USING A SOLID STATE SWITCH FOR A 60KV BOUNCER TO CONTROL ENERGY SPREAD DURING THE BEAM PULSE *

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Abstract

The beam injected into the IPNS Linac is from a column utilizing a Cockcroft-Walton voltage source. The accelerating column consists of a single high gradient gap. To lessen the likelihood of gap voltage breakdown we pulse ("bounce") the column voltage up during the beam pulse allowing the column DC voltage to be lower. The accelerating voltage is supplied through a 5 MΩ resistor and has only small capacitance to hold the voltage constant during the beam pulse. A capacitor is connected between the high voltage end of the column and the bouncer pulse generator. The bouncer pulse increases the column voltage to the proper level just microseconds before the beam pulse. A slope on the top of the bouncer pulse allows for correction to be added, compensating for the voltage droop that results from beam loading. The bouncer that has served this purpose in the past utilized a tube amplifier. In searching for a suitable replacement system it was decided that the system should be able to deliver a 60 kV pulse and the slope on the top of the pulse could be controlled by an RC rise. A solid state switch was purchased for this application. Switch protection and other design decisions will be discussed

INTRODUCTION

The Intense pulsed Neutron Source (IPNS) injector linac[1] delivers 70 to 80 microsecond long pulses of 50 MeV H- particles to the 450 MeV synchrotron. The H- ion source is capable of delivering about 1.6×10^{13} particles per pulse at a 30 Hz rate. The linac is designed for a 750 keV input beam, but can operate at a reduced efficiency with input beams as low as 700 keV[2].

Column arc rate is acceptable if the DC voltage is below 700 kV. Our present operating energy is 730 keV out of the column. The DC voltage is operated at 690 kV, the extractor is 20 kV and the bouncer makes up the remaining 20 kV. The bouncer coupling network couples 50% of the supplied pulse so this requires that the bouncer supply a 40 kV pulse to the coupling network. The old bouncer meets these requirements but the tubes are no longer manufactured. Recent plans to upgrade the synchrotron by adding a third rf cavity may require more charge per pulse out of the linac, leading to a need to improve linac transmission efficiency. Furthermore, calculations indicate that much better control of linac output longitudinal emittance is possible if injection is at the design 750 keV. This could improve capture and lower losses in the synchrotron independent of the new rf cavity. Column redesign was a possibility but had no guarantee of success and would have required a long downtime for the modifications and commissioning. However improving the capability of the bouncer added little additional risk and could be incrementally tested during our regular machine research periods. To replace our present bouncer, the new bouncer would need to run at 40 kV; to meet future plans a 60kV bouncer and 700kV DC will provide a 750keV beam from the column.

Ideally, the bouncer should rapidly increase and decrease the column voltage in time for the beam pulse, and should compensate for the beam loading voltage droop of the Cockcroft-Walton during the pulse. This led to the following specifications:

1 Operate at 30Hz
2 Output up to 60 kV
3 Rise time ≈100 µs
4 Top slope of 5 0 V/µs
5 Top width of 90 µs
6 Fall time ≈ 1 ms
7 Survive in an environment where 700 kV pulses at several amperes are frequently generated.

DESIGN

Recent advances in semiconductor technology have made available fast high-voltage solid-state switches that can be cascaded to provide current and voltage capabilities unreachable only a few years ago. We now use these devices for our 20 kV extractor as well as for the bouncer. Figure 1 shows the 60 kV switch that we purchased from Diversified Technologies, Inc.

Figure 1: 60Kv 20A-50A switch as installed at the base of the IPNS ion source.

This switch has 6 plates assembled on a fiberglass channel and a control box with leads ready for connection

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to the insulated trigger wire. The plates contain multiple insulated gate bipolar transistors. The plates can be stacked to make switches with a wide range of current and voltage capabilities. [3] This switch is capable of handling 25A at 60 kV for a pulse ≤ 500 µs. With switch turn on and off times much faster than 100ns, this switch is much faster than is required for our application. It is controlled by an optically-coupled pulse to turn the switch on and off. This is ideal for operation in an electrically noisy environment.

To design the bouncer, the load needed to be characterized. This was done by measuring the voltage, current and rise time from the tube circuit. It was determined that a large part of the load was the stray capacitance of the source enclosure to ground. The bouncer was built with sufficiently low impedance that rise time would not be significantly effected by this capacitance. Rise time would be controlled by components chosen to achieve the desired rise and slope on the top of the pulse. Components R1, R2, and C1 in the figure 2 accomplish this task.

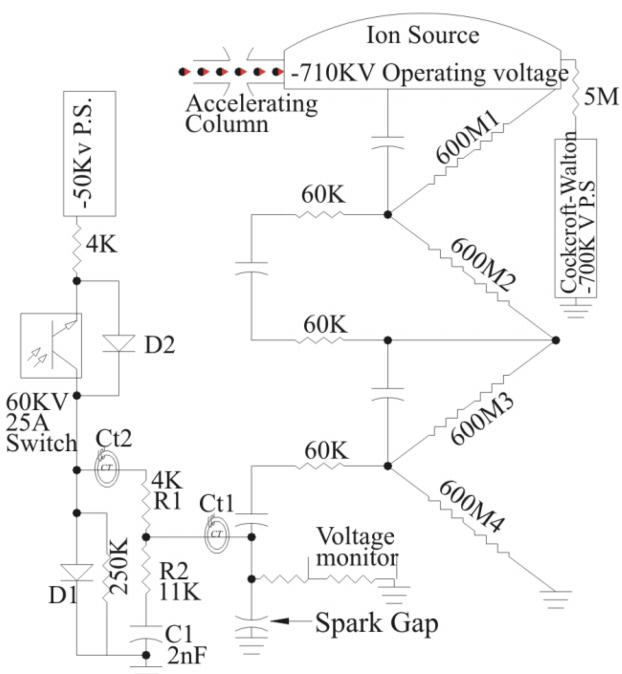

Figure 2: Block diagram of bouncer and coupling network.

