Characterization of High Power Pseudospark Plasma Switch (PSS)

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Abstract. The Pseudospark switch is able to control high voltage and high current discharges and operates at low pressure like Thyatron but much simpler in construction and does not suffer in electrodes wear. This switch is bipolar and has 100 % reverse current capability, much faster than Thyatron and has applications in pulse power modulators, linear accelerators, laser systems etc. Such switch has been developed at CEERI Pilani and tested in a demountable setup. For this switch, as a cold cathode based ferroelectric trigger source has also been developed and characterized. High dielectric material has been opted for such a source. The hold off voltage can be doubled if the gap of the electrodes is stacked to two single stage gaps. Such stack of two single stage switches has also been fabricated in a demountable setup. Switching behavior has been observed up to 23 kV and 7 kA in single stage. High voltage conditioning and characterization is still in progress. The paper includes the introduction with working principle, description of the demountable set up, simulation by TriComp, AMaze and OOPIC Pro (Without Comparison among them), and switching behavior.

1. Introduction

Developments in pulsed power technology, especially in the field of high power excimer laser etc, often exceed the capabilities of the commercially available switches such as Thyatron or Spark Gaps. Therefore over two decades, considerable interest has been generated in low pressure switching device with a cold cathode. Such device is known as Pseudospark switch (PSS)\(^1\)\(^2\).

The pseudo-spark is a low-pressure gas discharge on the left branch of the Paschen breakdown curve. This device is mercury free, unlike Ignitron, high pressure Spark gaps for its limited life, and alternative to Thyatron with the advantage of fast rise time and low jitter. Principally the switch is like cold cathode Thyatron with a grounded grid. This device is simple in construction and free from electrodes erosion and comprises hollow cold cathode and anode. Most of the investigations have been done in the literature in the demountable setup. There is now some progress of such device in sealed off state in which the operating pressure is maintained due to attached Hydrogen reservoir\(^3\).

The switch has applications in pulse power generators, producing intense pulsed electron beam for material processing, medical techniques, discharge heated copper vapour laser, and soft x-ray source.

Owing to the symmetric design of the electrodes, 100 % reverse current capability is possible without any failure of Pseudospark switch. The hold off capability of a single gap Pseudo-spark switch is limited by surface flashover and field emission. Scaling the switch into multi-gap switch configuration can perform improvement of hold off voltage.
The Pseudospark is defined as a high voltage discharge which employs a discharge-gap and pressure such that the PD product is smaller than PDmin of the Paschen’s curve, but larger than the PD value of a vacuum discharge. To increase the hold off voltage, Hydrogen, Helium, Deuterium and other inert gases are filled.

The PSS’s essential feature is its closed hollow cathode geometry. The electrons are multiplied very rapidly because of the hollow cathode effect. The multiplication in any other part is considerably low. Therefore PSS’s are usually triggered by electron or plasma injection into the hollow-cathode. The high dielectric trigger unit furnishes all the qualities of a good trigger system. Ferroelectric cathodes are attractive cold electron emission sources, allowing the generation of high electron emission current density up to 100 mA/cm². The cathodes can be handled and operated in poor vacuum conditions and do not require heating or activation process before operation. In the present work, a Pseudospark switch for 25 kV hold off voltage and 5 kA peak current, has been designed, fabricated and has been evaluated for their performance in a demountable setup. Single gap PSS has been upgraded to double gap switch to increase hold off voltage capability from 25 kV to 40 kV. Electrostatic simulators TriComp, AMaze, OOPIC Pro have been used to study electric fields penetration and shape various electrodes.

2. General Operating Principle of Pseudospark Switch

The general operating principle of the switch is shown in the figure 2. The electrode system of the switch consists of a hollow anode and a hollow cathode whose cavity communicates with the main gap through the main axial hole or several holes. In the cavity of one of the electrodes (typically, the cathode), the trigger unit is placed intended to initiate breakdown in the main gap. The main gap spacing is comparable to the borehole diameter for the high current discharge so that high current hollow cathode discharge can take place.

![Fig: 1: Single Stage PSS (Demountable)](image)

![Fig: 2: General picture of Pseudospark Switch, 1-Insulator, 2-Hollow Cathode, and 3-Hollow Anode](image)
3. Fabrication
The fabrication is done to test the device actually it is a demountable fabrication for more flexibilities.

3.1. Demountable setup
The Pseudospark switch mainly consists of a hollow cathode, a hollow anode with axially symmetric radial slots and a trigger source of PLZT material. The electrodes are made of nickel-plated 304L stainless steel material. The Pseudospark switch is housed in a Ceramic cylinder, which serves as an insulator between cathode and anode. The assembly has been assembled on conflate flange in a demountable format. The complete demountable PSS consists of a hollow anode, hollow cathode, reservoir, header, ceramic flange and trigger unit assembly. Hollow anode and hollow cathode assemblies are fabricated of SS components by brazing techniques. The gap between the main electrodes is 2.5 mm. Ultra pure hydrogen is filled of known quantity for the pre calibrated hydrogen reservoir.

