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A LOW JITTER TRIGGERED GAS SWITCH TO SYNCHRONIZE MODULAR ACCELERATORS*

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Abstract

Physics International (PI) has developed a high voltage, low jitter, command triggered gas switch to serve as an output switch for the slow-charging transfer capacitor in EAGLE,[1] a 2 TW pulsed power research facility presently under construction. EAGLE is a prototype module of PI's conceptual design for a 40-50 TW, 4-5 MJ pulsed accelerator called ROULETTE (see Figure 1). The use of our triggered gas switch in ROULETTE provides distinct advantages over conventional water switches: considerably lower intermodule jitter, less ohmic dissipation, reduced mechanical shock loading of structures, and better control of the current distribution.

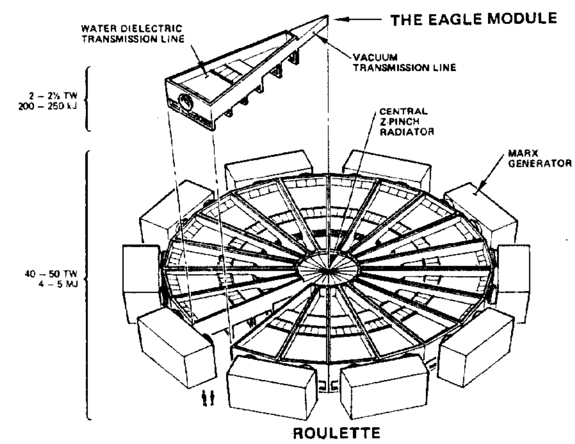

Figure 1 The PI ROULETTE accelerator.

The PI triggered gas switch (TGS) is a modular (multistage) SF_6-filled, UV-illuminated, annular rail switch with a midplane trigger electrode in the first stage. Its structural strength is provided by a central nylon drawbar, which also encloses an independently pressurized, V/4 trigger switch with an adjustable, UV-illuminated isolation gap.

The TGS has been thoroughly tested at both PI and Sandia Laboratories in Albuquerque to characterize its properties and compatibility with multimodule pulse generators. It was operated at up to 3.0 MV, 525 kA, and 0.25 C with switch-out times ranging between 0.7 and 1.2 μs. Jitter (1σ) was measured to be less than 2 ns. The slope of the closure times versus percent-of-self-break (%SB) curve was ~ 0.5 ns/%SB.

Introduction

Very large, high power pulsed accelerators are being planned and built to support research in nuclear weapons effects simulation and inertial confinement fusion (ICF). The largest such accelerators in operation today use multimegajoule capacitor banks (arranged in Marx circuits) to drive liquid-dielectric pulse-forming networks. Within these networks, high power closing switches are used to transfer energy between successive power amplifier stages. These switches must operate with low enough jitter to provide synchronization between energy handling components within the accelerators and, often, with external devices. The jitter and charge-handling requirements of such switches become more demanding as accelerator designs become larger.

Of particular concern to machine designers is the first-stage switching of Marx-generator-driven water-dielectric pulse-forming lines. Because Marx generators are inherently inductive, first-stage switches must withstand high voltage for 0.7-2.0 μs before closing. In machines with coaxial lines that produce 1-10 TW pulses, this switching requirement is usually satisfied with a single, untriggered water switch operating at 4-6 MV. But for larger accelerators, such water switches become impractical because of resistive losses and, if multiple switch sites are used, jitter (most such switches exhibit jitter in the 50-100 ns range, which is usually comparable to the accelerator output pulse duration).

PI's solution to the first-stage switching problem for the conceptual design of ROULETTE[1] (see Figure 1), a 40-50 TW, 4-5 MJ accelerator being considered by the Defense Nuclear Agency, is to use 20 triggered gas switches (TGSs), one for each module in the system. The TGS concept affords the advantages of low jitter, small resistive losses, minimal capacitive effects, low accoustic shock, and well-controlled current distribution. But, the design requirements of the ROULETTE TGS were beyond the state of the art when our program started, so a development effort was necessary.

To satisfy the ROULETTE design requirements, we launched a program to produce a UV-illuminated multistage TGS capable of transfering ~ 0.3 C at > 3.0 MV and < 1 MA with < 10 ns jitter. Previous efforts to develop such a switch (e.g., Pulsar Associates, Inc.[2] at CASINO) had demonstrated the efficacy of UV illumination in producing lower jitter switching in gas dielectric and had pointed to various problem areas that needed further attention: blast containment, insulator tracking, and energy-dependent failure modes.

