Installation and Commissioning of the New FNAL H- Magnetron

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The Fermi National Accelerator Laboratory (FNAL) 40 year old Cockcroft-Walton 750keV injectors with slit aperture magnetron ion sources have been replaced with a circular aperture magnetron, Low Energy Beam Transport (LEBT), Radio Frequency Quadrupole (RFQ) and Medium Energy Beam Transport (MEBT), as part of the FNAL Proton Improvement Plan. The injector design is based on a similar system at Brookhaven National Laboratory (BNL). The installation, commissioning efforts, and source operations to date will be covered in this paper along with plans for additional changes to the original design to improve reliability by reducing extractor spark rates and arc current duty factor.

I. INTRODUCTION

The new FNAL magnetron source [1], part of the Proton Improvement Plan (PIP)[2], was installed during the 2012 shutdown. The removal of one of the existing Cockcroft-Walton accelerators took place over a 1 week period. A platform and stands for the new 750keV injection line were then installed, followed by the ion source, beamline, and RFQ. The entire injector was constructed and commissioned in a test room prior to installation into the existing Linac. During the installation the source, LEBT, and RFQ were re-commissioned in place prior to connecting to the Linac tank 1.

As shown in Figure(1) there are 2 ion sources mounted on a slide for redundancy, similar to the old Cockcroft-Walton accelerators. A slide for the sources and LEBT was chosen to minimize the overall length of the injector based on BNL experience.

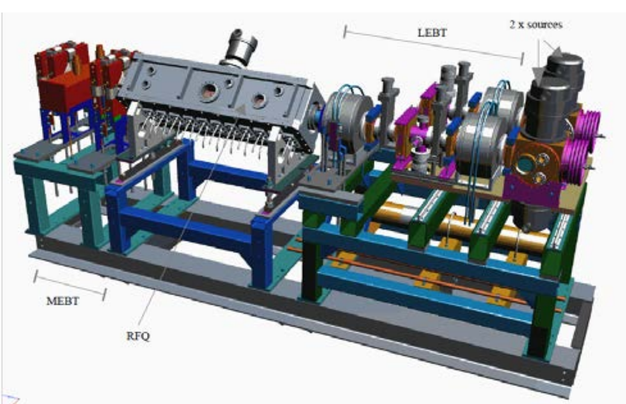

Figure 1 New 750keV Injection Line

II. OPERATIONS

A. TYPICAL PARAMETERS

The injector line has been providing beam for the Linac since last December. Table 1 shows the current operating parameters. Due to the compact size of the injector beamline the beam current is measured about 60cm downstream of the source cube and the emittance is measured at the entrance to tank 1.

Table 1 CURRENT OPERTING PARAMETERS

Parameter	Value	Units
εx (normalized 90% after RFQ)	0.44	πmm*mr
εy (normalized 90% after RFQ)	0.51	πmm*mr
Beam current (60cm from source)	70	mA
Arc current	17	A
Arc Voltage	150	V
Arc impedance	9 - 10	Ohms
Average cube pressure	2x10-5	Torr
Cesium boiler temperature	120	Degrees C
Cathode temperature	300-400	Degrees C
Arc pulse width	230	µs
Rep Rate	15	Hz
Duty factor	0.35	%

B. SOURCE SWAP USING SLIDE

To date we have swapped sources using the slide 3 times. Initially there was concern about keeping the turbo pumps running while moving the slide. According to the turbo manufacturer specifications, they can keep spinning with up to 1G of acceleration. Accelerometers were attached to the turbo housing during one of the slides. As shown in Figure(2) the acceleration was far less than 1G. Subsequent slides we have kept the turbos, and source running, which has reduced the beam OFF to beam ON time to less than 1hr. We should be able to reduce that time further with more experience.

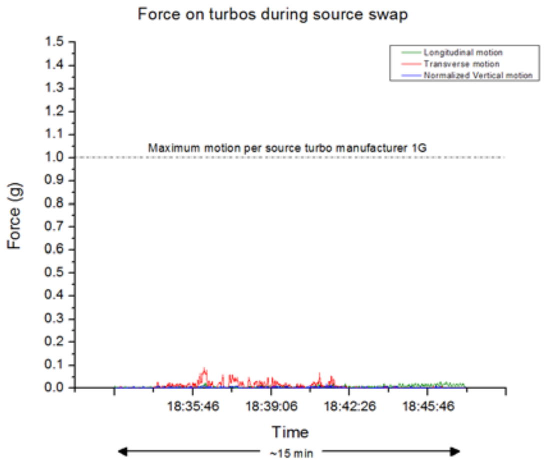

Figure 2 Force on source cube turbos during source swap.

