DEVELOPMENT OF A HERMETICALLY SEALED, HIGH ENERGY TRIGATRON SWITCH FOR HIGH REPETETION RATE APPLICATIONS

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Abstract

Triggered gas switches increase the reliability of pulsed power systems. In particular, the performance of high power, repetitively rated impulse generators is greatly enhanced by including a triggered switch. In order to simplify the pulsed power subsystem for field testing, the Air Force has developed a reliable, fully sealed, trigatron switch. A low inductance, 70 J capacitor bank charged to 50 kVDC is discharged through the hydrogen insulated trigatron at a pulse repetition rate of 600 Hz. The switch is designed to be used for up to one year without replacing the hydrogen gas.

The hermetically sealed switch is intended as the primary switch for a resonant transformer. In order to test the limits of the technology, a high energy, low inductance primary capacitor bank was constructed, and switched with the trigatron. The switch construction, the trigger circuit, and the hermetic seal are fully described.

I. INTRODUCTION

Many applications, such as space-based, airborne, or man portable systems, increasingly require compact, lightweight, highly reliable, efficient components and systems. In particular, weight and system complexity is of prime concern and may significantly impact transport platforms, range, and operating costs. In this interest, the Air Force Research Laboratory has developed a high voltage triggered switch that is capable of high pulse repetition rates (PRR) and can maintain its insulating gas pressure for a year without refreshing. It is anticipated that the insulating gas will be recharged at the same maintenance cycle as the electrodes. The immediate application of the hermetically sealed trigatron is for field tests requiring pulsed power systems. For instance, the testing of high power transient radiating devices and their antenna pattern is most effectively performed in a remote, open range. Testing in remote sites can be cumbersome with all of the accompanying accoutrements necessitated by the measuring equipment and source. To this end, the Air Force wants to facilitate field testing, and the initial step was the development of a hermetically sealed triggered switch to eliminate the need for a gas reservoir.

Spark gaps are extremely versatile, high voltage switches that are used extensively in a wide variety of pulsed power systems. Spark gaps can be relatively simple yet exhibit excellent switching performance over a wide parameter space. The principal advantages of spark gaps are their fast turn on time, good current handling capability, wide operating voltage range, and acceptable pulse repetition rate. In general, high pulse repetition rate spark gap switches require the insulating gas to be flowed through the discharge region, cooling the switching channel and sweeping out the heated gas of the previous shot. Dynamic gas schemes, however, can be eliminated by careful choice of gas insulating media, for a given PRR [1]. Other schemes for increasing the PRR have also been tested [2,3].

Triggered switches are used to provide precise timing of one or more cascaded components. The objective of implementing a triggered switch is often the reduction of switching jitter since consistent switching delay can often be incorporated into the overall system design. A trend in repetitive pulsed power system design is towards higher average power, larger energy per pulse and faster pulse repetition rates. The addition of a triggered switch to the pulsed power system increases the pulse-to-pulse repeatability of the overall system. A trigatron was chosen as the switch configuration due to its simplicity, reliability and good triggering characteristics. An excellent overview of trigatrons and their operation is given by Williams and Peterkin [4]. The trigatron design specifications are summarized in **Table 1**.

Voltage	50 kV
PRF	> 600 Hz
Energy per Pulse	70 J
Average Power	> 40 kW
Gas Replenish Period	1 year

Table 1. The design parameters of the trigatron.

II. SWITCH DESIGN

A. *Electrical Design*

The crossectional view of the trigatron is shown in Figure 1. The trigatron is designed as a uniform field electrode gap with the trigger pin imbedded in a grounded adjacent cathode. The gap spacing between the adjacent and opposite electrodes, d_g, is set at 0.43 cm. The spacing

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14. ABSTRACT

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between the trigger pin and the adjacent cathode is 0.217 cm. The trigatron is designed to withstand 50 kVDC charge voltage, and fixed gap space, d_g, and the self break pressure is 150 psi of hydrogen. The electrode faces are made of copper tungsten for its superior resistance to erosion and is backed by aircraft aluminum (7075-T6). Aircraft aluminum is lightweight and retains the conductivity of common aluminum but is significantly stronger. The plates provide the mass necessary for dissipation of the heat generated under the high pulse repetition frequency as well as necessary mechanical support.

