Design and development of a high current pseudospark switch for pulse power applications

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Abstract

A relatively low current rating 25 kV/5 kA Pseudospark switch (PSS) has been developed at CSIR-CEERI [1]. Recently it has been realized that for high power applications a radial channel PSS is the right choice [2] while a coaxial PSS is better suited for medium power applications. In a radial channel PSS, the discharge spreads to several discharge channels radially that provides for self-cancelling of the magnetic fields induced by the discharge, and thus prevents discharge constriction and provides for very high current conduction. It utilizes linear discharge apertures (length greater than width) in the electrodes. The linear aperture provides over significantly higher current conduction without discharge constriction than round-hole pseudospark switches.

The electrostatic simulation of the geometry has been carried out using Omni Track software to analyze voltage penetration through the linear apertures. To study the voltage profile, discharge phenomenon and dynamics of charged particles in the PSS, a particle-in-cell simulation code "Oopic-Pro" has also been used. The simulation results have been applied as a feedback to design and develop this PSS on the specified parameters. A demountable high current pseudospark switch with radial discharge channel has been developed and ready for experimentation.

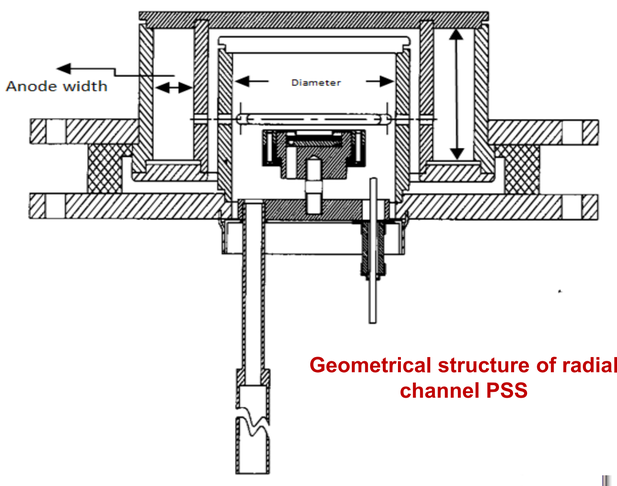
Motivation and Objectives

- A Pseudospark switch can overcome the limitation of life time, electrode erosion in earlier commercial switching devices like ignitrons, thyratrons, spark gap when operated at large charge transfer.
- The high current rating PSS are of great importance in many pulse power applications like pulse modulator, shock wave generation, mine blasting, radar, laser, etc and are in great demand. Such PSS are presently being imported for various applications and have always been a subject to import restriction, causing hurdles in Indian effort, for advancing technologies in high energy research area.
- Therefore, the main objective of this work is to design and develop a radial multichannel PSS with more diffused discharge, allowing the device to transfer large amount of coulomb transfer rate.

Introduction to High Current Pseudospark Discharge

- Pseudospark discharges are created in special geometric arrangement and operated on the left side of Paschen's minimum in Paschen curve. When they are transferring high current of several kA, they are operated in super dense glow mode.
- The access to high current can be achieved by making use of multichannel arrangement, where the current is distributed over a large area.
- In this work a radial multichannel switch with linear aperture exhibiting a special geometry is being developed, where the problem of erosion can be minimized.

Design and Development



Geometrical structure of radial channel PSS

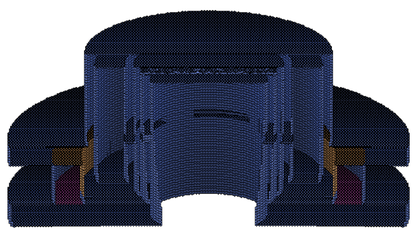
- Gap width =3 mm
- Aperture width= 2.5 mm
- Electrode thickness =4 mm
- Hollow cathode cavity diameter = 48 mm
- Hollow cathode cavity depth= 50 mm
- Hollow anode width = 15 mm

Triggering

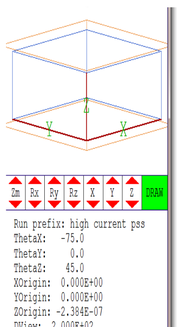
✓Initial seed electrons are provided by the emission from a high dielectric constant (~1500) ferroelectric disk on the principle of ferroelectric emission.

