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A NEW SOLID STATE EXTRACTOR PULSER FOR THE FNAL MAGNETRON ION SOURCE[a)]

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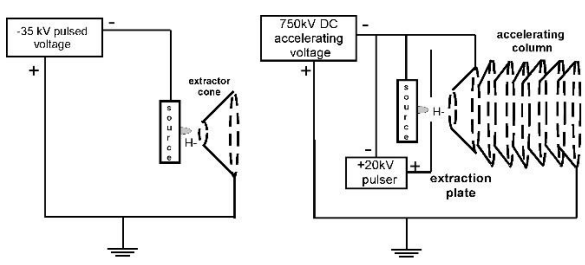
A new solid state extractor pulser has been installed on the FNAL magnetron ion source, replacing a vacuum tube style pulser that was used for over 40 years. The required ion source extraction voltage is 35 kV for injection into the Radio Frequency Quadrupole (RFQ). At[DSB1] this voltage the old pulser had a rise time of over 150 microseconds due to the current limit of the vacuum tube. The new solid state pulsers are capable of 50 kV, 100 A peak current pulses and have a rise time of 9 microseconds when installed in the operational system. This paper will discuss the pulser design and operational experience to date. [2015 AIP Publishing LLC. [http://dx.doi.org/10.1063/1.4932121]

I. INTRODUCTION

The original magnetron ion sources that were installed in the FNAL Cockcroft Walton (CW) pre-accelerators required a positive extraction voltage between 15 kV and 18 kV to pull the H– ions from the ion source. The source was floating at –750 kV and the H– ions were accelerated to ground potential through an accelerating column. The new magnetron ion source design requires a –35 kV extraction voltage which both extracts and accelerates the H- ions to ground potential with the correct energy for the RFQ to capture and accelerate the ions to 750 keV [1]. The different extraction schemes are shown in figure (1). The first generation of negative pulser was a modified version of the original positive one. The pulser had a long rise time, short lifetime (on the order of 3 months), and long lead time for tube replacement, which led us to investigate using a solid state pulser similar to what we are using for our Einzel lens chopper [2].



a) b)

Figure 1. Comparison of extraction schemes. a) RFQ ion source extraction. b) CW extraction showing accelerating column.

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II. DESCRIPTIONS OF PULSERS

A. Original Positive Extractor pulser

The extractor pulser was initially designed in 1978 for a magnetron negative ion source that was replacing a duoplasmatron which supplied protons for the FNAL linac. The magnetron was installed in a CW preaccelerator that accelerated the ions to 750 keV which is the injection energy required by tank 1 in the linac. The pulser operated at + 18 kV to pull H- ions out of the source as shown in figure (1b).

This pulser used a 4 PR 250C tetrode vacuum tube which has a peak current of 4 A and 50 kV peak voltage. The tube was used as a switch between a capacitor bank and the extractor plate shown in figure (2a).

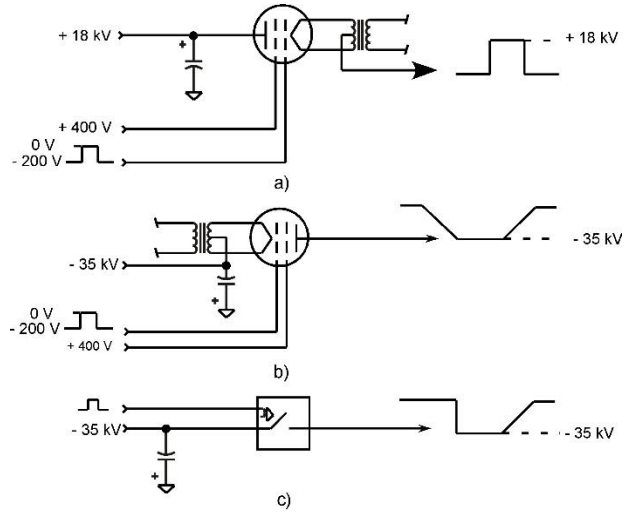

Figure 2. Comparison of extractor pulsers. a) original positive pulser, b) original pulser converted to a negative pulser, utilizing the same vacuum tube and c) the solid state switch pulser.

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The 4 A peak current presented problems because the co-extracted electron current hitting the extractor plate would affectively load the extractor voltage down. This can be seen in figure (3a) as the droop in the extractor voltage. This typically happened when the ion source was not running efficiently so the electron to H – ion ratio was large. When the ion source was running well the electron to H – ratio is approximately one.