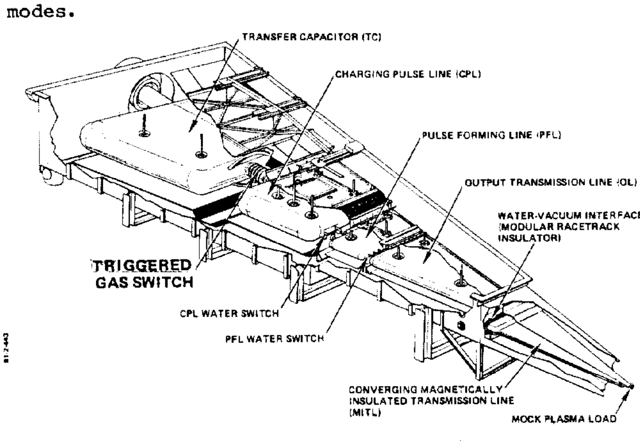

Figure 2 EAGLE waterline and front-end construction.

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To solve these problems and to demonstrate switch performance adequate for EAGLE,[1] a 2 TW module of ROULETTE presently under construction at PI (see Figure 2), we built and tested a prototype TGS. The results of initial tests at PI encouraged Sandia National Laboratories, Albuquerque (SNLA) to consider our TGS design for transfer switching in PBFA II,[2] a 100 TW accelerator presently being designed. Consequently, further tests were conducted in a simulated PBFA II geometry. Results from both of these tests, and a description of the TGS, are given below.

Description of Switch

Our modular, prototype TGS is shown in Figure 3. Six identical stages are stacked between two end plates pulled together by a 12.7 cm o.d. nylon drawbar. Each stage consists of a 40.6 cm o.d. annular grading plate that extends into the water region surrounding a 30.5 cm o.d., 2.45-cm-thick acrylic pressure cylinder, which defines the spacing between the stages. The water between grading plates helps to ensure multichannel operation. Divided, toroidal brass electrodes are mounted on both sides of the grading plates. These electrodes have wide, annular slits to provide interstage UV illumination. They also provide communication channels for the dielectric gas (SF_6) introduced at the end plate.

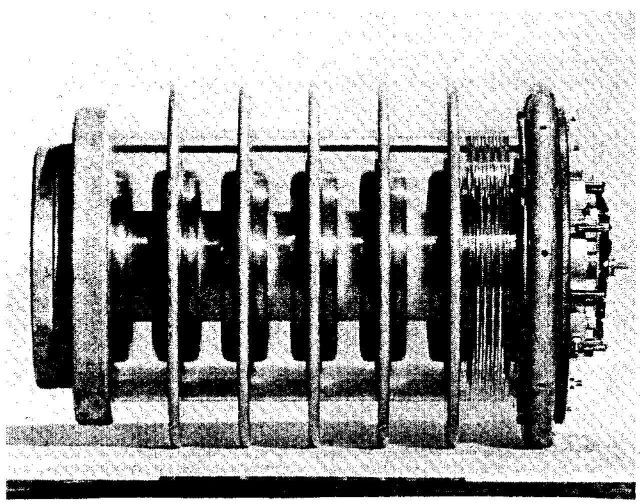

Figure 3 Triggered gas switch.

A floating, annular midplane electrode is located in the triggered stage, next to the low voltage end plate. The midplane is pulled to ground by a triggered breakdown in the master trigger switch located inside the drawbar. The master trigger switch is basically a V/n switch, in which the dimensions, and thus the capacitances, of a sharp-edge, triggering "mushroom" are chosen so that it floats at about one quarter of the gap voltage. Voltage for the master switch is provided by capacitively tapping the midplane of the triggered stage. The floating mushroom is isolated from the trigger cable by a gap, whose breakdown jitter is minimized by UV illumination generated by the incoming trigger pulse. Illuminators are also placed within the ground rails of the triggered stage to spray UV onto the cathode concurrently with the trigger pulse.

In the triggering process, the sequence of gap closures is as follows: After the isolation gap, the larger gap of the V/4 switch breaks down. This action is followed by breakdown of the smaller gap, which in turn initiates a closure between the midplane and the cathode rail of the first stage. A breakdown between the midplane and the ground rail electrodes completes the closures in the triggered stage. Closure of the trigger stages causes a pulsed-overvoltage breakdown in the next stage. This process continues until all stages are closed.

Experiments and Results

For both the PI and SNLA experiments, we adapted our prototype TGS to an existing high power generators. At PI we used OWL II[4]; at SNLA we used SUPERMITE,[3] a test facility for PBFA. By using two different machines, we were able to span a 0.7-1.2 μs switchout range and test at up to 3.0 MV. To electrostatically grade the TGS, we used JASON[5] (a Poisson-solver code) to design toroidal field shapers. These shapers provided a grading uniformity of 5% (deviation from perfect grading) in both machines.

In the OWL II experiments, the TGS was mounted by replacing OWL's triggered water switch located between the 3.9 Ω pulse-forming line and the 2.8 Ω transformer section. A shorted vacuum diode and closed diverter switches, connecting two 2.4 Ω resistors to the transformer, served as loads for the switch. In Albuquerque, the TGS was fitted to one of the intermediate stores in SUPERMITE. The intermediate store, a 21 nF water capacitor, was switched into a 7 Ω load resistor by the TGS. In both experiments, inductive transit time isolators provided housing and support for the trigger and diagnostic cables and the plastic gas feed lines. Diagnostics included the standard current and voltage monitors in the generators and loads, and B-dot probes located in the trigger and the main switch sections of the TGS. Open shutter photographs of the luminous breakdown channels in the switch stages also were taken.

