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HIGH REPETITION RATE MINIATURE TRIGGERED SPARK SWITCH

M. F. Rose and M. T. Glancy

Naval Surface Weapons Center
Dahlgren, Virginia 22448

Abstract

A miniature triggered spark switch designed to operate at high repetition rates has been constructed. The device, along with associated trigger circuitry, has been incorporated into a simple L-C generator which produces an oscillatory discharge at a frequency of 150 MHz. The switch is operated in the pressure range 760 torr - 2.6×10^3 torr using commercial dry nitrogen as the working gas. Both brass and aluminum electrodes were investigated for repetition frequencies as high as 20 kHz and for gas flow rates as high as 8 cm^3/sec. The effect of repetition rate on switch jitter and switch breakdown voltage is presented and discussed in terms of gas pressure and flow rate.

Introduction

High repetition rate switching in the region greater than 10 kHz can be accomplished by thyratrons, and in some cases, vacuum gaps. Unfortunately, these techniques often suffer from jitter or inductance problems. A quenching spark gap, however, appears to be one of the simplest and most efficient devices for this purpose, if fast turn on and low losses are desirable. The general idea of a quenching switch is one which has a large (> 10) A/d ratio and additionally, a small value of d. The quenching action is based upon the fact that small plasma volumes can maintain good electrical conductivity in the small gap spacing very soon after initiation of the switch process. After the driving potential has been removed, the small plasma volume can quickly recover. Excess thermal energy associated with the gap dissipation can be transferred to the switch electrode surfaces or blown from the system with sufficient gas flow. It is difficult, however to provide an adequate trigger mechanism to take advantage of the high repetition rate in applications which demand precision pulse spacing. Single stage switches of this type have gap spacings no more than a few mils which make it difficult to design and implement a "third electrode" trigger of the trigatron type. The purpose of this paper is to describe the operating characteristics of a simple, high repetition rate, quenching spark switch, under gas flow, when configured as part of a small hertzian generator of the type described by Moran[1] and by others in this conference[2].

Experimental

Figure 1 shows a cross-sectional view of the oscillator and the switch. The device has circular symmetry and is held together using several nylon bolts. The pressure collar is made of plexiglass and is sealed to the switch electrodes via o-rings. The electrodes are 1.02 cm in diameter, giving an A/d ratio of approximately 50. In addition, the electrodes are removable for examination of wear and other electrode effects[2]. For our experiments, we have investigated both brass and aluminum electrodes with 6 mils gap spacing.

The electrodes are provided with a gas inlet immediately in the center of one of the switch electrodes and gas flow outlet holes located around the periphery of the other electrode. Figure 2 shows a schematic of the gas flow and pressurization scheme. While we realize that the configuration is probably not optimum from a gas dynamic point of view, it offers minimum inductance a desirable characteristic for our application.

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14. ABSTRACT

A miniature triggered spark switch designed to operate at high repetition rates has been constructed. The device, along with associated trigger circuitry, has been incorporated into a simple L-C generator which produces an oscillatory discharge at a frequency of 150 MHz. The switch is operated in the pressure range 760 torr - 2.6 x 103 torr using commercial dry nitrogen as the working gas. Both brass and aluminum electrodes were investigated for repetition frequencies as high as 20 kHz and for gas flow rates as high as 8 cm3/sec. The effect of repetition rate on switch jitter and switch breakdown voltage is presented and discussed in terms of gas pressure and flow rate.

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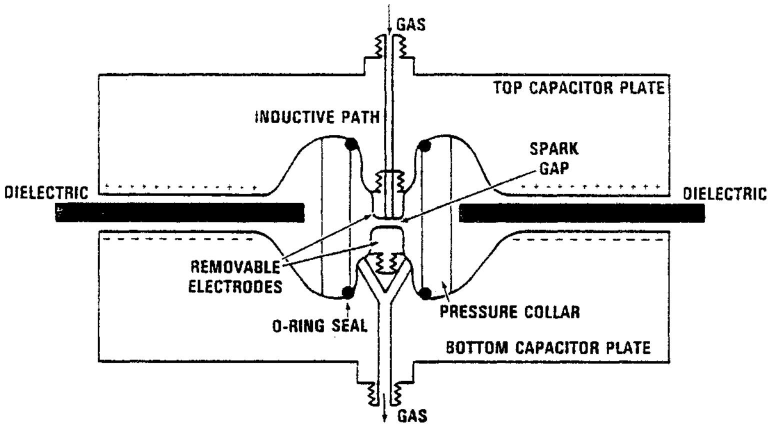

Figure 1. Cross sectional view of oscillator and switch.

