THE LINEAR PSEUDOSPARK: A HIGH CURRENT PSEUDOSPARK SWITCH

J. Lehr, J. W. Benze, W. R. Cravey, H. Pak, A.E. Rodriguez, C. M. Young
Tetra Corporation
3701 Hawkins Street, NE
Albuquerque, New Mexico 87109

ABSTRACT

High power switches are important components in virtually all pulsed power systems. Pseudosparks have exhibited most of the desirable properties: high repetition rate, long life, a high voltage standoff, and impressive rates of current rise. Pseudospark switches, however, are limited in their high current capability. A novel Pseudospark device, called the Linear Pseudospark, is being developed as a high performance switch. The research is concentrating on high current and multiple series gap operation.

INTRODUCTION

A novel approach of increasing the current carrying capability of the class of gaseous closing switches which operate in the superdense glow mode has resulted in the development of the Linear Pseudospark Switch. While performance of the state of the art switches in this class is impressive, the current carrying capability, can be pushed higher. The LPS has achieved this through modification of the geometry.

The class of switching devices based on the superemmissive properties characteristic of hollow cathodes include the Pseudospark Switch and its optically triggered cousin, the Back-Lighted Thyratron. For simplicity, these devices are referred to herein as PseudoSpark Switches, PSS. The PSS's exhibit high values of a large crossection of the desirable switching parameters. For instance, typical value for the rate of current rise in PSS technology is on the order of 10^{11} A/s. This is comparable to that of a commercially available thyratron. However, the PSS can stand 100% current reversal and 100 kA while the thyratron switches 10 kA with a 10% reversal[1]. As such, the PSS encompasses those applications which need the fast switching available with thyratrons but at higher power levels.

Commercial high power PSS devices switch 20 kA at 40 kV for repetition rates of 100 Hz[2]. The advancement PSS technology mandates the development of higher power capabilities. This may be accomplished by increasing the holdoff voltage, the switched current or the operating repetition rate. A quick recovery time is a feature of PSS, and is already acceptable for many pulsed power applications. As such, the research for pushing the high power envelope of these devices has centered on the VI characteristics.

To date, a method for increasing the blocking voltage has been developed. A comprehensive study of several configurations was reported by Hsu, et.al.[3]. Stacking several PSS, so a series arrangement results, increases the static holdoff voltage. The value of such an arrangement is illustrate by the following: The limit for single PSS gap operation is quoted at about 50 kV[4]. Under pulse charge conditions, standoff voltages of 700 kV have been achieved.

To be a serious competitor for high pressure spark gaps, PSS must demonstrate considerable current carrying capability. The efforts to this end, spearheaded by the researcher Mechtersheiner[5], have centered on developing multichannelling techniques for PSSs. Multichanneling, as in high pressure spark gaps, is desirable in high coulomb transfer applications. The current is divided in some way, such that each channel carries only a fraction of the peak current. Some success has been achieved in this arena: Michel, et. al.[6], reported a radial mulltichanneled pseudospark device which switched up to 400 kA. These impressive results, however, come at the expense of a high incidence of prebreakdowns.

The Linear Pseudospark demonstrates that elaborate schemes to increase the current carrying capability are unnecessary. A change in the geometry of a PSS results not only in increased coulomb transfer, but also, improved performance. As previously stated, the crucial parameter for the PSSs is the peak current, however, this must be accompanied by maintenance of the static voltage holdoff for truly pushing the high power performance of the device. In this paper, experimental and theoretical results are reported which show the Linear Pseudospark achieves the promise of high deliverable currents while maintaining the static holdoff voltage.

THE LINEAR PSEUDOSPARK: DEVICE OPERATION

Pseudosparks operate in the low pressure, high voltage regime, where values of the reduced electric field, E/N, are on the order of 10^6 Td. In this regime, the electronic mean free path is of macroscopic dimensions. For the Pseudospark, the interelectrode gap is made to be on the order of the electronic mean free path. These electrons then, do not contribute to the ionization of the gas. A long path, however, is available (see **Figure** 1) at the aligned apertures in the electrode plates. This long path allows an electron to collide with the fill gas, resulting in a plasma. The plasma reacts to the applied voltage, and switching occurs. The plasma discharge generated in the hollow electrode is diffuse, ensuring low erosion, until it constricts to pass through the holes in the electrodes. When the plasma constricts, it's temperature increases accordingly, lowering the discharge resistance, which results in low switch losses.

The Linear Pseudospark (LPS) elongates the aperture of the conventional Pseudospark into a slot. The differences between the Linear Pseudospark and the PSS is illustrated in **Figure** 1. The length of the slot, increased the surface area through which the charge carrying plasma passes, increasing the current.