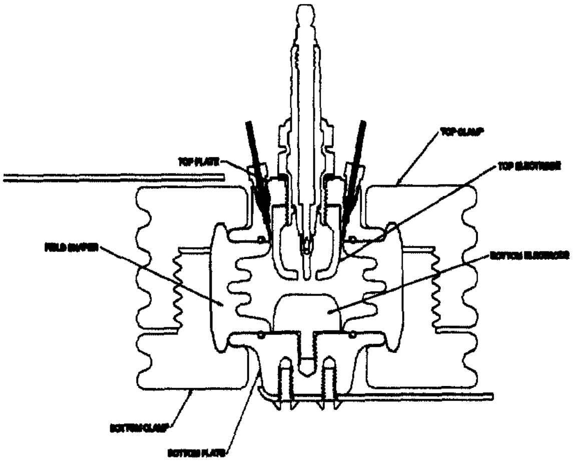

Figure 1. Crossection of the hermetically sealed trigatron.

The threat of failure by surface breakdown becomes more likely as the size of the component decreases. Moreover, there is evidence that the likelihood of both bulk and surface breakdown increases with increased pulse repetition rate [5]. Fortunately, the applied DC voltage is not very high, however, the total length of the trigatron switch housing is a mere 2.4 inches. The insulator, KEL-F, is corrugated parallel to the discharge path in the well known technique to increase its resistance to surface flashover. Since the switch is sealed and used in high PRF application, the corrugations also serve to collect any debris. Although extensive electrostatic modeling was not performed, a field plot confirmed that excessive increase in the electric field did not occur in the corrugations.

B. *Mechanical Design*

The mechanical design consists of two intermingled tasks: a pressure vessel design with a sufficient factor of safety for manned operation, and the incorporation of a semi-permanent seal for a variety of high pressure gas.

The ASTM standard lists the required factor of safety as four for the safe operation in the vicinity of humans [6]. Careful selection of materials was the main method used to handle the mechanical stresses. For instance, Aircraft aluminum (7075-T6) is lightweight yet considerably stronger than standard aluminum. The aircraft aluminum is both the mechanical structure and a sink for the heat generated during high PRF bursts. Threaded glass reinforced plastic (G-10) gave the switch structural integrity and provided access to the interior of the trigatron. Bulk breakdown is a well-known difficulty in exploiting the superior strength of G10, and lining the interior of the G-10 pressure vessel with KEL-F mitigated this problem.

The trigatron is designed to remain sealed with high pressure hydrogen gas for a minimum 1 year cycle. Hydrogen, being a small molecule, is notorious for migrating into materials and its difficulty for containment. KEL-F is a unique thermoplastic that, among many other desirable properties, has a particularly low permeability to hydrogen [7]. Combined with its resistance to surface flashover, a listed breakdown strength of 200 kV/cm, and its ability to withstand UV make KEL-F an exciting material for compact pulsed power switches. Other seals

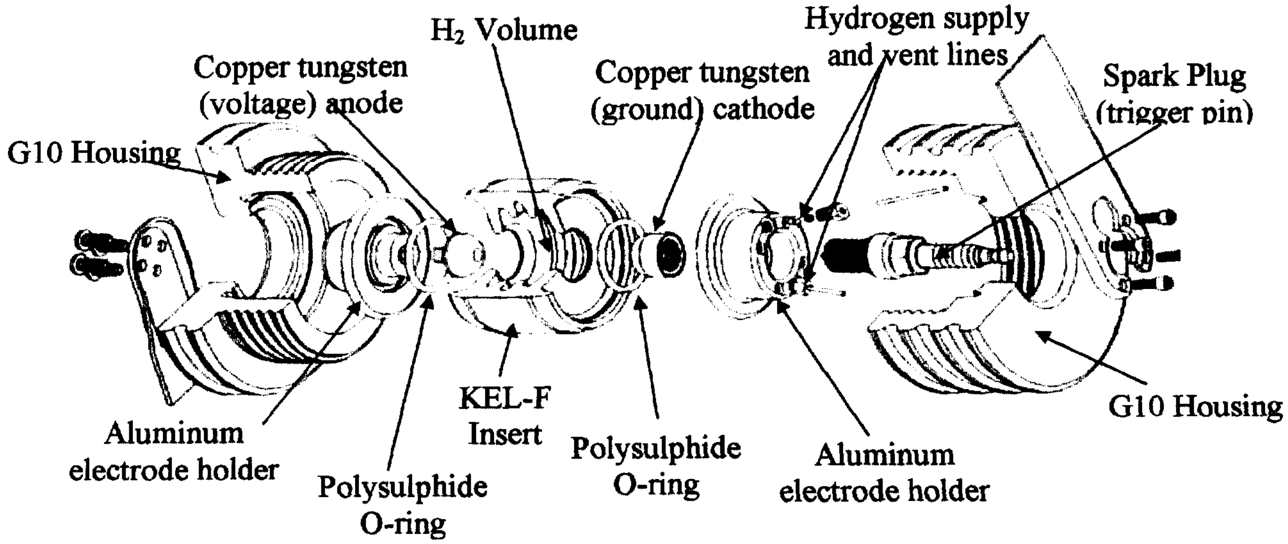

Figure 2. Exploded view of trigatron showing details of the mechanical design.