The working gas used is commercial dry nitrogen. The high pressure tubing connecting the various components was constant diameter and all components were placed as close to the switch as possible. A Heiss pressure gauge was used and calibrated with an accuracy of ±1 psig (51.7 torr). A Rate Master flow meter was used which provided the capability for accurately measuring flow rates of .4 cm^3/sec. A bleed valve was used to flush both the oscillator and gas lines prior to operation.

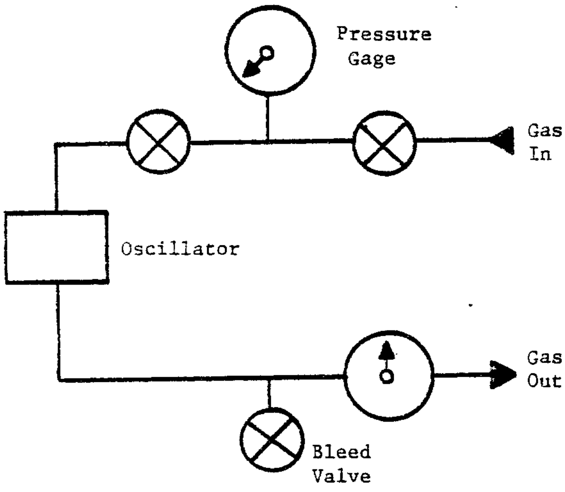

Figure 2. Schematic of the gas pressure and flow system.

Figure 3 illustrates schematically the system used to charge the oscillator and to provide a reliable trigger. The oscillator capacitance, C_o, (433 pf) is charged through a variable charging resistor R_c. When the charging voltage on the oscillator reaches a preset value, the impulse generator (IMP) sends a pulse into the oscillator, rapidly overvolting the gap, and causing it to fire in a time short in comparison to the RC charge time. The diodes, D, are so arranged to prevent the oscillator from discharging through the secondary of the impulse generator transformer or alternatively through the power supply. As a result, the energy from the impulse generator is added to that of the power supply so that no energy is wasted from the trigger pulse. The energy stored in the oscillator is "latched" in and can dissipate rapidly by firing switch S or slowly leak off through the back resistances of the diodes.

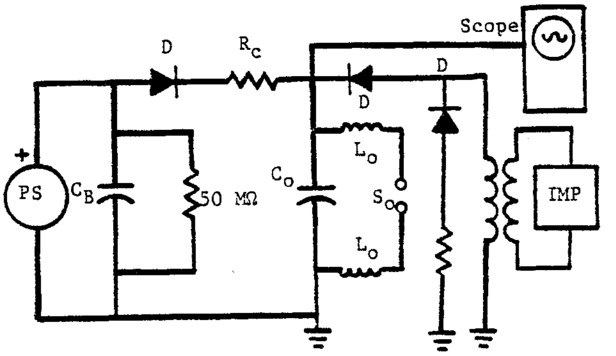

Figure 3. Schematic diagram of the oscillator charging system and trigger arrangements.

The pulser itself is a Velonix model 350 with the output transformer modified to provide pulses as high as 12 kV into a matched load. Prior to running, the surfaces were ground flat and metallurgically polished as described elsewhere[2]. Figure 4 summarizes the operating characteristics of the experiment. Figure 4a shows the voltage-time history as provided by the main power supply (top trace) and the output of the impulse generator (lower trace). Figure 4b illustrates the final impulse charge provided from the trigger generator. Figure 4c illustrates the repeatability of the trigger system and shows jitter. For our purposes, we define jitter as the maximum spread in switch times as integrated over several seconds or several hundred events chosen at random. For this experiment, we routinely sampled 400 separate trigger events to determine the distribution, however, the photo shows some 50 events. Figure 4d shows the RF envelope for the oscillator output. The system impedance is about 3 ohms which ensures a large damping constant ($Q \simeq 3$) and maximum current in the kiloampere range.

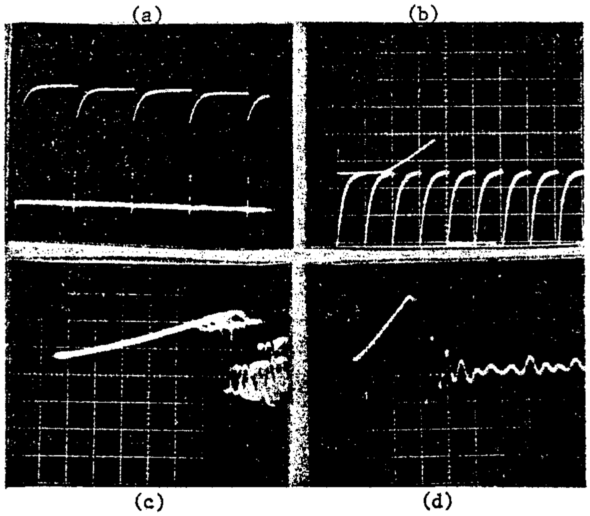

Figure 4. Voltage-time traces for the oscillator and switch.

