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Investigation of UV Laser Triggered, Nanosecond, Surface Flashover Switches

W. C. Nunnally, R. Neurath, C. Holmes, S. Sampayan and G. Caporaso

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INVESTIGATION of UV LASER TRIGGERED, NANOSECOND, SURFACE FLASHOVER SWITCHES *

W. C. Nunnally#, R. Neurath, C. Holmes, S. Sampayan and G. Caporaso
Lawrence Livermore National Laboratory
Livermore, CA 94550

Abstract

Triggered, multi-channel, surface discharges or surface flashover switching have been investigated as a low inductance, low pulse rate switch for conducting large currents. This paper discusses the investigation of UV (355 nm) laser triggered, single channel, low inductance, ns closure and sub-ns jitter switches for applications in switching high dielectric constant, compact pulse forming lines into accelerator loads. The experimental arrangement for evaluating the switch performance and for measuring the high field dielectric constant of the pulse forming lines is presented. Experimental results of delay and jitter measurements versus optical energy on the flashover surface and dc electric field charge.

I. INTRODUCTION

Induction accelerators require the generation of a number of high power pulses in a precise, prescribed sequence for coupling electrical energy into a particle beam. This process thus requires the charging of a large number of pulse forming energy storage systems and the closure of a large number of high current, high voltage switches with precise timing to generate the power pulses.

A. Pulse Generation Structure

In a compact accelerator, one method of embodying a single pulse system is to combine a solid dielectric pulse forming energy storage network and the switch into a single unit as illustrated in Fig. 1. The next step is to replace the electronic switch with a surface flashover in the same location.

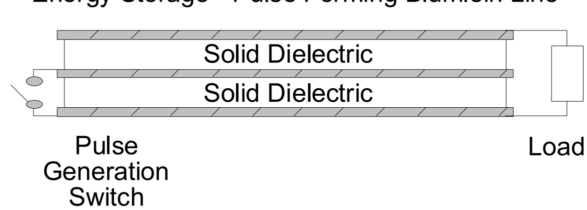

Figure 1. Blumlein Pulse Generator

B. Surface Flashover switching

In order to initiate the surface flashover or surface conduction at a precise time, the surface flashover can be initiated with a UV laser pulse as illustrated in Fig. 2.

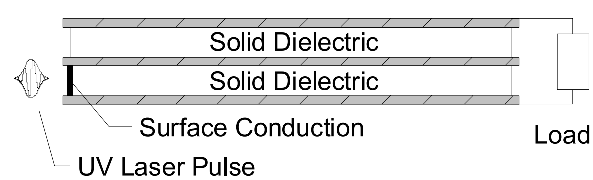

Figure 2. Surface Flashover Switch

II. EXPERIMENT DESCRIPTION

The surface flashover switch experimental arrangement characterized the UV triggered switch behavior and the parameters of the solid dielectric materials.

A. UV Laser Triggered Surface Flashover Switch

The mechanism for UV laser initiated surface switching is surface absorption of laser optical energy that local increases the surface temperature which subsequently results in gas desorption from the surface. The desorbed gas density at the surface, initially too large for gas breakdown through electron avalanche. The desorbed gas thermalizes and expands into the vacuum until the conditions are appropriate for gas breakdown or the product of the gas pressure and the electrode separation match the Paschen breakdown conditions. Since the electrode distance is fixed by the switch geometry, the pressure of the expanding gas region and the electric field across the electrode separation determine the switch behavior. The gas expansion time should therefore be observed as a delay in the gap closure after the optical pulse arrives at the switch surface.

The optical pulse used in these experiments is a 355 nm pulse with a Full Width Half Max (FWHM) duration of approximately 5 ns. The optical energy was varied from 1 to 5 mJ. The optical energy was focused with a

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cylindrical lens to form a linear image with a width of approximately 100 microns that spanned the electrode gap. The optical energy incident on the surface is estimated from the total optical energy and the fraction of the total line image determined the electrode gap. The range of optical energy density was approximated to be in the range of 0.5 to 1.5 mJ/mm^2.