III. EXTRACTION GAP SPARKING

With 35kV across an extraction gap size of 4.65mm there has been several times when the spark rate was 1spark/minute. During most of these sparks the source controls microprocessor needs to be rebooted which takes on the order or 5s. As a result several 15Hz pulses are missed during this time. This has been the single biggest issue associated with operations and source lifetime. We have made several improvements that have reduced the spark rate and have improved the reliability of the source. However, high spark rates continue to have the largest impact on operations that we have.

A. MAGNETIC FIELD

The original magnets were of a similar design to the ones in the High Intensity Neutrino Source (HINS)[3] magnetron. The transverse magnetic field of these magnets was 850G which is low compared to the ideal field of 1 – 1.5kG[4] Initially the source would start extractor sparking after it had been running for about 48hrs. We connected a thermocouple readback to the magnet yoke and discovered that the yoke temperature would reach 65C. A set of magnets were then heated on a hot plate and when the temperature reached 40C the field had already dropped to 700G, which is ½ of the ideal field for proper confinement in a magnetron.

As a test, we installed a set of magnets that were modified with a twice the number of magnets mounted in series. This increased the field to 1.15kG which reduced the increased spark rate that occurred after the source warmed up. Based on this we redesigned the magnets and yoke for a higher field. Figure(3) is a comparison of the 3 different magnet designs. The new design not only has a better field in the plasma region, but a larger field in the extraction region which helps sweep away co-extracted electrons.

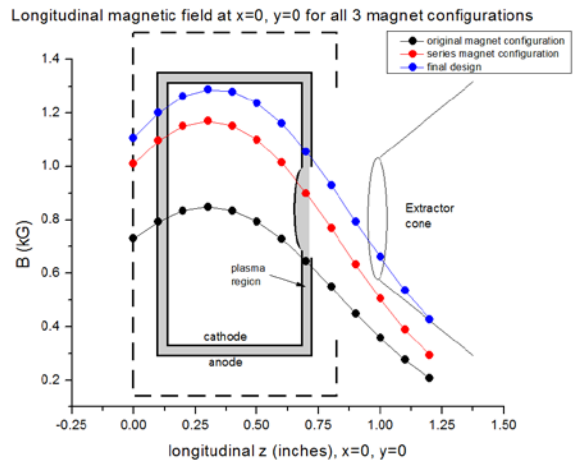

Figure 3 Magnetic field for the 3 different magnet combinations. The black curve is for the original configuration, red is for a test configuration in which magnets were installed in series, and the blue trace is for the latest configuration. All magnets were SmCo.

B. CESIUM CONTROL

The temperature of the cesium boiler also plays a large role in the spark rate. Figure(4) shows the effect of lowering the cesium boiler temperature by 6 degrees C. After about 1.5hrs the spark rate decreased substantially. This is also seen in the BNL source during times that they have boiler temperature issues [5].

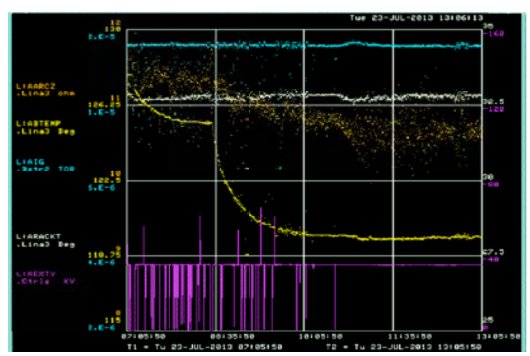

Figure 4 Effect of lowering cesium boiler temperature. Yellow trace is the boiler temperature in degrees C and purple trace is extractor voltage in kV.

C. PASCHEN CURVE

Gas pressure in the extraction region also contributes to the spark rate. The only measurement of gas pressure that we have is the average pressure in the source cube. Originally we thought that we were operating on the lower side of the Paschen curve see Figure(5). However, increased cube pressure did lower the spark rate. We now run with twice the pressure that we initially started out with.