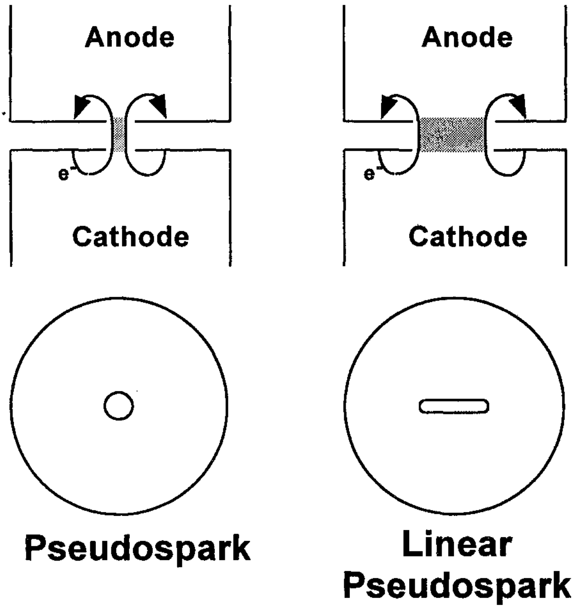

Figure 1. Comprises of normal pseudospark with new Linear Pseudospark.

The unique feature of the LPS is the use of the geometry to increase the peak current without degradation of its other attributes, particularly the holdoff voltage. In PSS devices, enlargement of the cathode hole radius decreases the blocking voltage of the switch. This effect is illustrated in **Figure** 2, after Pak[7]. The benchmark for the LPS in this paper is to illustrate the feasibility of the LPS technology by demonstrating discharge uniformity and significant voltage holdoff.

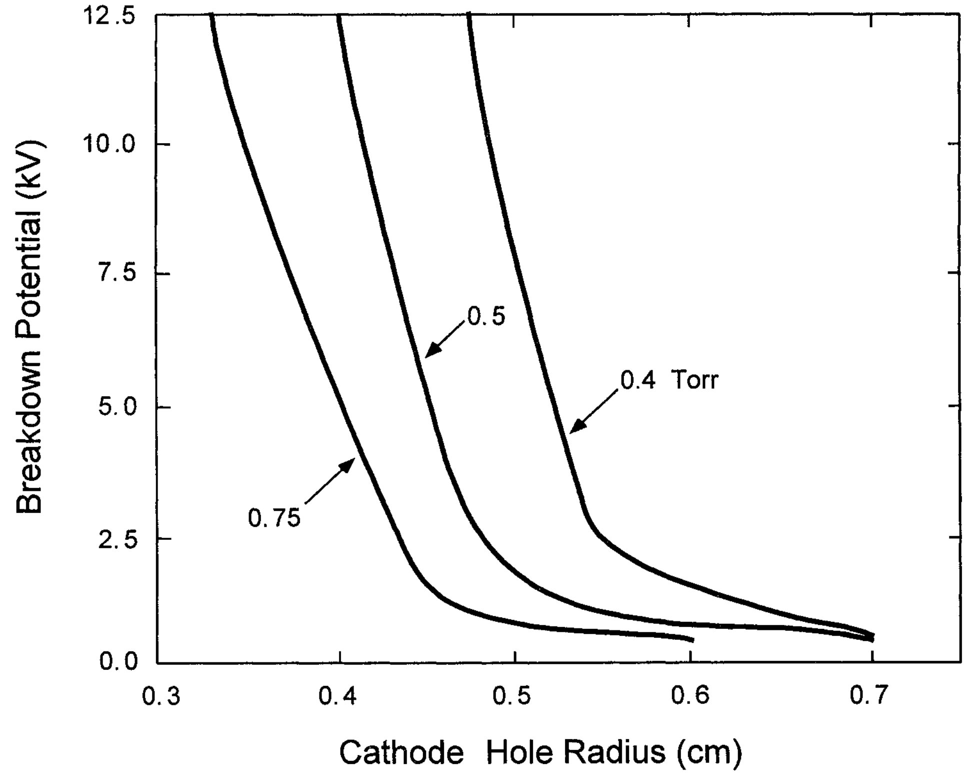

Figure 2. Breakdown voltage as function of cathode hole radius for conventional PSS.