used polysulphide, which is also resistant to hydrogen, with a gas permeability rate of 1.2 cm/cm^2-sec-bar for hydrogen, and for comparison, Viton™ has a rate of 160. The junction between the aluminum electrode plates and the KEL-F insert is sealed with polysulfide o-rings and Sylgard is used to fill the air gaps external to the o-rings. Insuring a long term containment for hydrogen, however, also required special design and manufacturing techniques. In particular, the use of CAD 3-D solid modeling allowed the creation of electronic data to allow the accurate production of the switch as visualized. This direct interface between data and machine allows closer tolerances to be achieved, which were required for the long-term containment of hydrogen gas.

C. *Triggering System*

The trigger pin is an extension of a commercially available spark plug and either a Champion C65YC or Accel 117 worked equally well. These particular spark plugs were chosen for the length of the ceramic path between the trigger pin and the aluminum support plate. The 0.22 cm trigger pin is a copper tungsten extension that is threaded onto the spark plug center pin. The spark plug is sealed to the trigatron housing with a manufacturer-provided copper gasket that was tightened to the recommended 25 ft-lbs.

The trigger voltage is generated using an off-the-shelf, Ford automotive ignition coil driven by a solid-state circuit. The solid-state trigger generator, shown schematically in Figure 3, is constructed as a push-pull network using 10 high-power MOSFET's. The storage capacitor is charged to 500 V by a 1000 V, 1 kW power supply. The "push" FET's charge the de-coupling capacitor through the primary of the ignition coil in 160 us. A ceramic resistor (2 Ohm, 50 Watt) in series with the "push" FET's critically damps the charging current. A reset diode prevents voltage from being applied to the trigger pin during the charge phase. The "pull" FET's subsequently discharge the de-coupling capacitor through the primary of the coil producing a negative 50 kV on the secondary with a 15 us rise time. Note that the coil primary current during the charge phase is opposite in direction to the current during the discharge phase. Therefore, the charge current resets the iron core immediately prior to the main trigger pulse to prevent core saturation at high rep-rate (up to 1 kHz) operation.

The electrical isolation of the trigger circuit from the trigger pin is important since, upon switch closure, the trigger pin can rise to the potential of the switch charge voltage for a short time. Additionally, access to the gap can also present difficulty [4]. The connection between the ignition coil and the trigger pin is made using ferrite-loaded, spiral wound ignition wire originally designed for automotive applications. The inductive/resistive wire greatly reduces the high frequency signals that couple back to the solid-state coil driver. Access to the switch gap is provided by a modified automotive spark plug.

III. EXPERIMENTAL SETUP

The trigatron switch was tested at voltages of up to 50 kVDC and pulse repetition rates of 600 Hz. One of the targeted applications for the trigatron is to discharge the primary capacitance of an air core transformer. Because of constraints which may be imposed by the low primary inductance of an air core transformer, the inductance of the 55 nF capacitor bank was kept small by enclosing the capacitors in a rectangular coaxial geometry. To avoid electrical breakdown interior to the capacitor bank, the capacitors are encapsulated in the rectangular coaxial geometry with Sylgard Dielectric compound [8]. In addition to a good bulk breakdown strength, $E_{BR} = 175$ kV/cm, Sylgard is used as a protection from mechanical stress and atmospheric contaminants, such as moisture, that may be introduced during field tests. Moreover, Sylgard is applied in liquid form which then cures, primerless, to form a cushioning, self-healing, gel-like mass. Thus, the gel retains many of the best features of a liquid, while also providing non-flow stability. The

