Investigation of Electrical Trigger Systems for a Back Lighted Thyratron*

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Abstract

This paper discusses electrical triggering experiments for an electrically triggered, super-emissive cathode switch. An electrically triggered, Back Lighted Thyratron, BLT, was investigated when operating in a high impedance discharge circuit. The BLT is a low pressure, hollow cathode type closing switch that can be either electrically or optically triggered. The BLT has been operated at voltages in excess of 50kV and peak current levels up to 50A.

Introduction

Super-emissive cathode switches, SEC,[1] are high power, hollow cathode devices that operate at low pressure. Two embodiments of the SEC devices are the electrically triggered Pseudo-Spark Switch, PSS, and the optically triggered Back Lighted Thyratron. The SECs do not have a heated cathode, but rely on the hollow cathode geometry and transient gas ionization that generates ions which subsequently heat small portions of the cathode surface to very high temperatures(3000-4000 K). As a result of the cathode heating, small regions on the cathode surface can emit current densities up to 10-15 kA/cm^2. However, methods of initiating the initial ionization and cathode heating process with minimal delay and jitter have not been well defined.

Thus the objectives of this work were to develop methods of minimizing the trigger delay, jitter, and effects of the pre-closure current in a SEC and to determine the best method of electrically triggering a SEC switch when operating in a high impedance discharge circuit. A BLT which can be triggered with electrical trigger connections was used for this investigation.

PSS/BLT Switch Description and Operation

The generic, cylindrical SEC switch (PSS or BLT), illustrated in Fig. 1, consists of anode and cathode structures separated by several mm, each with a several mm diameter hole on axis to form a symmetrical, hollow cathode structure. The electrodes are of molybdenum and are in the form of inverted cups with holes in the faces of the cups such that some electric field lines penetrate the electrodes from the back of the anode through the gap to the back of the cathode. The initial discharges occur along the longest field lines because of the low pressure gas fill.

The anode and cathode structures are sealed and insulated within a ceramic container filled with hydrogen gas. The hydrogen pressure within the envelope is controlled by a thermionically heated reservoir, similar to that used in conventional thyratrons, between 100 and 600 mTorr.

The closure process of a SEC switch (BLT/PSS) is initiated by producing free electrons in the cathode region. In the PSS, electrons are provided by a small thermionically heated cathode and an electrical grid while in the BLT electrons are provided by photons through the photo-electric effect. Impact ionization of the background gas produces ions that are subsequently accelerated to impact the and heat localized areas of the cathode. The time required to heat the cathode with anions results in a delay after providing the initial electrons. The ion current that flows through the switch while heating the cathode is observed as a slowly increasing current through the switch. When the cathode temperature is sufficiently large, the super-emission of electrons causes the hollow cathode discharge to proceed to a very dense diffuse discharge in which the rate of current rise is much greater than possible with thyratrons($>10^{12}$A/s). Triggering delay is observed in both the PSS and the BLT and the current observed during heating is observed as a "foot" on the main discharge current pulse. During the transition from 2the conduction to the superdense diffuse discharge, the conduction channel moves from the axial region between the holes in the electrodes to the region between the faces of the plates.