We determined the temporal history of the TGS triggering process by carefully studying voltage waveforms from a capacitive probe mounted on the trigger cable. By comparing this signal to those of the load or switch currents, we gained information on closure time and jitter. At PI, we made the timing measurements with fast scopes and time interval counters. At Sandia, we used the PBFA data acquisition system. An example of the PBFA output is shown in Figure 4, where the trigger monitor signal, delayed and inverted by computer, is displayed as a time reference for the superimposed load current signals of a six-shot test sequence at 2.2 MV.

Timing mark 1 in Figure 4 corresponds to the arrival of the trigger pulse at the master switch. During the time interval between marks 1 and 2, the gaps in the switch are still open and the reflected voltage is superimposed on the incoming trigger pulse. At time mark 2, the switch gaps begin to break down and the monitoring signal collapses toward the overall RC decay curve of the trigger discharge circuit. At time mark 3, all the gaps, including those in the first stage of the main switch, are closed and pulled close to ground plate potential. About 40 ns later, the buildup of the main switch current begins by consecutive breakdowns in the neighboring stages. To obtain the real time relation between the current signals shown in Figure 4 and the trigger pulse, an additional 75 ns time shift must be included to compensate for differences in cable lengths. The time spread of the six load signals at the 50 kA level is about 3 ns, corresponding to 1σ jitter of ~ 1.2 ns. Similar test runs performed at various voltage and pressure levels produced less than 2 ns switching jitter, when the pressure, trigger

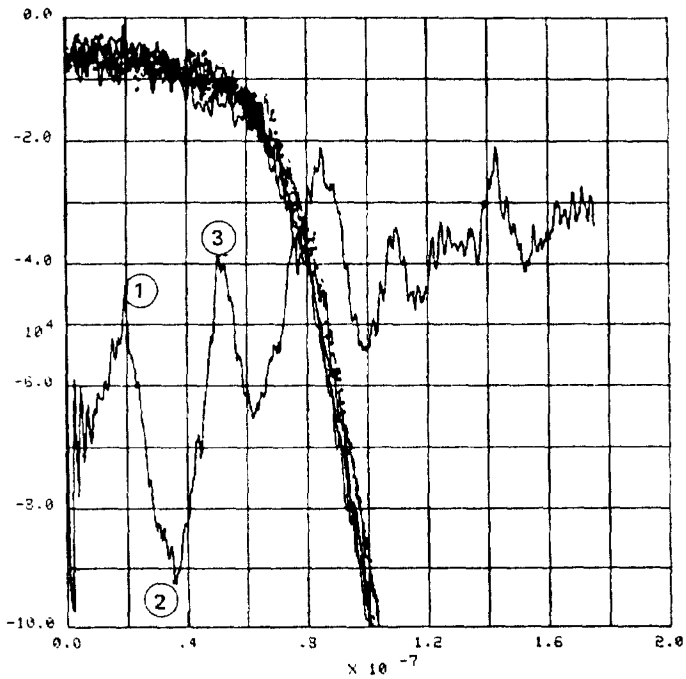

Figure 4 Trigger monitor and load current signals.

pulse, and isolation gap spacing of the trigger switch were optimized for the operating voltage. The dependence of switch closure times on the ratio of the switch voltage to self-break voltage (expressed as %SB, or "percent of self-break") indicated a slope of about 0.5 ns/%SB for 72 to 90% of the self-break range.

Conclusion

The triggered gas switch developed at PI has been shown to be a viable candidate for first-stage switching in large systems where synchronizing requirements call for low jitter operation. Its main characteristics are briefly summarized below.

1. The switch has been tested up to 3.0 MV, 525 kA, and 0.25 C. The switch-out times were varied between 0.7 and 1.2 µs. With a well-tuned master trigger switch, 1σ jitter was measured to be less than 2 ns. The empirical self-break voltage versus SF_6 pressure dependence of a well-graded switch was described as $V_{SB} \simeq 1.5$ MV + 25 kV/psig, for pressures above 0 psig. The slope of the closure times, t_{cl}, versus the percent of self-break (%SB) was shown to be

$$\frac{\Delta t_{cl}}{\Delta(100\ V_s/V_{SB})} = 0.5\ \text{ns/\%SB}$$

when switching voltage, V_s, was in the range of 72-90% of the self-break voltage, V_{SB}. The value t_{cl} is the closure time of the TGS measured from receipt-of-trigger to main-current-onset.

2. Optimum electrode conditioning to produce multichannel, prefire-free, minimum-debris operation was achieved in several prolonged series of triggered shots. Seven to 10 shots between gas fills, and more than 50 shots between debris cleanings could be maintained. Water conditions (i.e., bubbles, particles, and resistivity) were found to be critical.

3. The structural integrity of the switch was destroyed only when breakdowns occurred on the water side of the pressure envelope.

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