MODELING JUSTIFICATION FOR LINEAR PSEUDOSPARK

In order for the Linear Pseudospark to be successful, the holdoff voltage of the switch must be maintained, relative to the circular aperture. That is, for a circular aperture of a certain size, a slot of the same width must be able to holdoff a comparable characteristic holdoff voltage. It had been postulated that a linear slot would result in considerable field enhancement at the ends, resulting in a strongly nonuniform discharge. To this end, the equipotentials of the two geometries were plotted: an aperture and an infinitely long slot. It was observed that the equipotentials are no less uniform than in the aperture. The electrode voltages were arranged to give a potential of 100 V at the line of symmetry between the two electrodes. To the first order, the greater the penetration, the lower the breakdown voltage. For the circular aperture, the 1 V contour penetrated 2.7 mm into the grounded hollow electrode, while the same contour for an infinitely long slot penetrated nearly 4 mm into the grounded region. This argues that a slightly lower holdoff voltage is anticipated. To fully investigate the effects of the geometry, the equipotential plot for an infinitely long slot with a width of just half the diameter of the original aperture was performed The penetration of the 1 V contour line is substantially reduced, and the holdoff voltage was greater than that of the aperture. The plot indicated the holdoff voltage is influenced by the width of the slot. Both parameters were referenced to their aperture counterparts. When the slot width is equal to the aperture diameter the potential is 2.5 times greater for the linear slot than for the circular aperture. This implies that to get the same potential for the slot and aperture, the slot width must be about 75% of the aperture diameter. This simple theoretical argument illustrated that voltage holdoff may be retained by elongating the aperture and permitted the experimental efforts to proceed.

EXPERIMENTAL RESULTS

Low Current Testing

Because the Linear Pseudospark is a new and unproved device, the first order of business is to verify the existence of the crucial features of the Linear Pseudospark: namely, the preservation of the blocking voltage and the uniformity of the resulting discharge. Initial testing used a helium test gas of pressures less than 1 Torr. The immediate parameters to be determined are the interelectrode gap, the backfill gas pressure range, and the blocking voltage. High current testing will commence with the parameters set by the low current tests. Of particular interest is the maximum slot length, that is, the minimum slot length which produces a nonuniform discharge.

The test setup consists of a 40 KVDC power supply which charges a small capacitor (0.1-10) microfarads, through a charging resistor. The LPS is connected in parallel to the capacitor and the voltage is monitored at this connection point.

To investigate the influence of the length of the slot, and to insure a fair comparison, slots of various lengths are tested with a reference aperture of diameter equal to the width (0.3175 cm) of the slot. In PSSs, it has been shown by Pak and Kushner[8] that the standoff voltage decreases with increasing aperture diameter. Preliminary testing was done with slots of length 1.5875 cm and 3.175 cm. The results of these tests are reported below.

The Vacuum Self Breakdown Test

To find the intrinsic limit of the device, a vacuum blocking voltage test was performed with each of the electrode faceplates in place. The pressure, measured with a Pirani gauge, was typically $1\text{-}4\times10^{-4}$ Torr. In all configurations, the device was found to exceed the 40 kV capability of the power supply.

Self Breakdown Test

The self breakdown characteristics were verified for two slot lengths as well as a reference aperture as well as for two interelectrode gap spacings (2.4 mm and 4 mm). The reference aperture has a diameter of 0.3175 cm, which is also the width of each slot. The length of the initial test slots were chosen to be 1.27 cm and 2.857 cm.

The variation of the self breakdown voltage with Helium fill pressure is shown in **Figure 3** for the slot of 1.27 width. Helium pressure was investigated in the pressure range from 100 mT to 750 mT. Characteristically, the blocking voltage increases rapidly with decreasing gas pressure. From this plot, the operating pressure range can be inferred: The switch is only viable when operated at a helium fill pressure below 200 mT. The features of the discharge depend on the gaseous dynamics, and hence, this pressure range is unique for each gas. The self breaking voltage for the conventional aperture (PSS) as well as the two initial test slots is shown in **Figure 4** for the 4mm anode-cathode gap. Note that no discernible voltage degradation is indicated throughout the tested pressure range. This important facet verifies that altering the pseudospark geometry does not necessarily result in degradation of the static holdoff voltage.

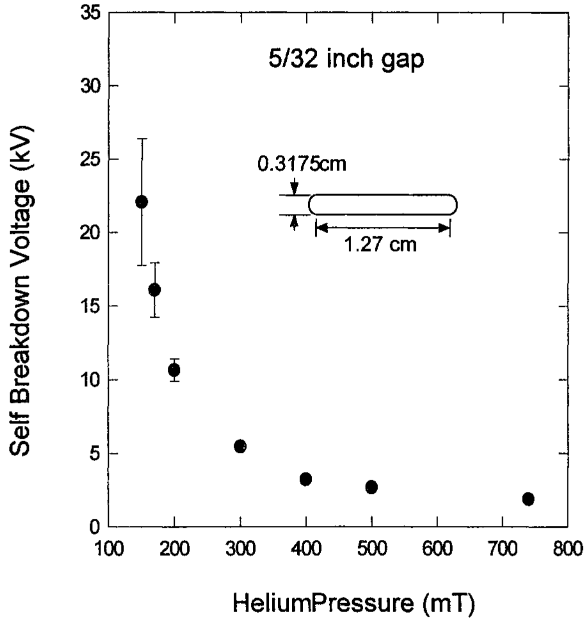

Figure 3. Plot of self-break voltage as function of pressure.