Experimental Arrangements

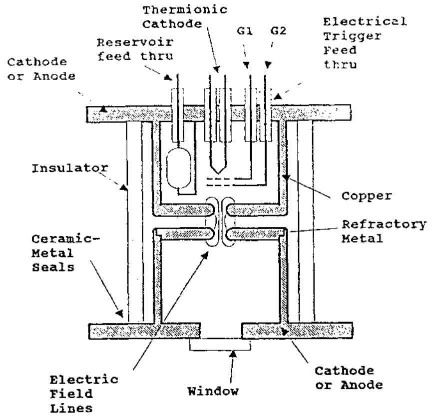

Figure 1. Illustration of Generic Super-Emissive Cathode Switch

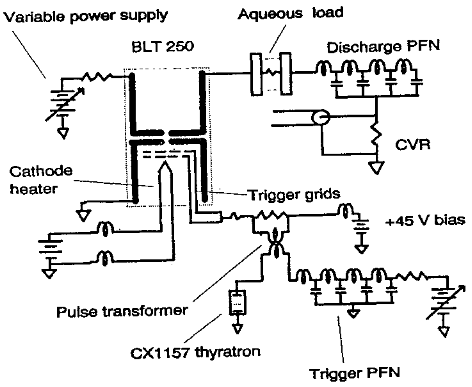

Figure 2. SEC (BLT) Trigger Investigation Circuit

The experimental arrangement used is illustrated in Fig. 2. An Integrated Applied Physics, BLT250E was used to discharge an 800 ns, 50 Ohm Pulse Forming Network, PFN, into a matched, resistive load as shown in Fig.1. The BLT and discharge PFN switch was dc charged for these experiments. A 100 Ohm, 400 ns PFN operating at 3 to 5 kV was used to generate the electrical trigger pulse.

The experimental setup is as shown below. The discharge circuit consists of an 800 ns, 8000 pf PFN charged resistively, an aqueous load of copper sulphate solution, the BLT 250 and a current viewing resistor. The aqueous load consisted of two copper plates about an inch thick separated by a pvc pipe section containing copper sulphate solution, made watertight by the use of viton O-rings. The trigger circuit consists of a smaller 2000pf, 400ns PFN, a pulse transformer and an AG&G CX1157 thyratron. The thyratron is in turn triggered by an SCR based trigger box. The trigger PFN was charged to voltages between 0.5 and 5kV. The whole setup was immersed in a large metal tank of oil such that the experimental setup could be raised or lowered by the use of a hydraulic jack. The oil used was Shell Diala AX oil, and was expected to give a voltage standoff in the region of 14 kV per mm. The oscilloscope and cameras, etc were isolated in a screen room. The oscilloscope used was a Tektronix 1 GHz scope.

The electrically triggered BLT250, has a small thermionically heated cathode and two grids as shown in Fig. 2. The cathode provides a source of electrons. When the first grid is biased slightly positive(< 100 V) the region between the grid and the cathode serves as an electron reservoir. Previous work with the PSS/BLT has determined that a small positive bias(< 100 V) on the second grid increases the voltage holdoff by preventing electrons from entering the main, hollow cathode-hollow anode struture.

The first trigger circuit arrangment investigated, a transformer coupled system, is illustrated in Fig. 3 that introduces a positive trigger pulse (3-5 kV) on the positively biased G2. For the experiments described in this paper, both G1 and G2 were connected together and biased at a positive 45 Volts.

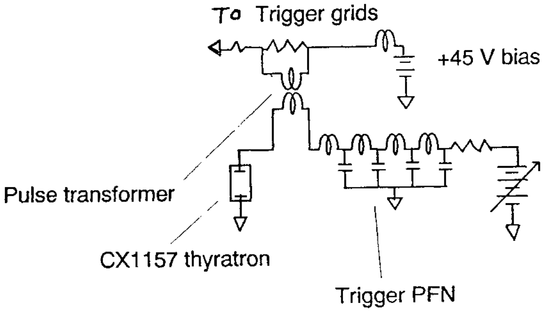

Figure 3. Transformer Coupled Trigger Schematic

In the configuration above, the trigger pulse applied to the grids is positive, but was also used as a negative trigger by reversing the polarity of the leads at the output of the pulse transformer. Various other configurations were used such as directly connecting the grids to the trigger circuit as shown in figure 4, below. This configuration can also be used as a positive trigger by connecting the cathode of the trigger thyratron directly to the grids and heating the cathode and reservoir with current through a pair of cables wrapped around a magnetic core.