BUILDING AND TESTING

The system was built and tested using a -50kV power supply that is the spare for another system. After more than 160 hours of trouble free operation connected to a test load, the bouncer was connected to the source coupling network. With the 700kV power supply turned off, a voltage monitor was connected to the source enclosure. The pulse amplitude and slope at beam time was compared to data taken on the tube bouncer. By changing the value of R1 and R2, the rise and pulse slope could be adjusted over the desired range. The output is shown in figure 3 for R1 and R2 at the values that were chosen for operations.

After the 700kV power supply was energized, it was observed that on most occurrences of a column spark the current was limited to 4 amperes by the three 60kΩ resistors. After C1 became charged, the entire current passed through R1 and D1 to ground. The purpose of D1 was to shunt this current to ground, preventing over-voltage from developing across the solid state switch.

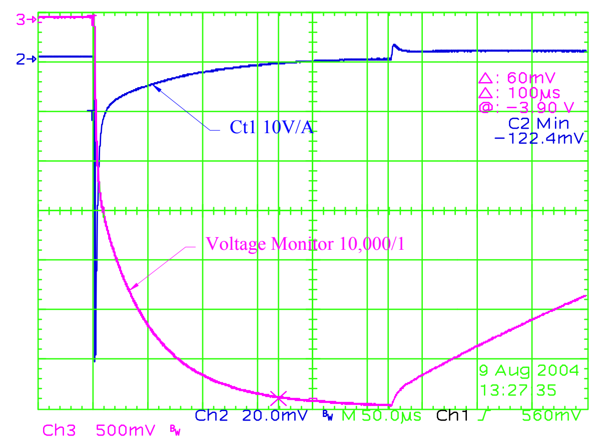

Figure 3: Scope trace of voltage monitor and Ct1.

OPERATIONS AND IMPROVEMENTS

After the system was in operation for several days, diode D1 failed. Although the failed diode could handle more current than the 4 amperes that should be the maximum current in the diode, a higher current capacity diode was used as a replacement. While investigating why D1 failed, it was noticed that on about 1% of the times the column sparked, the current on the two current toroids Ct1 and Ct2 was higher than the 4 amperes that was expected. After studying scope traces of Ct1, Ct2, and the voltage monitor, it was decided that something in the bouncer coupling network was occasionally breaking down when the column arced. Study of the bouncer network revealed that the transient voltages associated with the arc are not equally distributed across the four 600MΩ resistors. Most of the transient appears across 600M2 while 600M1 and 600M3 have no voltage across them. If 600M2 were to arc over that would leave only one 60kΩ resistor to control the current. The Ct1 reading was close to what would be expected if this happened. Diode D1 would most likely not be damaged by this current pulse, although the R1 voltage was observed to be over 3 times the manufactures maximum voltage rating. It was observed on a few pulses that the current in Ct2 was over 80 amperes. On these high current observations the voltage on the voltage monitor would increase for about 30µs to a voltage of about 60kV, then drop as the current increased at Ct2. Our conclusion was that R1 was arcing over. That would place nearly all of the voltage on C1 across R2 and cause it to arc over. The diminished impedance of R1 and R2 would do little to control the current as C1 discharged through R1, R2, Ct2, and D1. A more robust resistor was installed for R1, and over several weeks of operations the current in Ct2 was not observed to be higher than would be expected if 600M2 arced over. The 600M2 was then relocated as shown in figure 4. This should reduce the transient voltage across 600M2 when the column arcs, such that 600M2 should not arc over.

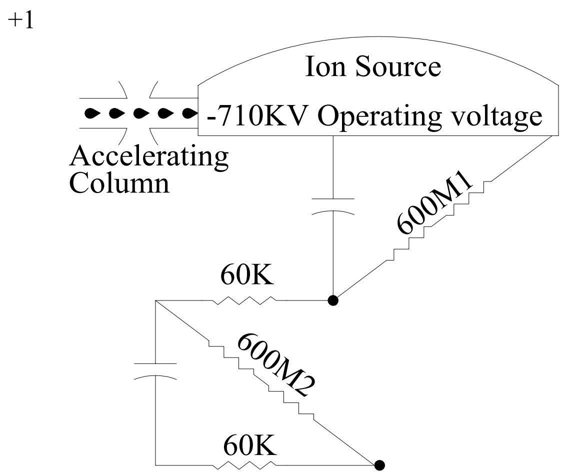

Figure 4: Modified diagram with 600M2 moved to lessen the likelihood it would arc over.

CONCLUSIONS

Tube circuits are no longer the only choice for applications that require fast switches that will operate in the tens of kilovolts range. Switches need to be protected from both over-current and over-voltage. Commercial switches have over-current trip protection built into them but require time to work. Switch loads need to either provide high enough impedance to limit current or limit the current rise so the switch's built in over-current circuit has time to protect the switch.

REFRENCES

[1] V. Stipp, et al, Proc. 18th LINAC Conference, CERN, Geneva, Switzerland, August 1996, p. 74
[2] J. C. Dooling et al., Proc. 19th LINAC Conference, Gyeongju, Korea August 2002, p. 439
[3] Dr. Marcel, et al,Proc. 23 Power Modulator Symposium, Rancho Mirage, Ca June 1998, p. 160