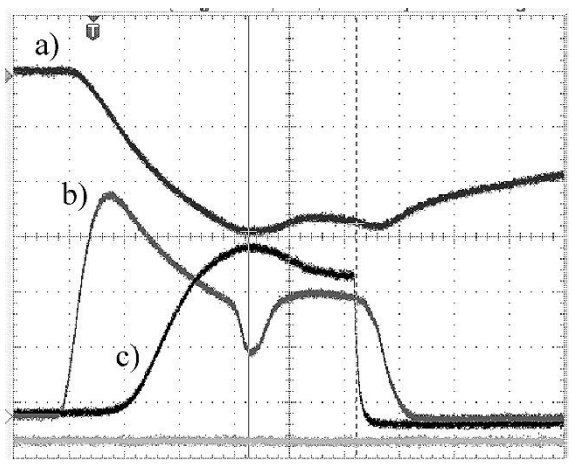

Figure 3. a) extractor voltage, b) total extractor current, and c) extracted beam current. The extracted electron current causes the extractor voltage to droop because of the current limit of the vacuum tube.

With the original CW extraction scheme, the rise time of the extraction pulse was 15 µs. The rise time was due to two factors. First, the extractor pulse began before there was plasma discharge in the ion source, so there were no electrons or H – ions ready to extract. Second the only capacitance in the extraction system was the high voltage cable and the capacitance between the ion source body and the extractor plate which was small.

With the 18 kV extraction voltage the tube lifetime was between 6 – 9 months, which was adequate for operations. The tubes were replaced when the rise time became too long or the voltage would droop due to the co-extracted electrons when the ion source was running well.

B. First Generation Negative Pulser

The first generation of negative pulser was a modified version of the positive pulser utilizing the same vacuum tube. After several modifications, the original pulser was converted from a positive pulse to a negative pulse as shown in figure (2b). The main modification was connecting the vacuum tube in the opposite direction as the positive pulser. With the new extraction scheme, the ion source and associated electronics in the high voltage rack are now pulsed to –35 kV with respect to ground. The total capacitance is much larger than previously and the extracted H – ion current is two times as much as the CW ion sources. As a result of the increased capacitance of the system, and higher extracted H – ion current, the rise time of the pulser is 150 µs. With the additional current draw and higher extraction voltage on the vacuum tube, the lifetime became limited to 3 months on average. As the tube aged, the rise time would increase until the total available flattop would decrease to a point where there was not enough extracted beam width. Figure (3b) shows an older tube that had a 194 µs rise time with less than a 50 µs flattop (the minimum extracted beam width required for operations is 80 µs).

C. Solid State Pulser

With the long rise time and short vacuum tube lifetime a solid state extractor pulser was designed. The pulser design is much simpler than the previous generation of pulsers as can be seen in figure (2c). This pulser utilizes solid state (SS) switches produced by Diversified Technologies Incorporated (DTI), which are capable of 10 kV and a peak current of 100 A [3]. Five switch plates are connected in series as shown in figure (4a) to increase the voltage rating to 50 kV. The maximum pulse (PW) width for the system is 250 µs with a rep-rate of 100 Hz. These parameters fit within our operating parameters of 150 µs PW with a rep-rate of 15 Hz.

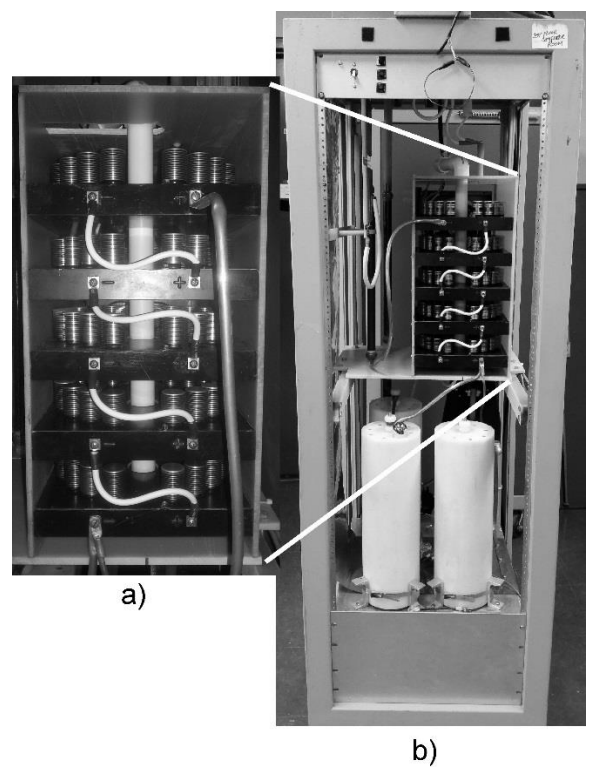

Figure 4. a) DTI solid state switches, b) pulser rack showing solid state switch assembly and capacitor bank.

DTI also supplied a switch controller which is similar to the one used for our Einzel lens pulser that has two solid state switches (one for an ON pulse and one for an OFF

pulse). For this application only one switch per pulser is required since the voltage bleeds off between the 15 Hz pulses. However, there are two ion sources used for redundancy, so one chassis controls both of the extractor pulsers for the operational ion sources. The controller is also set to limit the peak current to 20 A before tripping off, to insure that the switches will not be damaged from excessive current during extractor sparks.

