Fast Risetime BLT Switches for Accelerator Applications*

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Abstract

A fast risetime BLT switch which has demonstrated 17kA at 30kV with <60nsec risetime, 1.5kA at 20kV with <18nsec risetime, and up to 240Hz operation at 20kV, 7kA is reported. A tetrode triggering method is described which reduces risetime by eliminating prepulse behaviour.

I. INTRODUCTION

Several particle accelerator systems require repetitive switches capable of switching peak currents of several kA with short risetimes, in particular kicker magnets used to transfer particle beams from one section of an accelerator to another require current pulses that rise from zero to 100% in a time determined by the separation between particle bunches which can be only 10's of nsec in some applications. One particular application is the injection and extraction kickers for the low energy booster (LEB) of the superconducting super collider (SSC) which requires <50nsec 0-99% risetime. Another system with similarly strict risetime requirement is the kicker for the Stanford Linear Collider electron damping rings.

In this work we report the development and testing of a BLT(1) switch which handles high currents with fast risetime yet is much simpler in construction and smaller in size than other switches with similar specifications. This work has concentrated on demonstrating the high current, risetime, and pulse shape ripple and repeatability capabilities of the switch, other aspects of switching such as jitter and repetition rate have also been investigated.

II. EXPERIMENT

The BLT switch is a hollow electrode low pressure gas discharge closing switch operating with an initially cold cathode that conducts high peak currents in a small diameter switch. Peak current capability is an order of magnitude larger than typical hydrogen thyratrons. The hollow electrode structure allows high reverse current to be conducted without damage to the switch. The switch can be optically or electrically triggered with low jitter and good pulse repeatability. Details of the physical characteristics of switch operation have been described in previous publications(2-4).

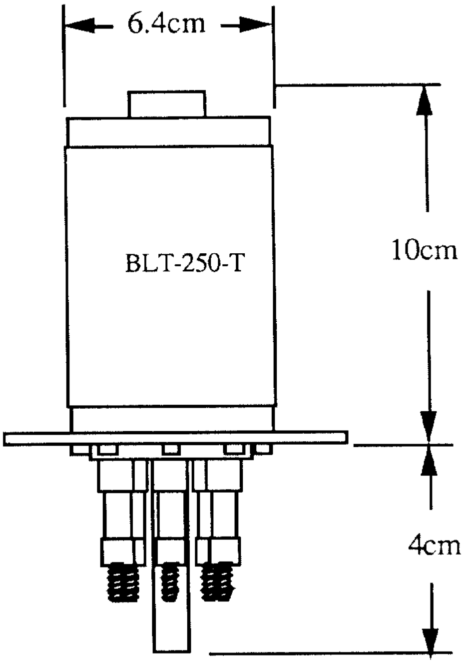

Figure 1. The BLT-250-T switch tested in this work.

The switch design tested in this work was a hermetically sealed BLT switch of ceramic-metal construction (figure 1). The electrode structure consists of an anode (top in figure 1) which is connected to the circuit using three 1/4-20 mounting bolts and a cathode which is connected by means of an 11cm diameter mounting flange. All triggering electrodes are behind the cathode and therefore do not interfere with implementation of very low inductance circuit connections to the anode and cathode.

Below the cathode mounting flange are electrical connections for triggering and the internal gas reservoir. The electrically triggered tetrode BLT-250-T is capable of operation at up to 40kV, 20kA, at an anode heating factor of several 10^{10}V·A·Hz. Average power, and current ratings have not yet been determined but are expected to be compatible with present accelerator requirements.

The BLT switch has been evaluated in several test circuits. For this work pulse forming networks (PFN) producing fast rising square pulses were constructed. Two different implementations of a Type E pulse forming network were used to give an impedance at the one ohm and six ohm level. At the 1 ohm level two 2 ohm lines are used in parallel each made up of 4 parallel 1nF ceramic capacitors per section and parallel plate conductors to provide the low ~16nH inductance of each section, 40 sections are used to give a 400nsec pulse(5). At the six

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ohm level two 12 ohm lines are used in parallel each made up of 2nF ceramic capacitors per section and a solenoid wound using 1/4 inch diameter copper tubing on a 6.5cm diameter air core with three turns per section giving ~300nH/section, 11 sections are used to produce a ~600nsec pulse. The main emphasis of our work was the performance of the switch therefore in both cases the PFNs were not optimized for pulse shape, overshoot compensation or impedance matching. The PFNs used were sufficient to demonstrate the risetime and peak current capabilities of the BLT switch. A schematic diagram of the BLT switch and test circuit are shown in figure 2.

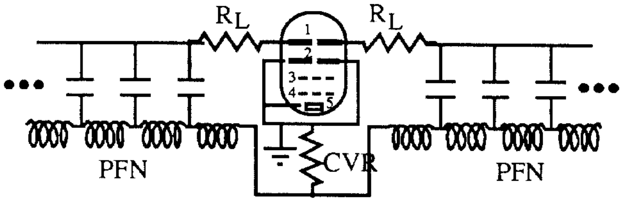

Figure 2. Schematic diagram of BLT switch and test circuit 1) anode, 2) cathode, 3) G2, 4)G1, 5) reservoir.

