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# Study on seven channel palm top triggered rail spark gap

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*To date, thorough study does not exist for multichannel operation of field distortion planner spark gaps. There is continuous demand to generate the complex phenomenon of multichannel in spark gaps. Seven channel discharges has been realised with compact field distortion trigger of 40 mJ, 100 V/ns, first of its kind. Spark gap is environmentally sealed and operated under atmosphere pressure. Copper trigger pins are replaced with brass material to enhance the life and uniform discharge. A high speed streak camera is exploited to catch the images of dedicated discharge channels. Streak images are useful to understand the formation of multiple arcs during triggering. Spark gap programming is electrically tested for number of plasma channels. This new concept is implemented by selective hard wiring of trigger pins. It is inferred that the multi-channel switching is beneficial for reduction of inductance (10 nH), increase in peak discharging current (50 kA) and life of 500 shots. It is experimentally confirmed a good life (100 shots) for higher current of 120 kA. Switch is tested without intermediate cleaning or air flushing. All the electrodes assembly and environment sealing is achieved in a palm top size of length: 120mm, width: 65mm and height: 25 mm. This paper presents study of electrode material, programmable seven channels discharge capability, circuit inductance, delay time and plasma channel's jitter using streak photography as a function of test voltage and number of channels.*

***Keyword:*** *High voltage, pulsed power, inductance, plasma channel, spark gap.*

## 1.0 INTRODUCTION

Various high voltage pulsed power applications such as: advanced radiation sources, pulsed plasmas, charged particle beams, electromagnetic launchers, flux compression generation, electromagnetic forming etc. have led to significant advances in high voltage, high current spark gaps [1-3]. An excellent overview of the various spark gap triggering techniques are discussed [4]. Spark gaps are sources of significant inductance and give rise to frequent maintenance in large discharge system [5]. In order to reduce the inductance and to increase the charge transfer, it is preferable to divide the switched current into multiple parallel channels [6]. Many researchers have tried to generate multi-channelling phenomenon using various methods to reduce the inductance and erosion. Multigap switches [7], laser triggering [8], surface discharge switches [9] and plasma jet [10] methods have shown multi channelling with low delay time, jitter and high life. Laser triggered spark gaps are more difficult to fabricate and require complicated large laser system [11]. Multigap and surface discharge switch are comparatively bulky and require trigger pulse of 5 kV/ns. This increases size, energy and complexity of the triggering system [12, 13].

Trigatron spark gap results in high jitter values due to fact that two break down events are required for switch closure. Erosion can be serious problem because the discharge goes to a limited area [14,15]. There are two types of spark

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gaps, which are commonly used in high-voltage switching applications. These are three-electrode spark gap and linear rail spark gap. Three-electrode spark gap is a single-channel closure device with nanosecond jitter characteristics. On the other hand, the rail gap, a multichannel closure device, has low inductance and relatively high jitter provided the trigger pulse rate of rise exceeds nominally 5 kV/ns [16]. Multichannel planner spark gap is also very much in demand in the upcoming new field as Linear Transformer Drivers (LTD) system [12]. Different rating spark gaps are developed in consecutive steps to increase number of discharging channels and its performances.

In this paper, seven channel discharge is realized in field distortion mode with rail gap configuration. Field distortion trigger method is chosen based on cost, complexity and performance [15]. Seven pin trigger gap is realised similar to previous results [17]. Multi pin planner rail spark gap is having both qualities of three-electrode spark gap and planner rail spark gap. Seven channel discharge has been realised with compact field distortion triggering of 40 mJ, 100 V/ns in comparison to 0.4 and 0.75 J [13]. Number of parallel plasma channels are controlled by the number of parallel pins connection to trigger line.

## 2.0 TRIGGER ARRANGEMENT

It is important to capture streak image little before the arc channel built-up. This helps to precisely measure and study the jitter among arc channels during conduction of the spark gap. Total delay time (3.5 μs) is measured between low voltage SCR switching and start of main spark gap conduction current as shown in Figure 1. A pulse generator (Quantum-9520 series) is used to generate two 10V pulses with little lesser delay time (3.0 μs) to the above total delay time. First pulse is fed to spark gap trigger circuit and second delayed voltage pulse is connected to trigger the streak camera. This idea confirms the readiness of streak camera for capturing the start of arc channels during spark gap conduction.