The switches are connected between 2, 0.1 μF 70 kV capacitors and the load. We did add a 500 Ω series resistor between the pulser and the ion source extractor cone to limit the amount of current during extractor sparking. With this configuration the rise time of the extraction voltage is 20 μs at 35 kV as shown in trace 2 of figure (5), which is a dramatic reduction in rise time over the tube based system. In our initial tests, with no current limiting resistor, rise times of 9 μs were observed.

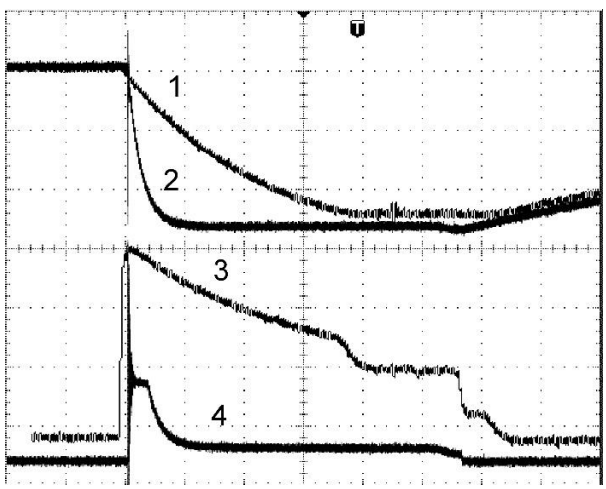

Figure 5. Scope traces showing difference between the tube based pulser and the solid state pulser. 1. tube based extraction voltage, 2. solid state extraction voltage, 3. tube based current, 4. solid state switch current.

III. Solid State Pulser Operations

The new SS pulsers were installed in the operational systems in November 2014. Both pulsers ran continuously for 8 months with no failures even with occasionally high spark rates (several per minute). Figure 6 shows the extractor voltage and current during a normal extraction pulse and during a pulse with an extractor spark. The highest current seen by the pulser is approximately 4 A, which happens as the switch starts to conduct at the beginning of the extraction pulse. During sparking the current is 1.5 A. Both of these peak currents are far below the maximum peak current setting of the controller.

Since the rise time of the SS pulsers have a shorter rise time than the tube based pulsers, we have begun exploring the possibility of reducing in the ion source discharge PW. With the tube based pulser rise time 150 μs, we needed to have arc discharge PW of 230 μs in order to allow for neutralization time in our low energy beam transport (LEBT) and for 80 μs of extracted H − ion beam for chopping. With the SS pulser rise time of 20 μs we should be able to reduce the arc discharge to 150 μs, still allowing enough extracted ion beam for neutralization and chopping. At 15 Hz this is a reduction in duty factor of 35 %, which could lead to improved ion source lifetime.

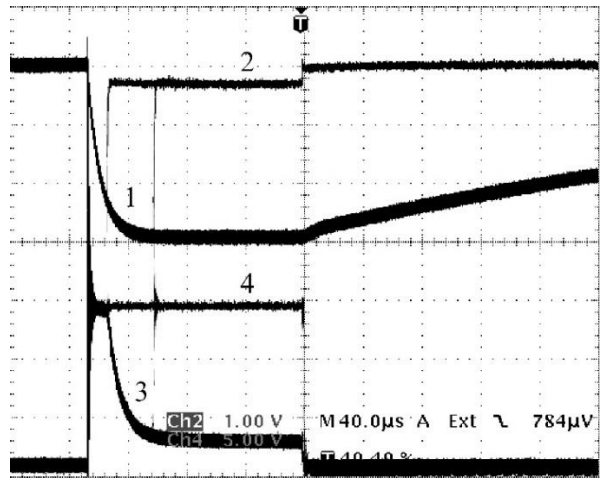

Figure 6. Scope traces of extractor voltage and current both during a spark and normal operations. 1. extractor voltage during normal pulse, 2. extractor voltage during spark, 3. total extractor current during normal pulse, and 4. total extractor current during spark (100 mA/V).

IV. Conclusions

The new solid state extractor pulsers have over 3×10^8 pulses with no failures or tips on over current. During a similar timespan prior to swapping over to the SS extractor pulsers, the tube style pulsers required a total of 7 tube replacements and additional downtime due to tube bias card failures. The SS extractor pulsers have also allowed us to explore reducing the arc discharge PW by 26% which lowered the cathode temperature by 50 C. We plan to continue studies on reducing the duty factor of the ion source which may improve source lifetime.

V. References

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[3]High Voltage PowerMod Switch Assembly Operation Manual, Diversified Technologies Inc., April 2014