(a) Top trace is normal RC charge for oscillator, 500 volts/cm, 2 ms/cm. Bottom trace is trigger pulse from impulse generator, 1000 volts/cm, 2 ms/cm.

(b) Bottom trace is normal RC charge for oscillator, 500 volts/cm, .2 ms/cm. Top trace shows impulse charging of oscillator and overvoltage which occurs as a result of impulse; 500 volts/cm, 200 ns/cm.

(c) Superposition of 50 pulses to illustrate jitter; 500 volts/cm, 10 ns/cm.

(d) Output waveform for oscillator; 200 volts/cm, 20 ns/cm.

The value of the charge resistor R_c can be chosen such that, at a given frequency, more than 90% of the energy is provided by the main power supply, thereby placing very little strain on the pulse generator. In these experiments, however, we did not always operate in this mode but held R_c constant (1.05 MΩ) for convenience.

Discussion

Among the factors which could affect the breakdown voltage in a system are pulse repetition rate, gas flow rate, gas pressure, electrode material, gas species, and time rate of change of the trigger pulse. In our experiments, we varied the first four of these parameters while holding the other factors constant to a first approximation. For the range of fields investigated (up to 260 kV/cm) varying the electrode material did not appear to influence the breakdown voltage. Slight deviations were sometimes noted but these were well within the experimental error. The effect of pressure on the static breakdown voltage is well documented[3] and our results are consistent with Cookson[4]. However, under impulse charging and flowing gas conditions, the breakdown voltage (illustrated in Figure 5) increased up to a value as high as 30% greater than the static value and slowly decreases as the pulse repetition frequency is increased. At a pulse repetition frequency of 20 kHz, the firing voltage for the switch has dropped to a value about 2/3 of the static value. The effect of flow was minimal on the breakdown voltage (over the range investigated) and in general was confined to pulse frequencies less than 3 kHz. We attribute this to the multitude of other factors which could be active in determining the breakdown voltage for the gap (e.g., particulate matter of a size comparable to the gap spacing, thermal energy deposited in the electrode surface and gas, plasma in the gap due to previous discharge.)

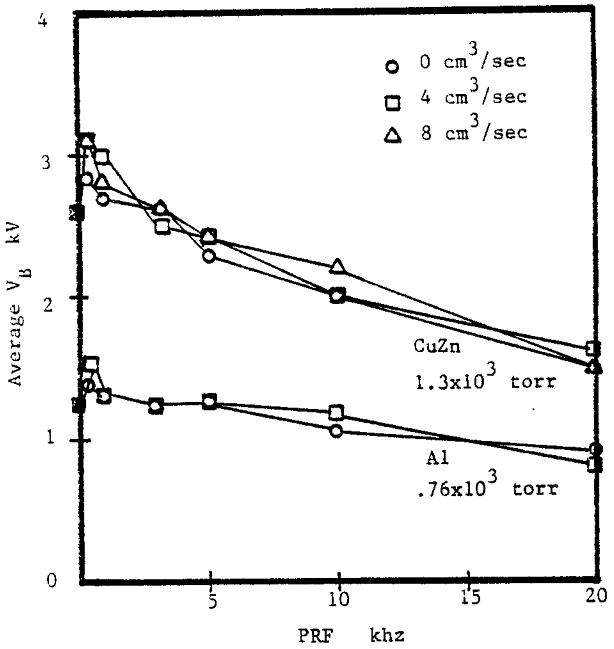

Figure 5. Effect of pulse repetition frequency and flow rate on average breakdown voltage as a function of gas flow.

At a constant gas pressure, without gas flow, strong material effects are present if the gap is to be operated in a triggered mode. For aluminum we could achieve stable triggered operation over the entire pressure range investigated with minimal jitter in the 2-5 kHz repetition range. By contrast, we could only achieve quasi-stable operation using brass electrodes. Table 1 summarizes some of the data for aluminum. The PRF at which the jitter is a minimum is not well defined but extends some 3 or 4 kHz on either side of the value quoted.