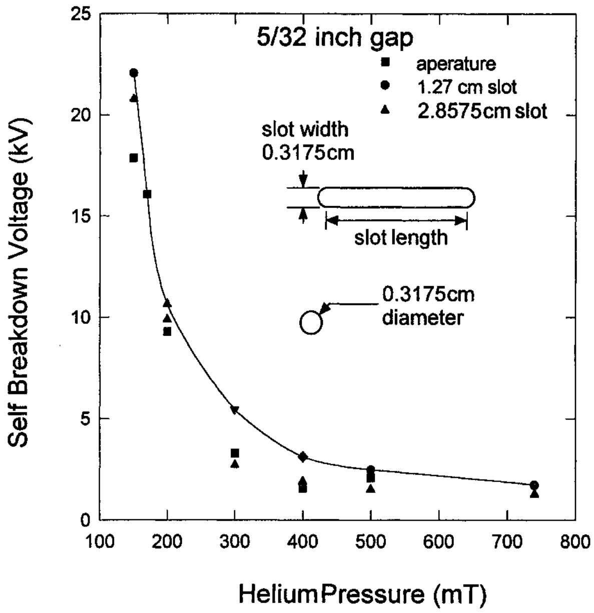

Figure 4. Self-break voltage as function of pressure for various slot lengths.

Experimental results indicate the LPS consistently discharges uniformly through the center slot. As such, the modified geometry of the LPS seems to eliminate several problems associated with the PSS:

- The aperture tended to breakdown along the rim, sputtering metal from the electrode onto the insulator. This is a well documented problem with PSSs, but is overcome in many PSSs by implementing complicated electrode configurations. The LPS consistently discharged through the center slot and metallic sputtering from the electrodes was not observed.

- The LPS consistently discharged through the center slot in sealed off conditions, which is favorable for commercial development. The conventional PSS would discharge through the aperture when the backfill gas was flowing. During sealed conditions, the discharge would occur along the rim. Other researchers[8] have also noted that the favorable conditions resulting from the pressure gradient

The LPS operation was determined to necessitate a helium pressure less than 200 mT. At these low pressures, however, the self breaking voltage jitter is high. This jitter, however, can be dramatically improved by reducing the interelectrode spacing. The increased field strength in the vicinity of the slot obligates the development of the discharge, reducing jitter. Self breakdown voltage curves were generated with two anode -cathode gas spacings: 2.4 mm and 4 mm. The average values of the blocking voltage for the two gaps are insignificantly different, however, the standard deviations for the 2.4 mm gap are significantly smaller.

Uniformity Studies

Of essential importance to switch operation, especially at very high currents, is the uniformity of the discharge. A non uniform discharge will not have an advantage over conventional PSSs.

Discharge uniformity is essential to LPSS operation: without uniformity, LPS has no technical merit over the conventional technology. Note, however, that because of the inherent properties of the superdense glow, such a discharge is not in danger of constricting to an arc. This is a manifestation of the dynamics which occur to the left of the paschen minimum. Initially ,the luminosity produced during the self breakdown tests were used to determine discharge uniformity. Photographs taken at several pressure and slot lengths indicate discharge uniformity. Bright white spots occasionally appear along the slot length, superimposed with the discharge luminosity, indicating the unrefined electrode may not be optimized. However, with both the test slot lengths, the plasma was distributed uniformly along the slot. When luminosity studies were attempted with the flashlamp trigger source, the trigger light masked the luminosity of the discharge. Presently, a technique to photograph the discharge perpendicular to the plasma velocity is being devised.

Future Work

A high voltage, high current test bed is presently being constructed. Design parameters are for 50 kV, 100 kA operation.

CONCLUSIONS

The principle of operation of the Linear Pseudospark has been demonstrated, with very encouraging results. We have shown the static standoff voltage does not degrade with the geometrical change required to increase the peak current capability of the Linear Pseudospark. A Monte Carlo code has predicted the discharge luminosity is a function of the slot length. Preliminary experiments have confirmed the modeling predictions.

The Linear Pseudospark shows great promise as a very high power switch. Initial tests have demonstrated the high voltage is maintained despite the alteration of the geometry which promises very high current capabilities. The Linear Pseudospark arises as the major challenger to high pressure spark gaps for high power applications.

ACKNOWLEDGMENTS

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