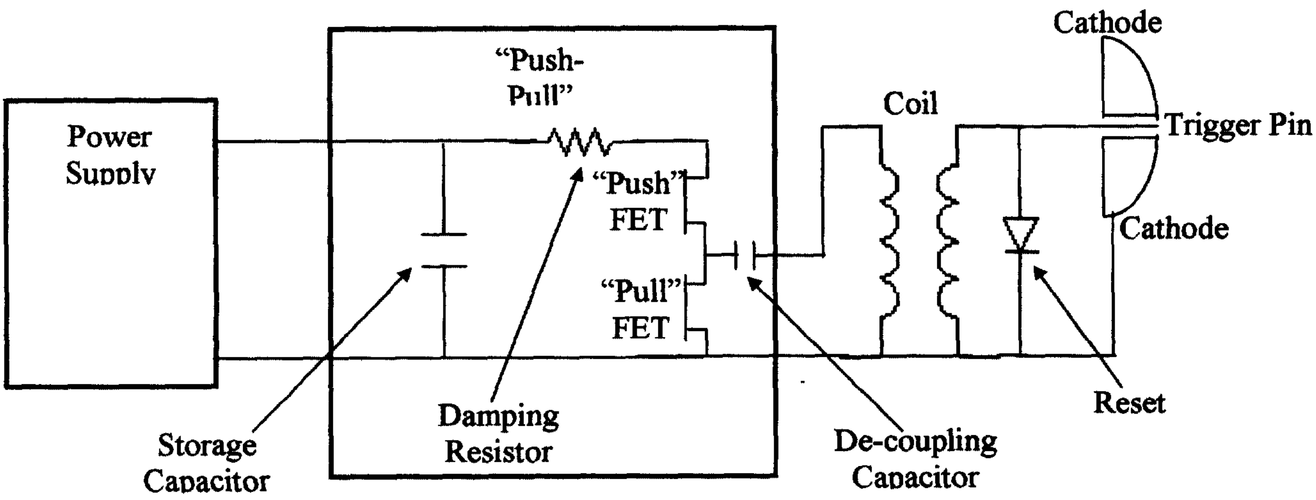

Figure 3. Trigger system diagram.

inductance of the capacitor bank was measured by discharging the capacitor bank into a short circuit and recording the waveform and found to be 100 nH.

The capacitor bank is charged to 50 kV in approximately 900 :s with 8 Maxwell CCDS, 8 kJ/s power supplies which provides sufficient current to obtain a pulse repetition rate of 600 Hz. For repetitive operation, the hydrogen pressure in the trigatron is increased to 300 psi, which results in the switch being operated at approximately 70% of the self-breaking voltage, and is triggered 500:s later. Results of repetitive operation at 600 Hz are shown in Figure 4.

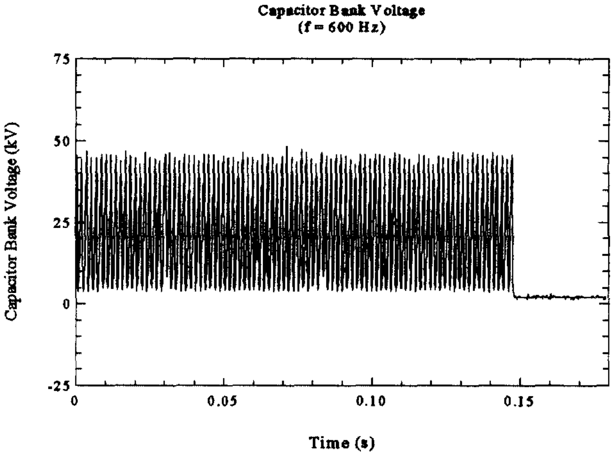

Figure 4: Capacitor bank and trigatron voltage at 600 Hz PRR. The irregularity is caused by an insufficient oscilloscope sampling rate.

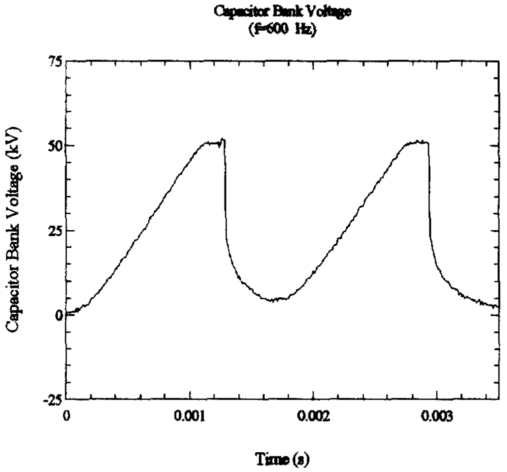

Figure 5. The first two pulses in a 600 Hz burst of capacitor bank voltage as it is discharged by the hermetically sealed trigatron. It was experimentally determined that the trigatron had less jitter when a sight "flattop" was permitted on the capacitor bank voltage prior to triggering.

The true reliability of the trigaton is indicated in Figure 5 that shows the first two pulses in at a a series for the 600 Hz. Note the slight "flattop" which was experimentally determined to result in a reduced pulse to pulse jitter. Operation at 600 Hz is shown in Figure 4. The slight inconsistency is attributed to an insufficient sampling rate on the oscilloscope. It is notable, that neither nitrogen or dry air was able to sustain the 600 Hz PRF at 70 J/pulse. Some dependency on the hydrogen purity was observed, and the above data is taken with UHP bottled (99.99999%) hydrogen.

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