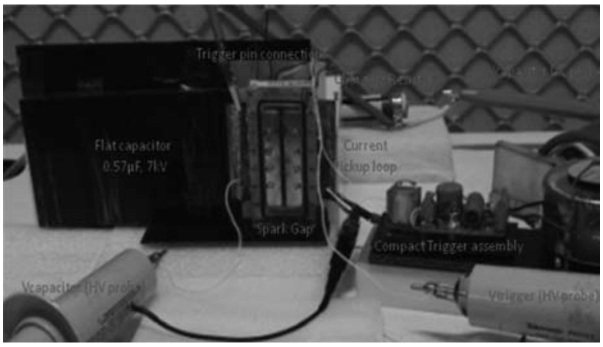



FIG 1. EXPERIMENTAL SETUP FOR MULTI CHANNEL SPARK GAP TESTING

All seven trigger pin connections are taken out from the spark gap assembly for ease and lesser time operation. Two high voltage probes (Tektronics, P-6015A) are connected for capacitor discharge and trigger pulse measurement as shown in Figure 1. Streak camera is placed in front of the spark gap assembly on physically isolated platform. Seven pins were focused at the centre of the 0.1mm slit. Streak mode is activated at sweep rate of 3μs/cm. It is experimentally observed that the cable length between trigger transformer and spark gap should be minimized to ensure low energy loss. Final, trigger pulse applied on spark gap pins is 15 kV, 150 ns (100 V/ns). Switch is environmentally sealed with Nitrialo-ring and multiple screws as shown in Figure 1. Poly Eather Eather Keton (PEEK) material is machined as electrode housing. It provides excellent mechanical and chemical resistance properties during discharge. Perspex is used as top cover plate material in order to have clear visibility during discharge.

## 3.0 EXPERIMENTAL STUDY

Flat-format capacitor is electrically connected with the spark gap using four M3 screws. Low inductance is confirmed by maintaining the flat format transmission line geometry in circuit assembly. Flat copper strip is connected as load to ensure maximum discharge current as shown in Figure 2. The left side of the spark gap is positively charged. All the experiments are operated under atmospheric pressure without cleaning of spark gap body or refreshing the contained air.

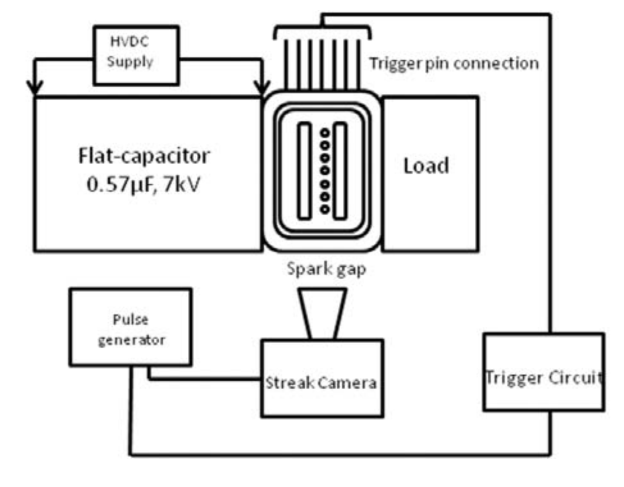



FIG 2. TRIGGER LINES WITH STREAK CAMERA

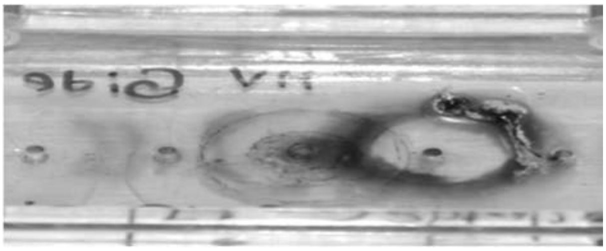


FIG 3. COPPER TRIGGER PIN'S EROSION DUST DEPOSITION AT BASE OF THE SWITCH BODY AFTER 40 SHOTS

### 3.1 Trigger Pin Material Study

Initially, triggered spark gap is assembled with copper trigger pins. There is deposition of copper metal dust on every discharging shot around the insulating base of the trigger pin. It degrades surface insulation resistance to a very low level of ≈100M Ohms. It creates problems of misfiring/pre-firing and does not allow charging of connected capacitor. This shows the end of life of the spark gap after forty shots as shown in Figure 3. Copper trigger pins are replaced with brass material to achieve uniform discharge (50 kA) with life of 500 shots.