Reservoir is a critical component of the device. When heated to around 500°C - 700°C, the reservoir maintains equilibrium of gas pressure inside the PSS. Ceramic insulator is brazed with conflate flange.

3.2. Processing
For the proper operation of the switch, the device after fabrication is mounted on the vacuum pump station. The tube is thoroughly degassed at 450°C for 18 hours. The ultimate vacuum attained this pressure was under 10⁻⁷ mbar. Subsequent to the vacuum processing, ultra pure hydrogen gas of known amount is loaded to the reservoir mounted inside the PSS. The reservoir has been pre-calibrated with pressure and filament power.

3.3. High voltage conditioning
A finished switch assembly needs to be conditioned before starting the performance evaluation, to achieve the desired operating characteristics. The first parameter, which is taken into consideration, is Hold-off Voltage. The conditioning process smoothen the high voltage electrode surfaces inside the Pseudospark switch by self/forced discharges in the tube at low current. Such smoothness on the
electrode surface cannot be obtained to desired order (up to 1 micron level and below) by machining. Therefore, conditioning is a process, preceding any Switch testing process.

4. Simulation Using TriComp

TriComp is a versatile two-dimensional software suite for charged particle optics. It is used for field analysis, which requires three steps- Mesh generation, applying the potential, analysis.

- Applied Potential at Anode = 25 kV
- Cathode Terminal is grounded [0 V].
- Epsilon Value for Insulator = 10.0 & Vacuum Region = 1.0

![Fig: 4.1: Generated MESH]

![Fig: 4.2: Potential Distribution [Max=2.500E+04 V, Min= -2.914E-01 V] & Point calculation at shown point [IEI= 1.428E+04 V/m, IVI= 1.768E+00 V/m]]

![Fig: 4.3 Vector Plot of Electric Field Distribution [Max=3.138E+08 V/m, Min=0.00E+00 V/m]]
5. Simulation Using AMaze
It is a versatile Three-dimensional software suite for charged particle optics. Actually it is 3-D version of TriComp. It is also used for field analysis, which requires three steps- Mesh generation, applying the potential, and analysis.

- Applied Potential at Anode = 25 kV.
- Cathode Terminal is grounded [0 V].
- Epsilon Value for Insulator = 10.0 & Vacuum Region = 1.0

Fig: 5.1: Generated MESH with Insulator

Fig: 5.2: Generated MESH without Insulator

Fig: 5.3: Potential Distribution at X=7.00E+01 mm [Max= 2.54E+04 V, Min= 5.21E+02 V]
6. Simulation Using OOPIC Pro

It is a feature-rich 2-D particle-in-cell (PIC) simulator. It is a dynamic simulator, where we can analyze the movement of electrons and ions and plasma formation, its density, energy etc.

- Applied Potential at Anode = 25 kV
- Cathode Terminal is grounded [0 V].
- Gas= H₂
- Pressure= 1bar
- Trigger Unit: Current Density= 0.100 A/mm², Pulse=10.0 E-09 Sec.

Fig: 6.1: Generated MESH [Light Blue: Anode, Pink: Cathode, Blue: Insulator, Lime: Trigger Surface]
Fig. 6.2: Potential Distribution [Max= 25 kV, Min= -4.10E-02]

Fig. 6.3 Electron Distributions after 4.6955E-09 Sec

Fig. 6.4 Ions Distributions after 5.266E-09 Sec

Fig. 6.5: Total Density of Electrons (Brown Line) & Ions (Blue Line) with respect to Time
7. Breakdown Test
The breakdown test was done at different pressure to find out suitable hold-off voltage for single stage PSS and was found 25 kV breakdown voltage at 30 Pascal.

8. Pseudospark Switch Characterization
Pseudospark devices are operated in a pulsed mode. A capacitor bank is charged for every pulse, prior to discharge. Then the discharge is triggered, draining the capacitors, where after they are recharged. In general there are two methods of controlling the timing of the discharge. One is to apply a voltage just below the breakdown voltage and to use a trigger of some kind, either optical (by shooting a laser pulse through the discharge), or electrical to initiate the discharge. Another method to initiate the
discharge is to apply a voltage greater than that required for spontaneous discharge and to use an electrical inhibitor. The inhibitor increases the voltage required for breakdown. The discharge is then initiated by releasing the inhibitor. Each cycle can be broken down in a number of different phases.

![Test Circuit](image)

**Fig: 8.1: Test Circuit**

![Switching Characteristics](image)

**Fig: 8.2: Switching Characteristics at 23 kV & 7 kA**

- **Green**: Ch-2, 2kA/div, Current
- **Yellow**: CH-1, 10kV/div, Voltage

### 9. Conclusion
Pseudospark switches developed in demountable setup with single gap for 25 kV hold off voltages and 5 kA peak currents respectively, have the capability to switch at designed specifications.
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