Abstract
A modular plasma based double gap pseudospark discharge switch has been designed and developed at CSIR-CEERI Pilani with an intention of generating repetitive pulsed power source. Operation of the developed pseudospark switch is comparable to that of commercially available thyatron switches in the range of typically 50 kV and up to 15 kA. A peak discharge current up to 10 kA has been achieved through a resistive load from the switching of the developed demountable double gap pseudospark at a breakdown voltage of about 40 kV.

Keywords
Pseudospark Discharge, Hollow Cathode, Pulsed Power, Dielectric Trigger

I. Introduction
There is an increasing demand towards the development of repetitive pulsed power in many applications, such as, high power gas lasers, high power microwaves and high power modulators for 3rd generation and 4th generation particle accelerators [1-9]. Productivity, cost and maintainability are important issues in the high power modulators. Beside these, the modulator stability primarily depends on pulse to pulse switching uniformity. Thyatron switches are widely used for such switching applications with their parameters well suited to high peak voltage, high peak current, high rate of current rise, and high efficiency. Manufacturers of thyatron switches for the development of the high power modulators are mainly English Electric Valve Co. (E2V), Litton and ITT Electron Tube Division. Now-a-days, researchers are trying to replace these thyatron switches by the low cost pseudospark switch with more simplicity in design and engineering [8-11]. In fact, there exist many advantages of pseudospark switches over the thytrons like − low standby power, ruggedness to current reversal, and fast rise time current, etc., but still these are not available commercially. Therefore, efforts are being made at CSIR-CEERI Pilani to design and develop pseudospark switches with operating parameters similar to that of thytrons used for pulsed power modulators [1].

A pseudospark switch is characterized as a low pressure gas discharge in a special geometry as shown in Figure 1 (a) [10-11]. The single gap pseudspark geometry consists of two planar electrodes having a typical separation of 3 mm. There is a circular hole in the axis of the electrodes with a diameter of 2-5 mm. There are hollow geometry electrodes at the back of the two holes with a configuration of inverted cup type.

Electrical breakdown of the electrode gap lies on the left hand side of aPaschen curve which is basically a function of pd (pressure times gap distance) for a given gas (hydrogen or helium) as shown in Figure 1 (b) [1, 10-11]. On the left hand side of the Paschen curve, the mean free path for ionizing collision between electrons and gas atoms/molecules is larger or comparable to the electrode gap distance and therefore occurrence of ionization is unlikely. However, due to central boreholes, the discharge starts along a longer distance with a lower breakdown voltage. When electrons are added to the hollow cathode, the ionization avalanche produces homogeneous discharge plasma via pendulum effect and then subsequent rise of the current starts. The phenomenon is known as hollow cathode phase [10-11]. An additional trigger source is also used to provide $10^2$–$10^3$ electrons in the hollow cathode to enhance the hollow cathode phase and efficiently ignite the discharge, thereby decreasing the delay and jitter values of the breakdown.

II. Design and Development
Typical operating parameters of the switches used for the high power modulators in the particle accelerators are 40-50 kV anode voltage, up to 10 kA peak current, 2-6 μs pulse width and with a repetition rate up to 120 pulses per second (pps) [5-7]. The pseudospark design and development has to be adapted for this kind of application. The maximum hold–off voltage capability of the single gap pseudospark as shown in Figure 1(a) is up to 35 kV for its overall lifetime [1, 9-10]. Therefore, a 50 kV switch needs at least two gaps.
A schematic diagram of the modular double gap pseudospark with a drift space region is shown in fig. 2. Here, the technical challenge is for the modified design of the single gap pseudospark geometry as shown in fig. 1 (a) in order to achieve smooth and enhanced plasma coupling between the electrode gaps during switching. Plasma coupling between the gaps is improved with multichannel apertures on each electrode [1, 10]. However, the hold–off voltage of the pseudospark geometry gets reduced due to the penetration of the anode potential with increased apertures in the electrodes. In our design, the hold–off voltage has been improved by well baffling of the electrodes with off–axis apertures.

A trigger module with a high dielectric constant ferroelectric disc has been inserted in the hollow cathode cavity to provide seed electrons for the discharge ignition of the double gap pseudospark geometry. For this purpose, a pulse generator is employed to generate voltage pulse of negative polarity. The negative voltage pulse on the dielectric disc leads to the emissions of electrons to initiate the hollow cathode phase and subsequent breakdown of the pseudospark switch.

**III. Results and Discussion**

The demountable pseudospark was initially evacuated down to the pressure in the range of 10-7 mbar. Then hydrogen gas was inserted inside the pseudospark geometry to measure the self-breakdown voltage as shown in fig. 3. As expected, the self-breakdown voltage of the pseudospark increased as the gas pressure inside it was decreased. The maximum hold-off voltage of each gap exceeded 30 kV at the hydrogen pressure of 40 Pa. Therefore, it can be estimated that the hold-off voltage capacity of the double gap pseudospark is above 60 kV taking into account of both gaps. Figure 3 also shows the self-breakdown voltage measurement for the double gap pseudospark against the gas pressure. It is to be noted that the experimental measurements were limited up to 40 kV due to the power supply and voltage probe.

Switching characteristic of the modular double pseudospark is shown in fig. 4. The peak discharge current is 10 kA through a non-inductive load resistance of 2.7 Ω at the breakdown voltage of 39.5 kV. The current rise time (10–90% of the peak) is 315 ns. The pulse width of the discharge current at full width half maximum (FWHM) is about 2.5 μs. The voltage curve shows a smooth transition of the breakdown between the two gaps. After the discharge ignition of the pseudospark by the trigger pulse, the high voltage gaps have gone into conduction starting with the gap nearest the cathode, followed by almost no delay for the conduction of the next gap. As a result, the second gap withstands the full anode voltage for extremely short time and a sharp breakdown voltage is measured. This kind of discharge transition between the two gaps for the smooth breakdown voltage critically depends on the geometry of the cavity drift space as well as apertures in the electrodes. The delay time from the trigger pulses to the breakdown voltages was in the range of 100 ns.

**IV. Conclusion**

A simple design of the demountable double-gap pseudospark switch with a drift space region between the two gaps is presented. We have demonstrated a peak discharge current of 10 kA through a 2.7 Ω resistive load at a breakdown voltage of 39.5 kV. The
measurement results from the switching of the developed double gap pseudospark indicate its capability as a promising alternative to thyratron switches in the development of pulsed power modulators. There are some experiments still needs to be performed for the pseudospark switch such as delay, jitter and life time.

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References