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Plasma-Puff Initiation of High Coulomb Transfer Switches

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Abstract

The plasma-puff triggering mechanism based on a hypocycloidal pinch geometry was investigated to determine the optimal operating conditions for an azimuthally uniform surface flashover which initiates plasma-puff under wide ranges of fill gas pressures of Ar, He and N_2. The optimal fill gas pressures for the azimuthally uniform plasma-puff were about 120 mTorr < P_{opt} < 450 Torr for He and N_2. For Argon 120 mTorr < P_{opt} < 5 Torr for Argon. The inverse pinch switch was triggered with the plasma-puff and the switching capability under various electrical parameters and working gas pressures of Ar, He and N_2 was determined. It was also shown that the azimuthally uniform switching discharges were dependent on the type of fill gas and its fill pressure. A new concept of plasma-focus driven plasma-puff was also discussed in comparison with hypocycloidal pinch plasma-puff triggering. The main discharge of the inverse pinch switch with the plasma-focus driven plasma-puff trigger is found to be more azimuthally uniform than that with the hypocycloidal pinch plasma-puff trigger in a gas pressure region between 80 mTorr and 1 Torr.

In order to assess the effects of plasma current density on material erosion of electrodes, emissions from both an inverse-pinch plasma switch (INPIStron) and from a spark gap switch under test were studied with an optical multichannel analyzer (OMA). The color temperature of the argon plasma was approximately 4,000 K which corresponded with the peak continuum emission near 750 nm. There are the strong line emissions of argon in the 650 - 800 nm range and a lack of line emissions of copper and other solid material used in the switch. This indicates that the plasma current density during closing is low and the hot spot or hot filament in the switch is negligible. This result also indicates considerable reduction of line emission with the INPIStron switch over that of a spark-gap switch. However, a strong carbon line emission exists due to vaporization of the plastic insulator used. In order to reduce the vaporization of the insulator, the plexiglass insulating material of INPIStron was replaced with Z-9 material. A comparative study of the INPIStron and a spark gap also reveals that the INPIStron, with a low impedance of Z = 9 ohms, can transfer a high voltage pulse with a superior pulse-shape fidelity over that of a spark gap with Z = 100 ohms.

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I. Introduction

New developments in high pulse power systems, such as lasers, intense relativistic electron beam accelerators, and fusion devices, often require electrical switching capabilities beyond what are currently available. The requirements for a high power switch are, in general, fast rise time, high current handling capability, fast recovery time (which affects the repetition rate), fast thermal energy dissipation, free from component damage, and high hold-off voltage. In addition, reproducibility of switching action and a long lifetime are particularly emphasized for space application of magnetoplasmadynamic (MPD) thruster technology.

Spark gap switches, commonly used for high pulse-power commutation, have short lifetimes because of severe electrode heating from which surface erosion occurs. Yet this switch still covers the highest transfer range. Also the important requirement of a fast recovery time has not been successfully realized in the spark gap.

One approach to providing a high coulomb transfer switch having a longer useful life, higher current capability and faster switching than those of existing high power switches has been developed by Lee (U. S. Pat. No. 4475066). The inverse pinch structure is designed to carry high currents with significantly reduced erosion of electrodes and to reduce the inductance of the switch by using coaxial current paths. Preliminary results show that the peak current handling capability was larger than 350 kA at a hold-off voltage of 14 kV when fill gas pressure of N_2 was 10 mTorr. An upgraded design for an inverse pinch switch was recently reported to meet the requirements for the output switch of an ultra-high-power (>30 GW) pulser. The hold-off voltage of 1 MV is met by adopting multistage rim-fire electrodes and using SF_6 as the dielectric gas of the switch.

For the inverse pinch switch, the initial uniform breakdown is a key factor for obtaining reproducibility and for long-life operation. Accordingly, the development of an inverse pinch current in the switch depends on the trigger mechanism. In the preliminary experiment, the triggering of the switch was provided by a pin-type or ring-type third electrode, and azimuthally uniform initiation was limited to a narrow range of working gas pressures. By using the trigger pins with a trigger pulse having 100 ns rise time, a switching phase reproduction of less than 20% at a pressure of 10 mTorr was observed. This indicated that a fast trigger pulse was required to increase the reproducibility. The wear of the trigger pins was eminent and the switch therefore had a short lifetime.