The assumed gas breakdown voltage, V_{BD}, behavior

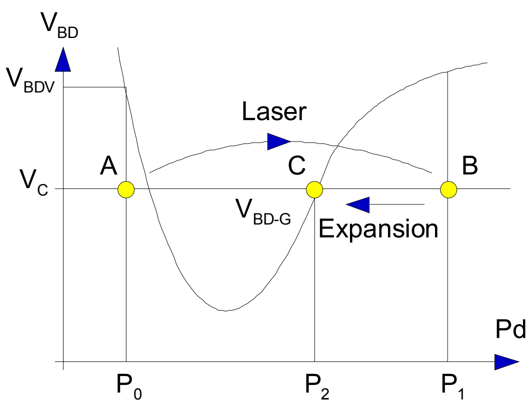


Figure 3. High Pressure Paschen Breakdown Curve

versus the product of gas pressure, P, and electrode separation, d, is illustrated in Fig. 3 The initial status of the surface switch geometry, is below the vacuum breakdown voltage at point A. The absorption of the laser pulse and the rapid gas desorption increases the surface pressure to P_1 at point B where the gas pressure breakdown is well below the Paschen breakdown curve. Gas expansion then moves the pressure to point C where the gas breakdown occurs and the switch closes. In this pressure range, the gas discharge should be a filamentary discharge due to the local gas pressure.

The discharge was also observed to be diffuse in some instances. This diffuse discharge behavior is assumed to be due to the cleanup of the surface after a number of laser pulses and before the surface could reabsorb the

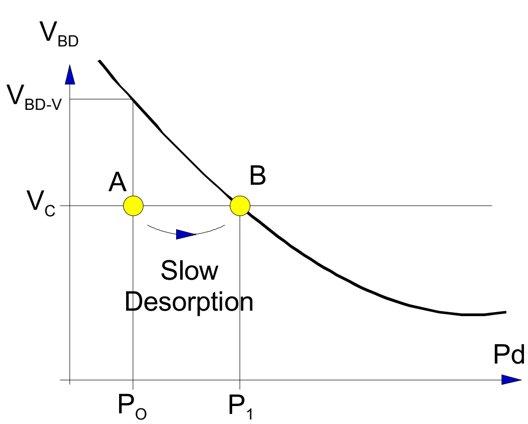


Figure 4. Low Pressure Paschen Breakdown Curve

background gases or adjacent gas density through diffusion. In this case, the breakdown path is thought to follow the pattern illustrated in Fig. 4. After a number of laser pulse – discharges, the surface is assumed to be devoid of a large amount of absorbed materials. Thus, after the absorption of the laser pulse at the surface, a low rate of desorption gradually increases the surface pressure to the point where low pressure, vacuum breakdown is possible, which results in a diffuse discharge.

B. Surface Switch Geometry

The vacuum switch experimental geometry, illustrated in Fig. 4, was used to determine the closure delay and jitter of an insulator surface flashover, initiated by a tripled Nd:YAG laser pulse with a wavelength of 355 nm. A large charging resistor was used to charge the capacitance of 2.7 nF which served as the energy driving the surface discharge.

A square sample of the insulator material was placed between two stainless steel electrodes as illustrated in