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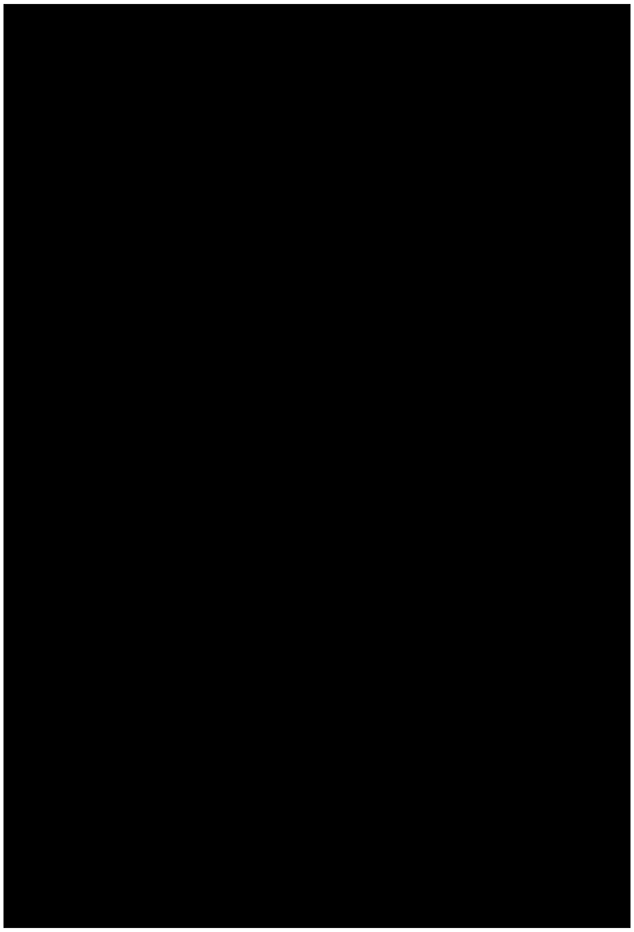
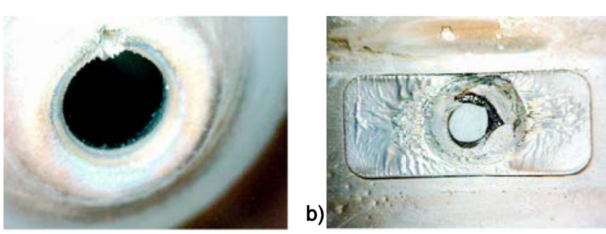


D. INTERNAL SOURCE DAMAGE

Early in the commissioning phase extractor sparking was causing damage to the extractor cone tip and the inner anode cover plate. Once the damage occurred, the source had to be removed and fixed. The causes of the damage were the amount of stored energy in a spark and the types of material used. We installed a series resistor between the extractor pulser and the source body to help reduce the energy released during a spark. Originally we were using molybdenum for our extractor cone tip and titanium for the inner anode cover plate. We have since changed the materials to tungsten for the extractor and molybdenum for the cover plate. Figure (6) shows the damage that was occurring and the new materials.



a) b)

Figure 5 Damage to source materials a) molybdenum extractor cone tip, b) titanium inner anode cover plate.

IV. PLANS FOR FUTURE IMPROVEMENTS

There are several plans for continued improvement of the source support electronics which include:

- Removal of a microprocessor system from our high voltage rack. This system works poorly in an environment where sparking occurs and needs to be reset after every spark.
- Our current extractor pulser utilizes a vacuum tube which limits the rise time to about 150μs. We have tested and purchased a set of solid state switches from DTI to replace this system. Initial test results indicate a rise time of only 9μs. This would allow a reduction in the duty factor of 43%.
- We are investigating new pulsed gas valves to replace the piezoelectric valves that are currently in use, which suffer from temperature drift.
- Currently the source is pulsed from ground to -35kV for extraction of H- ions[1]. We will be testing a different extraction scheme where we will extract in 2 stages, reducing the voltage across the extraction gap.
- We are currently experimenting with a spectrometer to help us better understand the amount of cesium in the system in hopes of better control.

V. CONCLUSION

A new style of magnetron and 750keV injector has been installed in the FNAL Linac and is delivering beam for the rest of the complex. The average lifetime of the sources is limited due to extractor sparking to about 2 months. Several improvements have been made during the commissioning phase to help reduce both the spark rate and impact of extractor sparking. There are several more improvements that will be implemented in the near future that should further reduce the effects of sparking.

VI. ACKNOWLEDGMENTS

I would like to thank Pat Karns for taking the magnetic field data, Mike McGee for the turbo accelerometer measurements, CY Tan for all of his input and the gifted electronics and vacuum technicians that made this project possible.

VII. REFERENCES

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