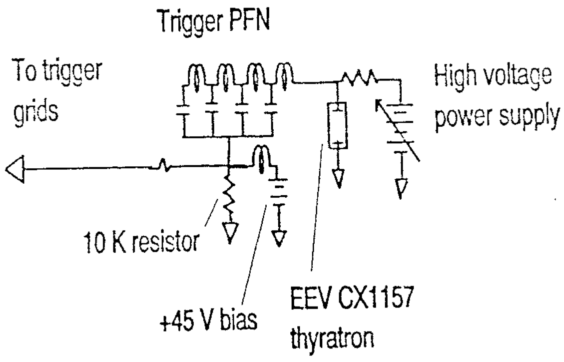

Figure 4. Direct Coupled Trigger Schematic

Only a few electrons (~ 10^9) released behind the cathode in the region of the central hole are required to initiate conduction through the SEC. They can be released by photoemission off the cathode or by the use of a glow discharge mechanism produced by an electrical trigger. In high impedance circuits however, the initial current rise is slower (due to the external circuit) and the trigger has to be strong enough to ensure that breakdown occurs rapidly. Therefore, a third arrangement was used to investigate the effect of providing a source of electrical energy for heating the cathode with the ions produced by the discharge is illustrated in Fig.5. The circuit of Fig. 5 indicates that the first section of the high impedance PFN is an inductor that limits the rate of current rise through the BLT. A capacitor was placed in parallel with the BLT to provide a low inductance source of electrical energy for heating the cathode. A resistor was subsequently added to damp the resulting oscillations.

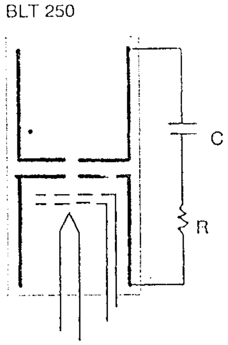

Figure 5. Capacitive Energy Store in parallel with BLT

Experimental Results

A typical trigger pulse, shown in Fig.6, was applied to both the grids of the BLT using the transformer coupled circuit. The figure below shows the voltage on the grids as measured by a Tektronix P6015 1000x probe.

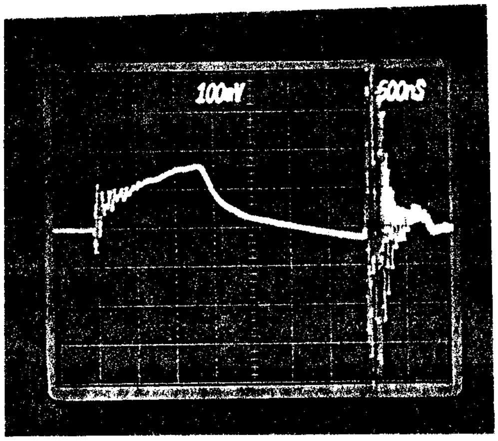

Figure 6. Positive, Transformer Coupled Grid Waveform

In this arrangement, triggering of the tube using a positive trigger was tried with both the cathode heater turned on and with it turned off. However, the gas breakdown did not seem to occur during the positive part of the trigger pulse. During the onset of the positive trigger, a small amount of anode current flows, however this ripple dies. Increase of trigger voltage did not help start the conduction during the positive part of the trigger. As the voltage at the grid drives negative, the anode current starts to flow and conduction occurs. At about the same time, high voltage spikes of small duration are present on the grids. This voltage is much in excess of the trigger charge voltage. Similar ripple was found on the discharge PFN current as measured by a CVR between the PFN and circuit ground. The increase or decrease of cathode heater current did not create any variation. The delay was large due to the fact that the switching occurs after the pulse goes negative, and due to the slow rise of negative voltage. This slow rise also gives rise to a higher jitter. Several modifications were made to the trigger circuit as seemed required.

Since the BLT triggered during the negative part of the trigger pulse, a negative trigger was tried (by reversing the polarity of the pulse transformer output). With a fast rising negative pulse in excess of about 3 kV, the delay was reduced to about a 100 ns, and jitter less than 10 ns, as can be seen in Fig. 7. In this figure the current is measured by a CVR of .0098 ohms placed between the cathode of the BLT and the circuit ground.