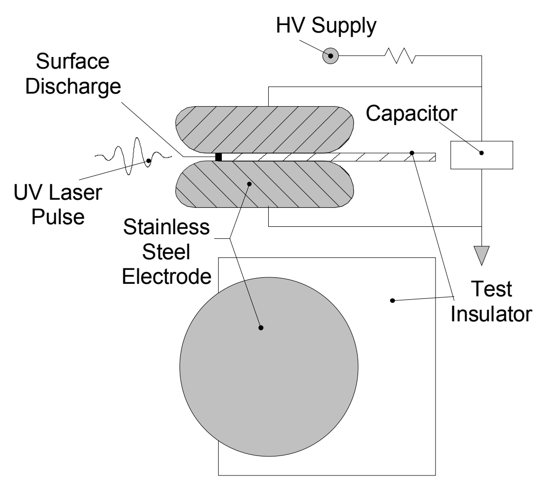


Figure 5. Surface Switch Experimental Geometry

Fig. 5. The square sample allowed many tests per sample and the angle of the edge with respect to the electrode surface was altered for the experiments. The best insulator material for this application was determined to be Lexan. Other insulators, including NPO Titanium Dioxide or T_iO_2 and Duroid™, were evaluated. Lexan demonstrated the greatest resilience to laser damage and surface arc damage and thus the longest surviving material. The NPO T_iO_2 and Alumina materials developed metallic conducting paths on the surface due to the presence of multiple discharges along the surface. The Duroid™ material also developed conducting paths on the surface after only a few discharges. The insulator samples and the experimental system were evacuated to background vacuum pressure was 5x10^{-6} Torr .

The specific geometry of the insulator – electrode investigated in these experiments is illustrated in Fig 6.

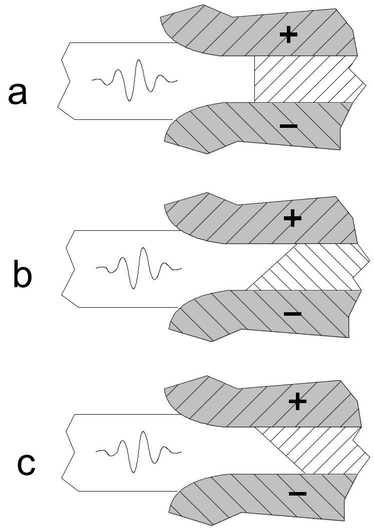
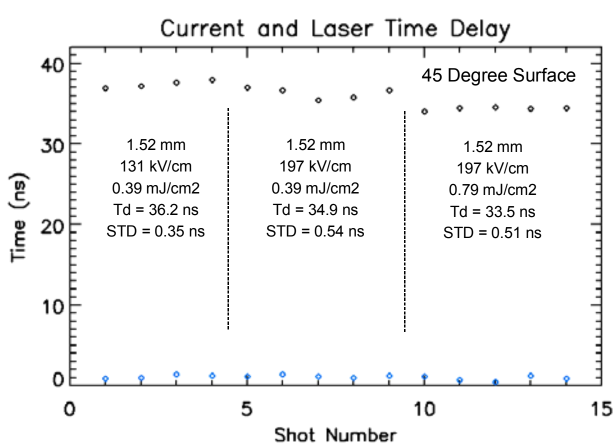


Figure 6. Electrode-Insulator Geometries

III. EXPERIMENTAL RESULTS

The time of optical pulse arrival at the surface and the time of closure (current rise) were recorded and the average time delay and Standard Deviation in the time delay calculated to define the temporal jitter. The cable length difference in the optical detector and the current probe on the capacitor discharge was 6 ns.

The raw data for a 0.06 inch (1.52 mm) with a 45 degree surface sample is illustrated in Fig. 7. The electrode- surface geometry is the "c" geometry of Fig. 6. The laser delays are plotted at the bottom of the graph in Fig. 7 and the time of current initiation or switch closure plotted in the top portion of Fig. 7. Note that the delay decreases slightly with increasing energy density, but the standard deviation increases with energy density in the 45 degree surface switch.



The raw data from a more extensive set of experiments with a 0.06 inch (1.52 mm) switch and a 90 degree switch surface is plotted in Fig. 8. The electrode geometry is the "a" geometry of Fig. 6.

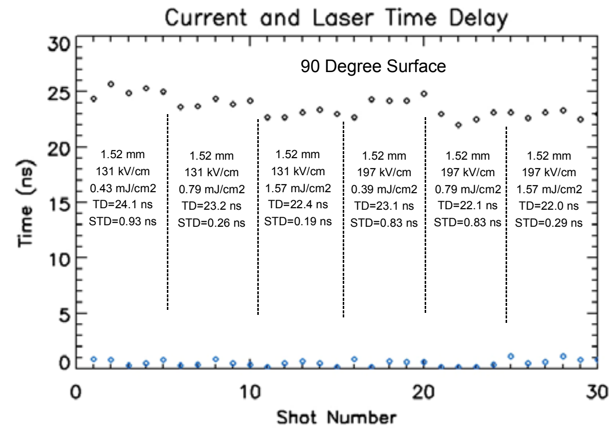


Figure 8. 90 Degree, 0.06 Inch Switch Data

The standard deviation in the time delay after laser pulse arrival is less than 1 ns for optical energies greater than 0.5 mJ/mm^2 for all the electric field values recorded in these experiments.