It is experimentally confirmed a good life (100 shots) for higher current of 12 kA. This high current is generated using flat format capacitor bank of 20.5 μF at 5.5 kV with circuit inductance of 25 nH and voltage reversal of 70%. It is observed that as the current increases the current distribution is non-uniform and major part of the current is conducted through four plasma channels.

### 3.2 Capturing of Seven Discharge Channels and Jitter

Dedicated seven channels are captured at various voltage levels in a field distortion flat format spark gap,first of its kind. It is observed that all the seven channels are generating up to a very low voltage level of ≈50% to self-break down voltage (SBV) 7 kV. This is a unique feature of this type of spark gap against previous developed spark gaps [12, 16]. Streak images (a) to (d) are captured at different voltage levels as shown in Figure 4. Streak images (a), (b), (c) are captured at 3μs delayed triggering and image (d) is captured at lesser delay at 2 μs to store the initial arc development phenomenon. Initial plasma point is shifting towards left of the images with increment of the test voltage. This confirms the decrease of the switching delay time of the spark gap. Plasma channel's jitter is measured between first and last arc originating point. Jitter values are calculated with help of streak camera software, which provides the vertical cursors. Fast camera is operated at streak length and sweep rate of 2 cm and 3 μs/cm respectively. Full length of streak image is 6 μs and correspondingly jitter is calculated. Jitter among seven channels does not show any fixed trend of variation with test voltage as shown in Table 1. It is inferred that the time period and the circuit inductance values decreases with test voltage increment.

**TABLE 1**

**DELAY TIME OF SPARK GAP AND JITTER AMONG SEVEN CHANNELS WITH VARYING TEST VOLTAGE**

| Sl. No. | Test Voltage (kV) | Delay Time(ns) | Jitter (ns) | Time Period (μs) | Circuit Inductance (nH) |
|---|---|---|---|---|---|
| 1 | 4.0 | 320 | 214 | 785 | 27.38 |
| 2 | 4.5 | 200 | 174 | 780 | 27.0 |
| 3 | 5.0 | 70 | 201 | 685 | 20.8 |
| 4 | 5.5 | 50 | 205 | 645 | 18.48 |

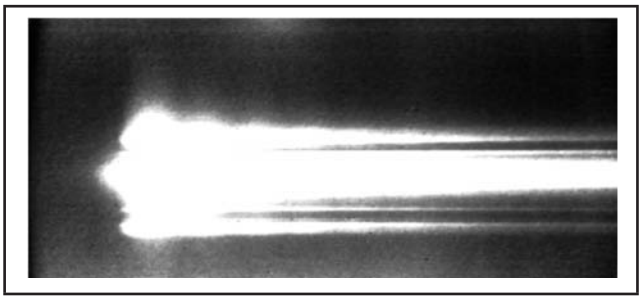
It is also inferred that the central pin no. 4 is always participating first then other side trigger pins start contributing in the discharge as shown in Figure 4. It indicates that the favorable condition for ionisation builds up early at central pin then at outer pins. These results agree with the multi-gap spark gap results triggerd by a large marx generator of 100 kV, 20 ns [12]. These experiments also confirm the formation of arc channels at the rate of 1Channe l/cm, which is first time shown in this type of compact low energy triggering system.

### 3.3 Estimation of Spark Gap Inductance

Inductance of spark gap has been an important feature for microseconds current discharge applications [18]. Inductance of the spark gap is calculated as 10nH by subtracting inductance of capacitor (5 nH, 0.57 μF, 7 kV) and strip line (3 nH) from circuit inductance (18.48 nH). Discharging current, trigger voltage and voltage waveforms of time period 645ns are shown in Figure 5. Inductance values at other voltage levels are similarly calculated as tabulated in the Table 1. Delay time (50 ns) of spark gap is inferred from trigger pulse and current discharging waveforms at 5.5 kV test voltage.

