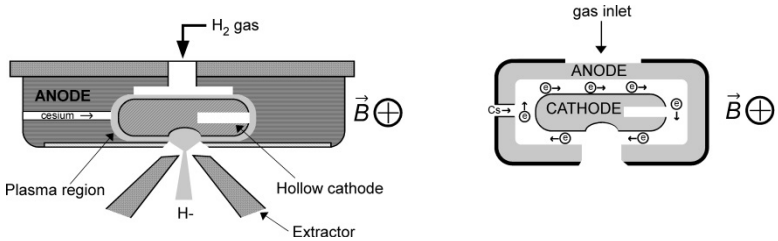
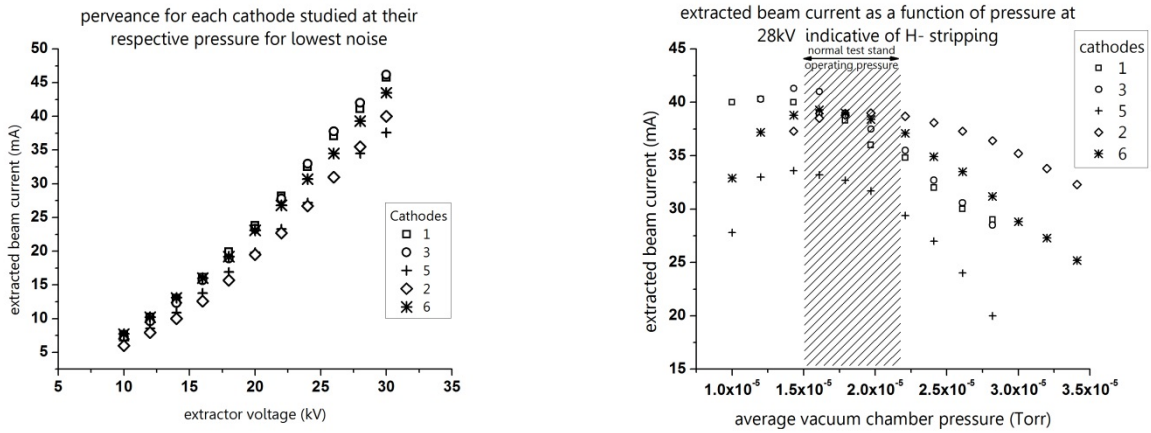
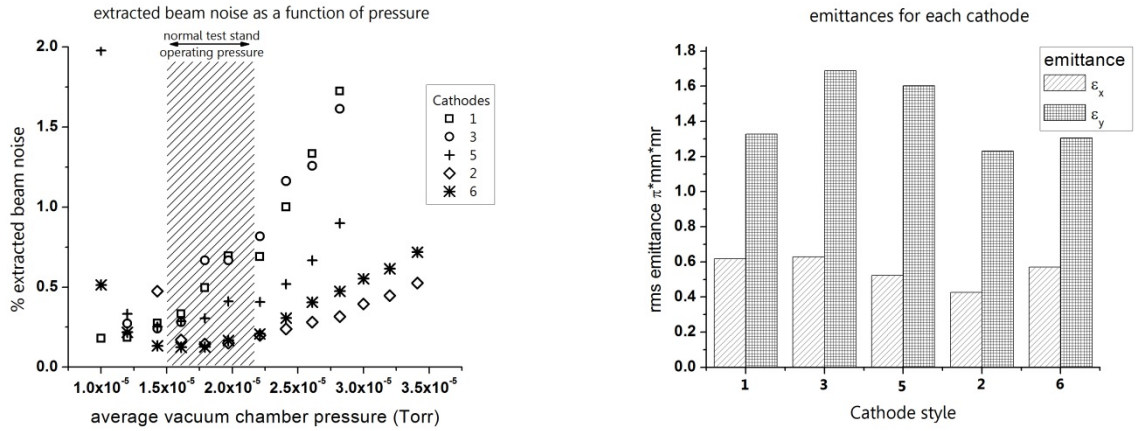


FIGURE 3. Schematic of hollow cathode. The cathode was installed in the source with the hole oriented so that the EXB drift would pull electrons from the hole to the front side of the source.



(a) (b)

FIGURE 4. Plots of beam perveance (a) for each cathode studied at their lowest beam noise gas pressure and (b) extracted beam current as a function of average vacuum chamber pressure (possibly indicating H- stripping)



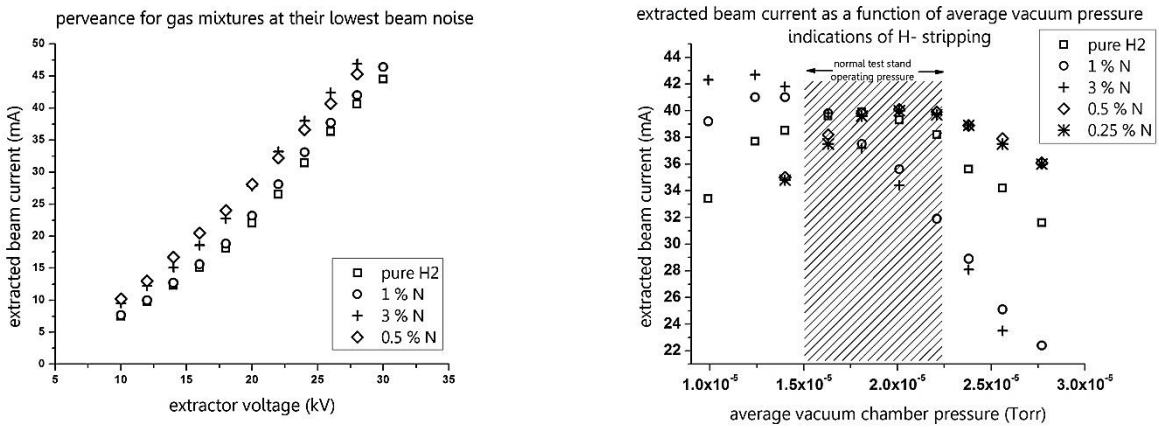
(a) (b)