Table 1. Jitter Data for Aluminum

Pressure torr x 10^3	Avg V_B kV	Flow cm^3/sec	Jitter min ns	Approx PRF kHz
.76	1.30	0	40	6
.76	1.25	4	10	3
1.29	2.40	0	70	4
1.29	2.20	4	70	6
1.29	2.50	8	75	3
2.58	3.20	0	20	1
2.58	3.40	4	20	1
2.58	3.60	8	20	1

The effect of flow for both aluminum and brass electrodes was to make the switch operate with less jitter over the entire range of parameters investigated. The decrease in jitter was quite dramatic in brass. Figure 6 illustrates the effect of gas flow on the switch jitter for brass electrodes at atmospheric pressure. The values given without flow showed no systematic variation with repetition frequency and are at best estimates of the maximum jitter at the time of observation.

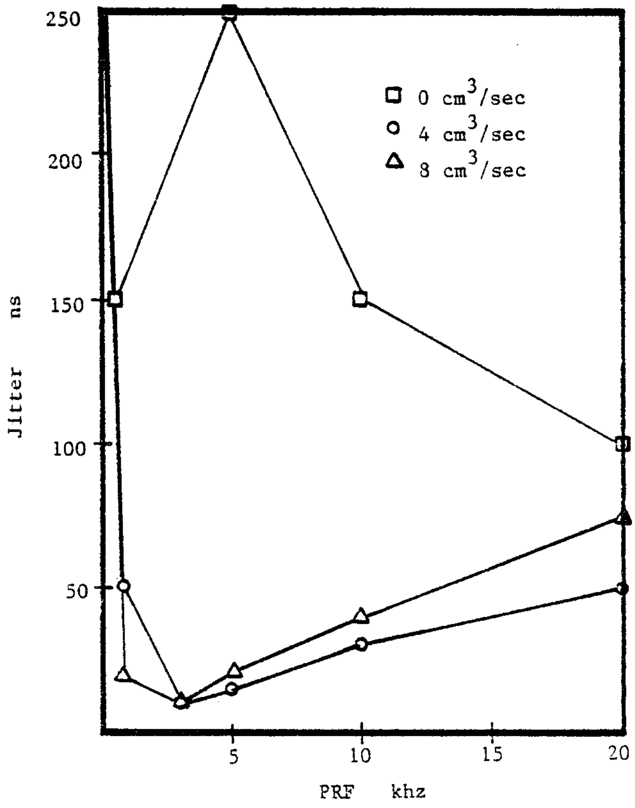

Figure 6. Effect of pulse repetition frequency on the maximum jitter for various flow rates. Electrodes are brass. Gas pressure is .76 x 10^3 torr.

When flow was initiated, the gap would run stable under any condition investigated in our experiments At atmospheric pressure, the minimum in the jitter distribution occurred at 3 kHz similar to that observed for aluminum (Table 1) and then slowly increased up to the maximum repetition frequency investigated.

The effect of pressure is equally dramatic for constant flow rate. The trends are similar for aluminum and brass but differ considerably in absolute magnitude. Figure 7 illustrates the effect of repetition frequency on jitter using brass electrodes for several pressures. The flow rate was held constant at 8 cm^3/sec. The increase in jitter at higher repetition rates is probably associated with the increased surface damage, larger volumes of plasma still in the gap, and electrode heating effects which enhance field emission. The minimum jitter occurs at lower pulse repetition frequencies as the pressure increases. It has been shown that the diameter of the "spark discharge" increases with pressure[2]. If we assume that this diameter defines the amount of plasma associated with a particular event, we can readily estimate the plasma volume associated with the switch at any given gas flow rate and repetition rate. This number is approximately constant at $3.4 \pm .1 \times 10^{-6} cm^3$ for the data shown in Figure 7. Similar results were also obtained for aluminum.