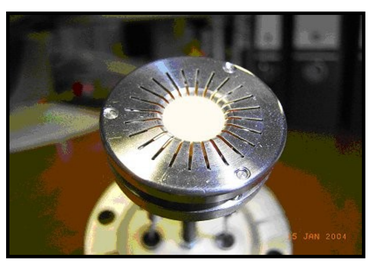
✓A patterned electrode is deposited on the emitting ferroelectric surface.

✓When grided electrode is negatively biased, triple point is formed at junction of vacuum, dielectric disk and grided electrode, resulting in high electric field at the junction responsible for electron emission.

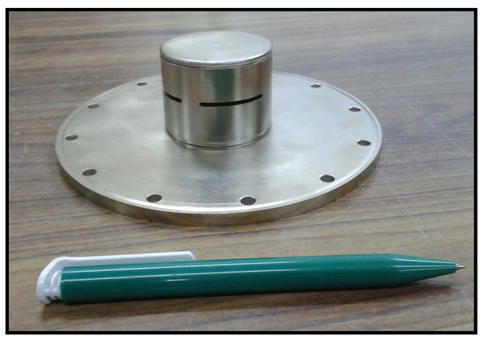


3D view of complete PSS geometry simulated in OmniTrack





Trigger unit



Hollow cathode with linear slot cutting

Results and Discussion

The Electrostatic simulation of the predicted geometry is done by Omni Track Software to know the initial field penetration inside the hollow cathode through the apertures as shown in Fig. 1. The presence of aperture perturbs the potential inside the gap resulting into increased effective gap distance from that of the predicted paschen curve in case of parallel plate electrodes.

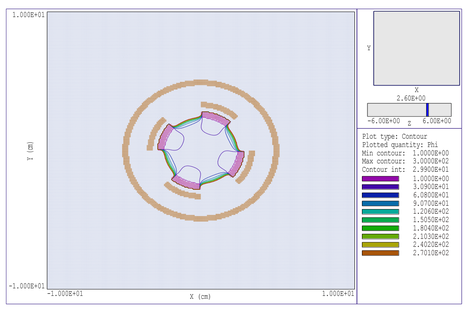


Fig. 1. Geometric voltage profile at 30kV anode voltage and 0V cathode voltage

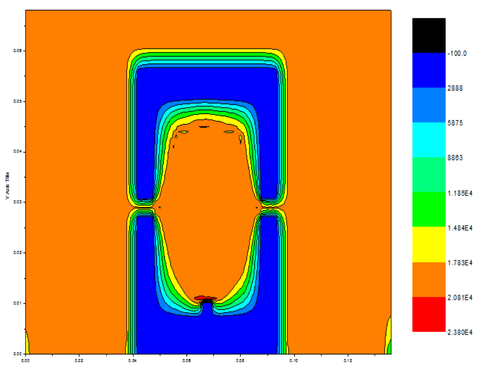
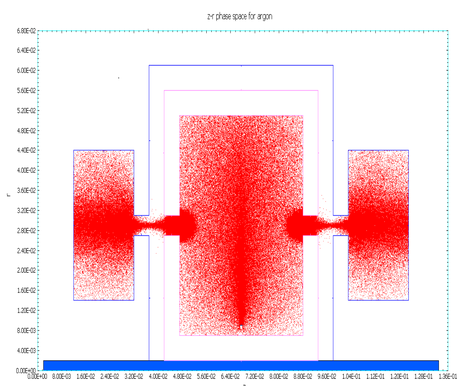
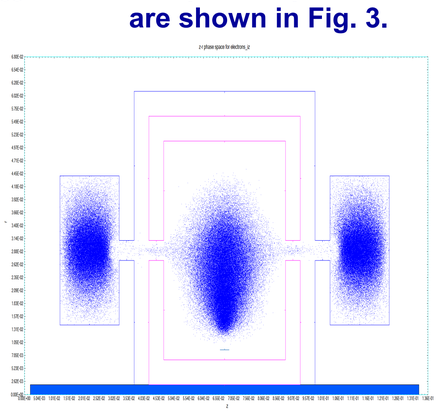