FIGURE 5. Plots showing (a) extracted beam noise as a function of average vacuum chamber vacuum for each cathode described in Table (1). (b) is the vertical and horizontal emittance for each cathode measured at 30kV.

GAS MIXTURE STUDIES

Based on previous studies at FNAL and Los Alamos we decided to study different mixtures of nitrogen and hydrogen on the test stand. The previous FNAL studies did show a reduction in the noise on the extracted beam current. However, the studies were limited in scope and did not explore mixtures other than 0.1% and 1.0% nitrogen. The magnetrons in the previous study operated in a much different regime with Arc currents of 50A, Arc Voltage 150V and a power efficiency of 6.7mA/kW. The current magnetron sources operate at 18A, 180V and a power efficiency of 28mA/kW. One thing to note is that our test stand has much less pumping speed than the operational vacuum chambers do and has a much larger volume. This results in a higher average pressure than the operational systems. The results are only an indication of the relative difference between the gas mixutres. As a result, the mixtures will need to be verified in the operational systems.

As can be seen in Fig. (6a) the total beam current for each mixture at the pressure where the beam noise was minimal, the 3% Nitrogen mixture had the highest beam current with the pure hydrogen having the lowest beam current overall. However, when one looks at the extracted beam current at 28kV as a function of gas pressure Fig. (6b), which is indicative of H- stripping, it becomes clear that higher concentrations of nitrogen have more H- stripping at the normal operating pressure for the sources in the test stand.



(a) (b)

FIGURE 6. Plots for different gas mixtures studied. The mixtures were pure H2, 3%N 97% H2, 1% N 99% H2, 0.5% N 99.5% H2,and 0.25% N 99.75% H2. Plot (a) is the perveance of each mixture (note there was no perveance taken for 0.25%N mixture due to the source snot running well) and (b) is a plot of the extracted beam current as a function of average vacuum chamber pressure, which shows where H- stripping occurs for each mixture (the shaded area is the normal operating pressure for sources in the test stand).

Figure (7) shows that for the normal operating pressure the 0.5% and 025% mixtures had the lowest noise. However, the supplier listed the analyzed mixtures for those bottle as +/- 5% which is large compared to 0.5% and 0.25%. As a result those data are inconclusive. The 3% mixture had the highest noise of any mixtures tried at the normal operating pressure. However, at lower pressures it performed better than pure H2 and equally as well as the 1% mixture. The 1% mixture had the lowest noise of any of the mixtures that was not inconclusive in the normal operating pressure. Also at lower pressures it outperformed pure hydrogen.

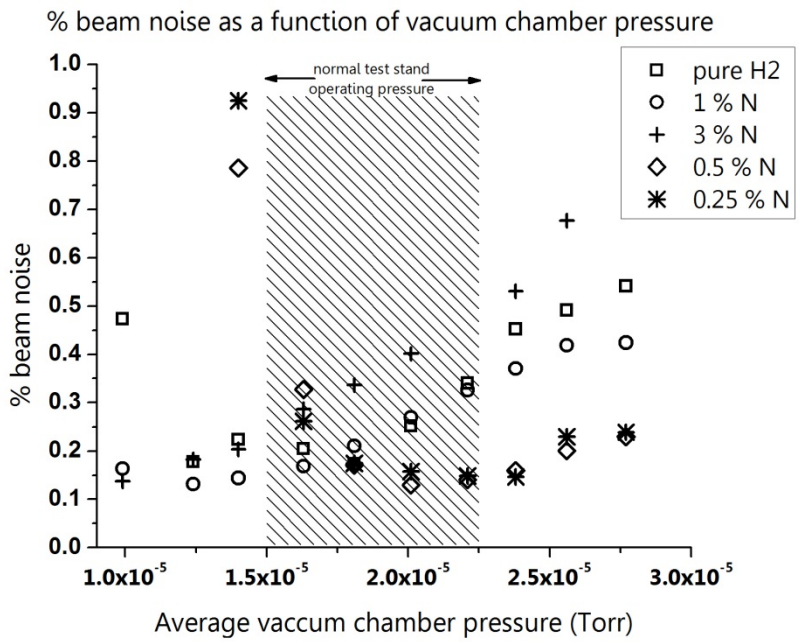


FIGURE 7. Plot of % beam noise as a function of average vacuum chamber pressure in the test stand. The0.5%N and 0.25%N are inconclusive due to the suppliers claim that the mixture analysis was +/- 5%, so it was unclear what the actual mixture ratio really was.

CONCLUSION

Based on the results of our testing, the lowest noise combination of cathode geometry and gas mixture would be the hollow cathode and 1%N mixture.

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