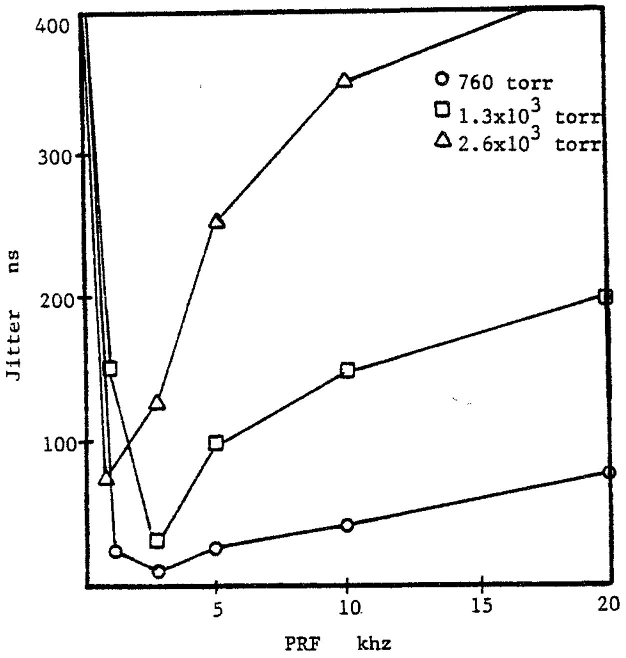

Figure 7. Effect of pulse repetition frequency on maximum switch jitter for constant flow rate (8 cm^3/sec) for various pressures.

Figure 8 illustrates a typical distribution of switch firings normalized with respect to the maximum in the number of switch events at a specific triggering time after the impulse was applied. These data were taken at a flow rate of 8 cm^3/sec, PRF of 5 kHz, and atmospheric pressure. The curves represents some 400 individual events, taken at random, over a period of several minutes. The distribution for brass electrodes is approximately Gaussian and the extrema agree well with the maximum jitter as observed directly from the oscilloscope. The results for aluminum were complicated, and we attribute this to local defects such as that shown in Figure 9 which eventually grow to such an extent that the gap is effectively shorted out. We did not observe similar failure in brass although running times of several hours were sometimes involved. In general, aluminum failed after some 45 minutes with a drastic increase in jitter and a decrease in breakdown voltage, and in all cases a localized damage area was observed.

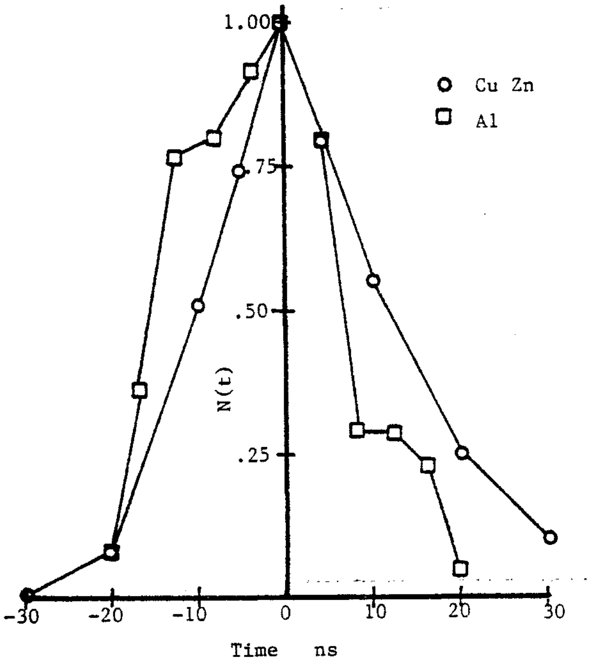

Figure 8. Jitter distribution in brass and aluminum. pressure 760 torr, flow rate 8 cm^3/sec, pulse repetition frequency 5 kHz.

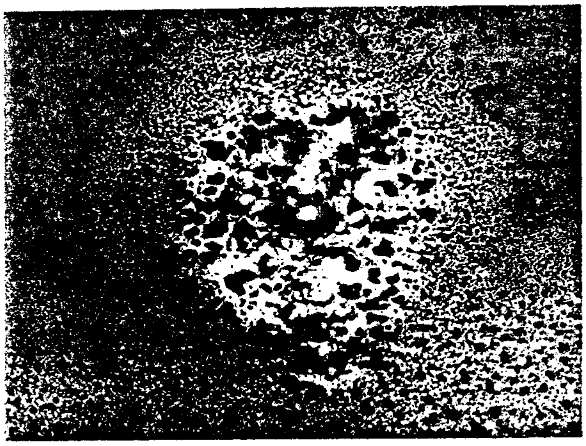

Figure 9. Failure zone on aluminum electrode surface.

Summary

Simple spark switches can be made to operate in a triggered mode for frequencies as high as 20 kHz with a maximum of 30% decrease in the breakdown voltage. In so far as we investigated, there is very little effect of materials on the average breakdown voltage of the switch. There are, however, large material effects associated with switch jitter which are probably due to surface chemistry and contamination of the working gas by particulate matter, blown from the surfaces. Introduction of gas flow greatly enhances stability and often results in orders of magnitude reduction in switch jitter. The effects of gas pressure are primarily to increase jitter at higher repetition frequencies and to decrease and better define the repetition frequency at which the minimum in jitter occurs.

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