### 3.4 Effect of Plasma Channels

Spark gap is investigated for a new concept of programming for number plasma channels. It is implemented by hard wiring to the pins in trigger plate up to seven channels. A test setup is developed to prove the feasibility of this concept as shown in Figure 2. Streak images are captured for plasma channels of 7, 5, 3 and 1 as shown in Figure 6. Average test voltage is 4.5 kV during above plasma channels experiment. It is inferred that the delay time and inductance of the spark gap is decreasing with increase of number of channels as shown in



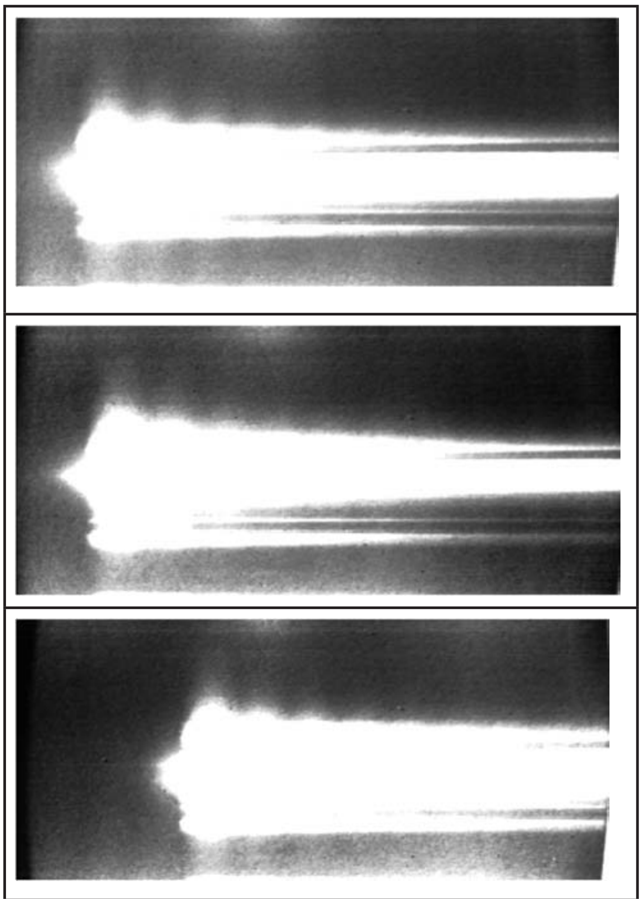


FIG. 4. STREAK IMAGES OF SEVEN CHANNEL SPARK GAP AT (A)4.0KV, (B)4.5KV, (C)5.0KV AND 5.5KV.

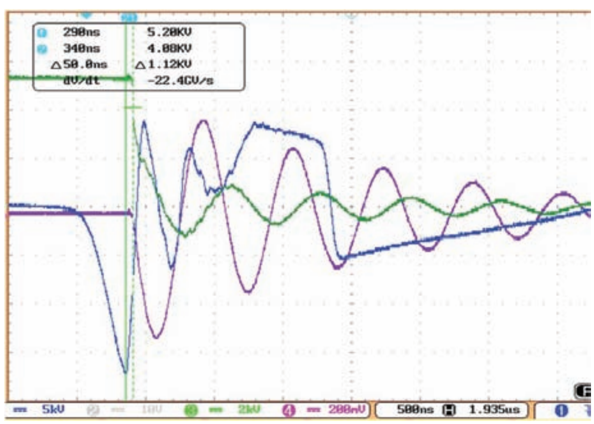



FIG. 5. DISCHARGE CURRENT (RED), NOT TO SCALE), CAPACITOR VOLTAGE (GREEN) AND TRIGGER VOLTAGE (BLUE) DURING ALL SEVEN CHANNEL DISCHARGE OF SEVEN CHANNEL SPARK GAP AT 5.5KV.

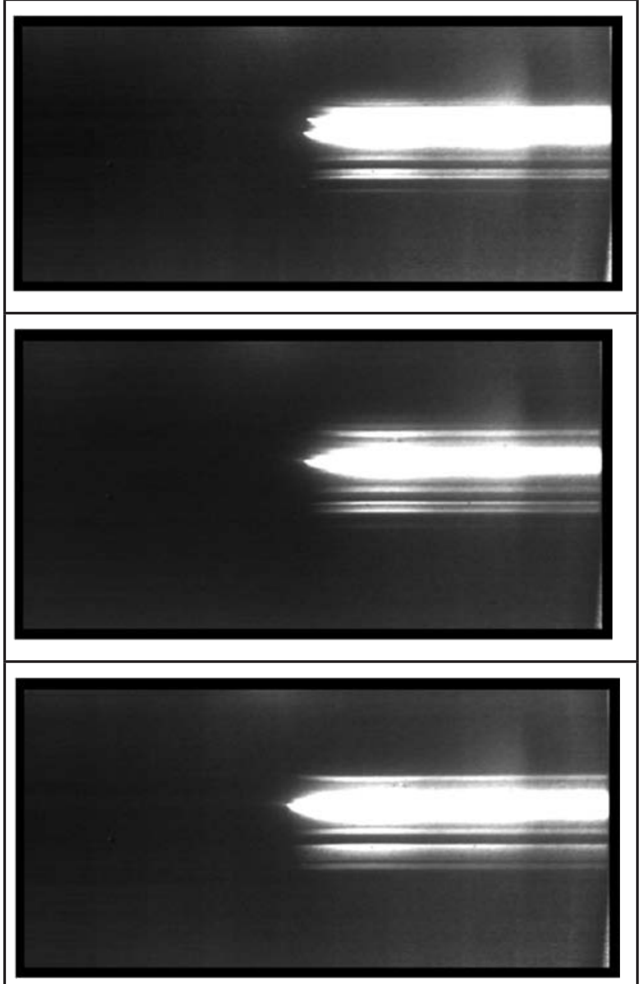
Table 2.Trigger pins are numbered 1 to 7 from top to bottom of the spark gap. Average inductance per channel value has comes out as a useful information. This value is calculated by dividing the number of channels to calculated spark gap inductance value (as discussed in previous