The raw data for a larger 0.24 inch (6.1 mm) 90

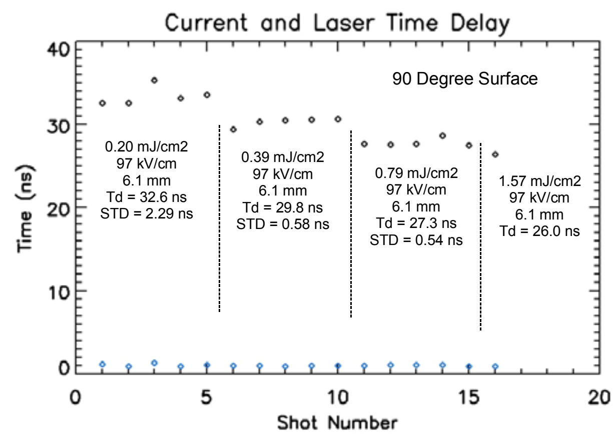


Figure 9. 90 Degree, 0.24 inch Switch Data

degree sample is shown in Fig. 9. Note that the delay decreases slightly with increase in optical power density at a constant surface electric field. Also note that the delay times are longer for the 0.24 inch switch than the 0.06 inch switch.

IV. CONCLUSIONS

The time delay between laser pulse and switch closure (current rise) and the standard deviation of the delay or temporal jitter from all the ray data is compared in Fig. 10 and Fig. 11, respectively.

The basic result of this study is that UV initiated surface flashover switch closure can be initiated with a delay on the order of 20-30 ns at an energy density on the order of 0.2 to 1 mJ/cm^2 with a resulting time jitter on the order of a single ns.

In addition, the 90 degree surface switch delay was less than that of the 45 degree switch surface. The trend observed in the delay and the time jitter after laser absorption on the insulator surface is that both decrease as the optical energy density is increased.

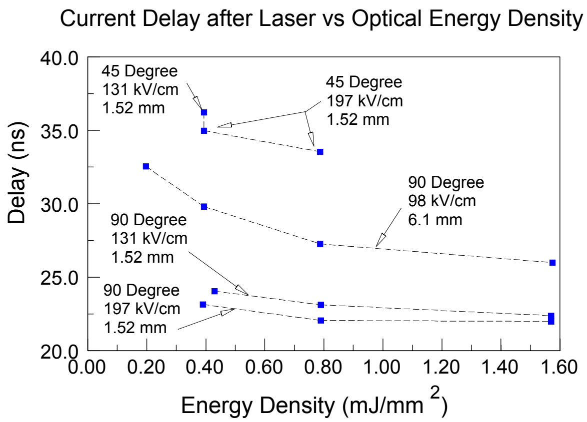


Figure 9. Time Delay vs. Optical Energy Density

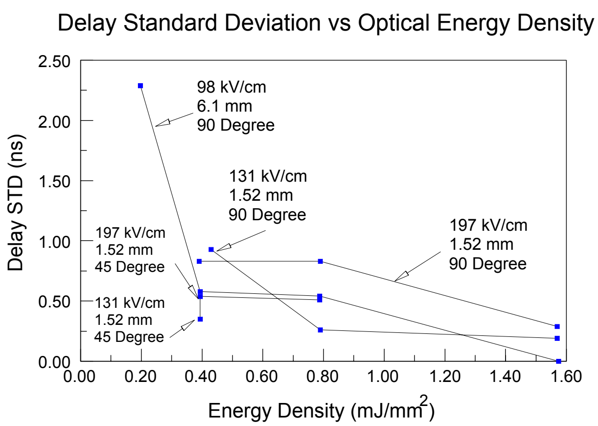


Figure 10. Closure Jitter vs. Optical Energy Density

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