The BLT is triggered using two triggering electrodes, G1 and G2. A DC bias of +50 to 200 V is applied to G2 to enhance voltage holdoff capability, for triggering a pulse of 3-6kV is applied to both G1 and G2. G1 can be used as a preionization electrode by applying a positive pulse of 1-5µsec duration prior to triggering G2. The hydrogen pressure in the switch is maintained at ~350mtorr by applying 0.65V, 2.6A ac power to the reservoir. A higher reservoir current results in lower triggering jitter, delay and power dissipation but also reduces the voltage holdoff of the BLT, therefore an optimum reservoir current must be determined for each specific set of operating conditions.

III. RESULTS

The BLT switch has been operated at up to 17kA at 30kV with <60nsec risetime in the ~1 ohm PFN and 1.5kA at 20kV with <18nsec risetime in the ~6.5 ohm PFN. In both of these circuits the switch was not limiting the risetime. In a 1.25 ohm, 100nsec PFN the BLT was operated at up to 240Hz at 20kV for short periods of time (minutes) and and continuously (several hours) at 20kV and 120Hz for a total of >2X10^7 shots with no degradation of performance.

The current waveform obtained with the 1 ohm PFN is shown in figure 3. This current trace was obtained at 30kV at 1Hz. A slight load mismatch resulted in a peak current of about 17kA, followed by current reversal, the rate of rise was 2.5x10^{11}A/sec, the 40 section PFN results in a very flat pulse shape and the measured current pulse shows no ripple that can be attributed to the switch.

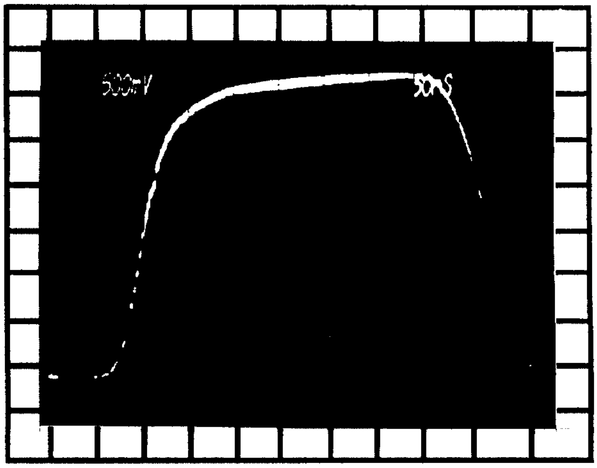

Figure 3. BLT switch current obtained in the ~1ohm PFN at 30kV, 50nsec/div horizontal, 2.5kA/div vertical.

In kicker magnet systems the current must rise quickly from zero to 100%, no prepulse can be tolerated. In early BLT switch tests we have observed a prepulse behavior where the current would rise slowly from 0 to ~15% before exhibiting a circuit limited risetime to full current, in some cases this prepulse was 50 to 100nsec long. We have eliminated this prepulse effect through the use of a preionization pulse before triggering the main discharge.

The BLT-250-T was tested in a 1.25 ohm, 100nsec PFN this pulse length was sufficient to study the BLT risetime. First electrodes G1 and G2 are connected together biased to +50V and triggered with a short 3-6kV pulse, the resulting waveform in figure 4 a, shows a short prepulse rising slowly to 1kA. To eliminate the prepulse a long 3-5µsec positive pulse is applied to G1 to initiate a preionization discharge in the hollow cathode space before triggering the main discharge with G2.

This triggering method results in the current waveform of figure 4 b, showing no prepulse and a circuit limited risetime from 0 to 6kA of <50nsec. Triggering jitter obtained was <5nsec. These results show the strong dependence of switch behavior on triggering circuits used. With careful design of triggering circuits jitter of 1nsec or less should be obtainable.

Most accelerator systems are designed at higher impedance levels due to circuit size and component constraints, Results obtained with a 6.5 ohm PFN have demonstrated that the BLT performs well at these impedance levels. Figure 5 a, shows the current obtained at 20kV, the PFN was not optimized for pulse shape and therefore shows overshoot and ripple. The current shape does not differ greatly from computer modeling results(6) for a similar PFN indicating that the BLT switch is not limiting the performance of this circuit. Figure 5 b, shows the current in this circuit with better time resolution to show the <18nsec risetime. The current shows a smooth rise with no prepulse. The rise from zero to top of overshoot is ~30nsec. The time from zero current to after the overshoot is still <50nsec indicating that with proper circuit compensation the risetime requirement of the SSC LEB can be obtained with the BLT switch.