paragraph). Decrease in inductance may be due to the mutual inductance effect or higher channels provide a continuous plasma surface in the discharge gap.

**TABLE 2**

**DELAY TIME OF SPARK GAP, TIME PERIOD OF DISCHARGING CURRENT AND INDUCTANCE VARIATION WITH VARYING NO OF CHANNELS AT 4.5KV**

| Sl. No. | No. of Trigger pins connected | Time period (ns) | Delay Time (ns) | Circuit Induc-tance (nH) | Avg. In-ductance (nH) |
|---|---|---|---|---|---|
| 1 | 7 (All pins) | 695 | 25 | 21.8 | 1.91 |
| 2 | 5 (1,3,4,5,7) | 740 | 55 | 24.3 | 3.26 |
| 3 | 3 (3,4,5) | 760 | 100 | 26.6 | 6.20 |
| 4 | 1 (4) | 770 | 145 | 26.4 | 18.3 |



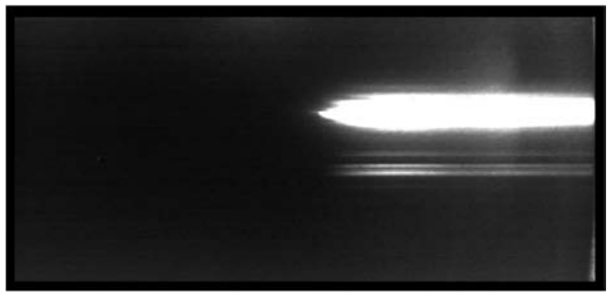


FIG. 6. STREAK IMAGES FOR VARIED NUMBER OF TRIGGER PINS CONNECTION(A)7-PINS, (B)5-PINS, (C)3-PINS AND (D) 1-PIN AT AVG. VOLTAGE OF 4.5KV

## 4.0 CONCLUSION AND SCOPE OF FUTURE

Dedicated seven channel formation is realised with compact field distortion triggering 40mJ, 100 V/ns in comparison to 0.4 and 0.75 J [13]. Trigger circuit and environmentally sealed spark gap are developed with a compact palm top size: 50 mm x 50 mm x 25 mm and 120 mm x 65 mm x 25 mm respectively. Seven channel discharges close to the return parallel plate configuration confirms low inductance of 10nH. Multi-channels are captured up to a very low test voltage (4 kV) 50% of SBV. It is generally recommended to operate the spark gap close to SBV and with 5kV/ns trigger pulse to get the multi-channel operation of a spark gap [12]. Jitter among plasma channels does not have any correlation with test voltage. Spark gap has been operated at high currents of 120 kA and 50 kA for 100 and 500 shots respectively without failure. Life can be extended for more than 1000 shots by intermediate cleaning of the stainless steel main electrodes, brass trigger pins and insulating base of the spark gap. A new concept of hard wired programming of spark gap is investigated. Development of multiple dedicated plasma channels motivates for further research in this area. It is experimentally inferred that the inductance and delay time decreases with increment of the spark gap channels. The formation of arc channels and its effect on switch inductance may be studied with different gases and pressure levels. Spacing of the trigger pins can be varied and checked for its optimized value for no. of plasma channel, inductance and size.

There is an opportunity to further investigate for increase in plasma channels with low energy 40 mJ, 100 V/ns trigger system.

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