Fig. 2. Voltage penetration inside hollow cathode through aperture in XY cross-section

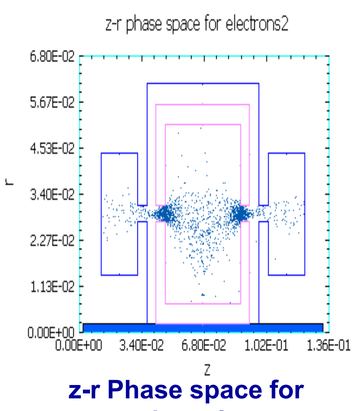
- Four long linear apertures perfectly aligned to each other have been used in cathode and anode instead of round aperture in the simulations.
- Initially, geometric field dominates the space charge field and gradually a virtual anode is formed inside hollow cathode by providing sufficient seed electrons from the ferroelectric emission of high dielectric trigger unit as shown in Fig. 2. This has been obtained using 'OopicPro'.
- In the high current phase, the dense plasma shield the major part of the hollow cathode aperture from being penetrated by the electric field, the cold cathode facing the anode takes over the entire discharge current.
- Field enhanced thermionic emission will be the major contributor of high current.
- The linear channels provides more area to carry discharge current offering low electrode erosion and synchronous triggering of all the radial channels.
- The phase space distribution of electrons and ions are shown in Fig. 3.



z-r Phase space for ions

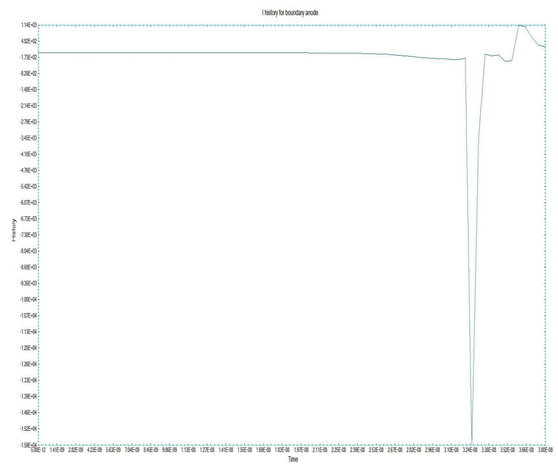


z-r Phase space for primary electrons



z-r Phase space for secondary electrons

Fig. 3



Current received at anode

Simulation parameters

- A 2-D PIC code Oopic Pro has been used to estimate the current and to see the electrodynamic potential profile inside hollow cathode.
- Operating pressure of argon = 30pascal
- Trigger current=5mA
- Trigger current rise time= 30nsec
- Trigger current pulse width=70nsec

Main Inferences

- Around the aperture, the plasma sheath contract near the walls and cathode fall voltage drop of 300-500V will cause high electric field and secondary emission of electrons starts resulting in dip in the current waveform measured at anode.
- When the full applied anode voltage has penetrated inside the hollow cathode during plasma formation, no further charge is collected by the anode and current again comes to zero.
- This is the typical characteristics of high current PSS for its operation.

Conclusion

- A radial channel PSS with linear apertures (length greater than width) has been studied for the development of high current PSS applications.
- The simulations shows that all the channels can be synchronously triggered in this geometry for homogenous distribution of plasma that will result into lesser electrode erosion and increased life time.
- A demountable setup of high current PSS is ready for experimental measurements.

References

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2. U.S. Patent number 6,104,022 (issued August15, 2000).
3. H. Heo, S. S. Park, and S. H. Nam "Experiments with a radial multichannel pseudospark switch for extremely high coulomb transfer," IEEE transaction on plasma science, VOL32, No. 1, FEB.2004.

Acknowledgement

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