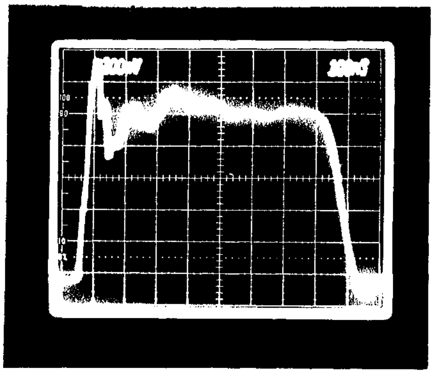

Figure 7. BLT current during ten consecutive discharges of the PFN

Connecting the grids directly to the trigger discharge circuit as in Fig. 5, and winding the trigger leads around a iron core to increase the impedance offered to a signal travelling along only one lead does not help since the other lead has both ends grounded. Hence one could conclude that the direct trigger has a higher interaction with the anode and the anode current ripple is more pronounced. But the current rise is smoother and the jitter equally low. The discharge current for a negative, directly coupled trigger circuit is shown in Fig. 8.

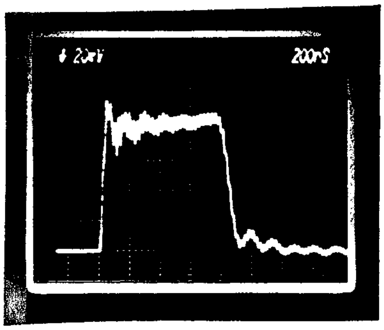

Figure 8. Negative, Direct coupled Grid discharge waveform

Efforts to make the switching more rapid by placing a capacitor in parallel with the BLT had the interesting effect of reducing the ripple in the discharge current but did little to reduce the risetime of the circuit. Comparisons of the different discharge currents are shown in Fig. 9. In both the waveforms shown, the resistance in series with the capacitor was zero. Increase of the resistance only affects the switch during turn-on

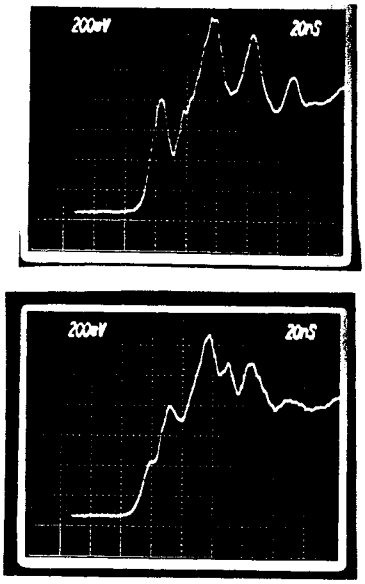

Figure 9. Effect of Parallel Capacitor on Discharge Waveform. Discharge current without capacitor (upper figure), with a capacitor(lower figure).

Conclusions

The results of the initial tests indicated that a fast rising negative trigger of a little over 3 kV, coupled by a pulse transformer, applied to the grids biased 20-40 V positive is the best way to trigger a BLT in a high impedance circuit. Increasing the trigger voltage beyond 3kV did not make a difference to the risetime. From the data obtained it was concluded that the trigger mechanism is basically a Paschen breakdown between the anode and the grids, the current subsequently transferring to the cathode. The breakdown process is slightly different in high impedance circuits from that in low impedance circuits, hence the triggering process is also different. In a circuit where the current is in the region of a few hundred amps or so, it is doubtful whether the switch remains in the super-dense discharge phase where conduction is between the faces of the plates or simply along the axis of the tube in the inter-electrode region.

Using a energy store such as a capacitor in a low inductance discharge path through the switch helps the switch turn on smoothly. Adding a resistance to this capacitor discharge path helps damp the oscillations created by the capacitor during the pulse itself, but reduces the efficacy of the capacitor in turning the switch on.

Acknowledgements.
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