In this research, a new triggering mechanism called "plasma-puff" was designed and investigated to determine the operating conditions for a wide range of filling gas pressures of Ar, He and N_2. A prototype of the plasma inverse pinch switch with plasma-puff trigger was tested[10] to characterize the hold-off voltage, the anode fall-time, the switch resistance, the energy dissipation, the recovery time, and the V-I phase relation with a high current load of 0.5 MA. The plasma-puff trigger electrode was coaxially located under the main gap electrode pair and initiated gap breakdown by injecting annular plasma rings into the gap. The major advantage of the plasma-puff trigger was a circumferentially uniform current sheet formed by the initial surface discharge which in turn could initiate a uniform annular breakdown over the insulator in the main gap of the inverse pinch switch. The plasma-puff triggering device was constructed in a hypocycloidal pinch geometry and drove the current sheet (plasma) radially inward into the annular gap of the main electrode. The plasma driven by the current sheet, i. e., the plasma-puff, produced electrons and ions for the main gap breakdown.

Another new triggering concept of a plasma-focus driven plasma-puff was designed and tested to determine the operating conditions and to optimize this system for azimuthally uniform switching discharges for a wide range of fill gas pressures of Ar, He and N_2. The trigger electrode in this geometry was coaxially located above the main gap electrode pair and insulated by teflon from the main gap electrode. The plasma-puff triggering device was in a plasma-focus geometry and drove the current sheet axially downward and radially inward into the annular gap of the main electrode. The plasma-focus driven plasma produced electrons and ions for the main switch breakdown.

Details for characteristics of switching in an inverse-pinch switch are found in Appendix 2 and Appendix 3.

II. Summary

The plasma-puff triggering mechanism based on a hypocycloidal pinch geometry and a plasma-focus Mather geometry was investigated to determine the optimal operating conditions for an azimuthally uniform surface flashover which initiates plasma-puff under wide ranges of fill gas pressure of Ar, He and N_2. The optimal fill gas pressures for the azimuthally uniform plasma-puff were about 120 mTorr $< P_{opt} <$ 450 Torr for He and N_2 and 120 mTorr $< P_{opt} <$ 5 Torr for Argon. The inverse pinch switch was triggered with the plasma-puff and the switching capability under various electrical parameters and working gas pressures of Ar, He and N_2 were determined. It was also shown that the azimuthally uniform switching discharges were dependent on the type of fill gas and its fill pressure. The main discharge of the inverse pinch switch with the plasma-focus driven plasma-puff trigger was proved to be more azimuthally uniform than that with the hypocycloidal pinch plasma-puff trigger in a gas pressure region between 80 mTorr and 1 Torr.

A hold-off voltage greater than the test voltage used here will be required for the inverse pinch switch for future applications. It might be necessary to adopt a multi-ring and multi-gap arrangement to obtain the optimal switching operating conditions for such high voltage applications.

An extended study of the INPIStron for pulse transfer fidelity and efficiency revealed the INPIStron as the superior performer over the reference spark gap. Also material erosion as compared with the emission spectra of the closing plasmas in the two switches, showed considerable differences which indicated the low current density and low material erosion in the INPIStron. These findings again confirm the superiority of the INPIStron already found with respect to other parameters associated with high powers switches such as the voltage hold-off, Coulomb transfer, lifetime, material erosion, and repetition rate.

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IV. List of all Participating Scientific Personnel

Period : March 1, 1989 - June 30, 1993

D. D. Venable	(Principal Investigator)	March 1, 1989 - present
K. S. Han	(Principal Investigator)	March 1, 1989 - present
E. H. Choi	(Research Associate)	March 1, 1989 - Feb 28,1990
Y. K. Kim	(Graduate Student)	Sept. 1, 1989 - May 30, 1990
J. H. Kim	(Graduate Student)	June 1, 1990 - May 30, 1992
D. X. Nguyen	(Graduate Student)	Sept. 1, 1991 - Present

Yong K. Kim completed his Master of Science degree in July of 1992. His M. S. thesis title was "Comparative Study of Closing Plasma in Inverse Pinch Switch".

Jong H. Kim completed his Master of Science degree in July of 1992. His M. S. thesis title was "Plasma Dynamics in a Hypocycloidal Pinch Device".

Dung X. Nguyen will complete his Master Science degree in the Fall of 1993.

V. List of Progress Reports Submitted

1. Annual Progress Report: Period Feb 1, 1989 - Feb 28, 1990

2.. Annual Progress Report: Period April 1, 1990 - March 31, 1991

3. Annual Progress Report: Aug. 9, 1991- Aug. 6, 1992

VI. List of Conference Papers

Presented

Period March 1, 1989-June 30, 1993

1. Eun H. Choi, Demetrius D. Venable, Change S. Han and Ja H. Lee, "Characteristics of Plasma-Puff Trigger for an Inverse-Pinch Plasma Switch", Bull. ASP Vol. 35, No. 4 1051 (1990)
2. Ja H. Lee, E. H. Choi, D. D. Venable and Change S. Han, "Ultra-High-Power Plasma Switch INPUTS for Pulse Power Systems", 25th Intersociety Energy Conversion Engineerging Conference (IECEC) Proceeding. Vol. 1, 414-419 (1990).
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