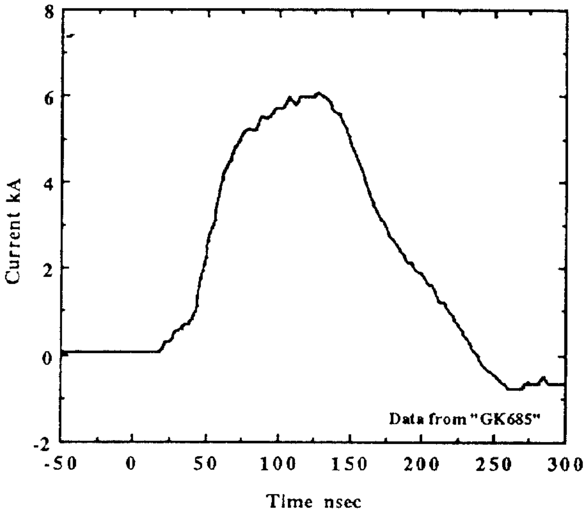

Figure 4a. BLT current pulse exhibiting slow prepulse behaviour.

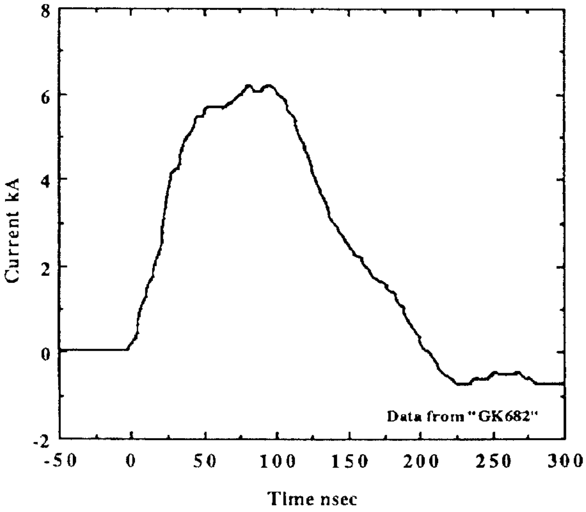

Figure 4b. BLT current pulse with no prepulse obtained using preionization before triggering. Current rises from 0 to 6kA in <50nsec

IV. CONCLUSION

A BLT switch with performance capabilities suitable for particle accelerator systems including fast kicker magnets has been demonstrated. With careful design of PFN and triggering circuits performance required by the SSC LEB kickers could be obtained with the BLT switch. The high current capability allows the possibility of driving several systems in parallel switched by a single BLT. Additional work is required to more accurately define the performance of the BLT switch in areas of lifetime, average power, and triggering.

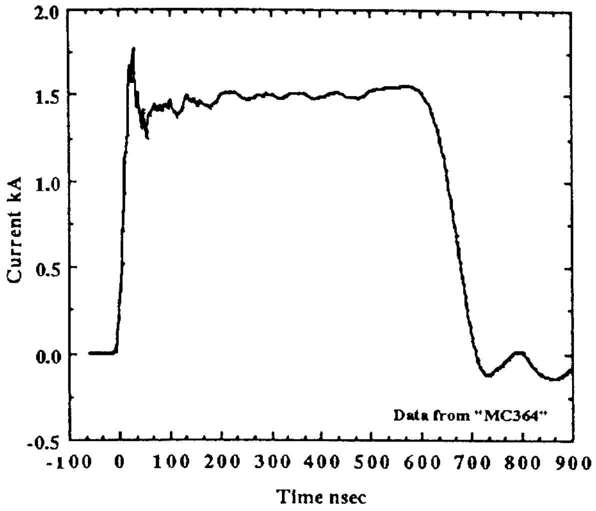

Figure 5a. BLT current pulse obtained in 6.5 ohm PFN.

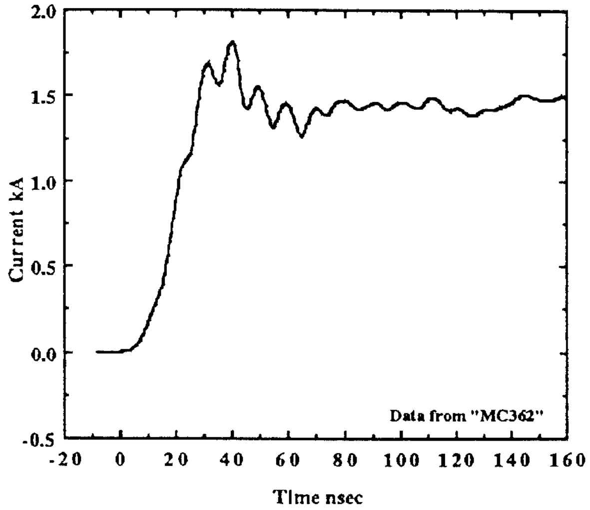

Figure 5b. BLT current in 6.5 ohm PFN showing <18nsec risetime.

V. REFERENCES

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