PERFORMANCE OF A HIGH CURRENT, LOW PRESSURE HYDROGEN RADIAL PSEUDOSPARK SWITCH

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ABSTRACT

Tetra, under contract to Sandia National Laboratory has designed, built and tested a high current low pressure radial pseudospark switch. The new switch utilizes a diffuse radial discharge (from which the name Radial Pseudospark Switch is derived) which greatly reduces electrode erosion and increased overall life-time. Switch testing was performed in two stages: low current testing at Tetra, and high current testing at Sandia. Low current tests were performed on the switch at voltage levels of 10 - 20 kV, peak currents of over 200 kA, and switched energies of 100 kJ. High currents tests were performed on the Sandia Switch Test Stand at energy levels of greater than 300 kJ and peak currents in excess of 500 kA.

INTRODUCTION

The NIF is the latest in a series of lasers which have been built for inertial confinement fusion (ICF) research. The concept of ICF is to compress and heat a capsule of fussionable material by placing it into a tightly focused laser beam for a short amount of time. The beam is split and focused onto the sphere from all sides so that the capsule implodes inward for all directions at the same time. The tightly focused laser beams vaporize the capsule surface casing a inward pressure which compress the fusion fuel inside the capsule to a high-density plasma. The generated energy from the fusion reaction is greater than the energy required to start the fusion resulting in a energy gain. Achieving fusion ignition and the corresponding energy gain is the mission of the NIF.

A pulsed power conditioning system is used to drive the flash-lamps in the NIF glass laser amplifiers. The switching requirements for the drivers are significant:

- 24 kV voltage hold-off
- 500 kA peak current
- 130 C charge transfer
- 10,000 shot life time with low pre-fire rate

Failure to achieve these performance goals will increase system cost relative to conceptual design cost estimates.

Tetra proposed a novel new switch design based on its experience with linear pseudospark switches[1,2]. The new switch utilizes a diffuse radial discharge which greatly reduces electrode erosion and increases overall life-time. The increase in life-time that is expected will greatly reduce the overall cost of maintaining the pulsed power conditioning system for NIF.

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TETRA TESTS

A low inductance parallel plate design was used for delivering the energy from the capacitors to the switch. The switch was feed with a coaxial cage arrangement which reduced overall inductance and maintained a uniform external magnetic field during high current conduction

The self-break voltage was measured for a pressure range from 150mT - 450mT. The hydrogen flowed at a rate of 0.035 - 0.040 SCCM (standard cubic centimeters per minute). The gas flow was measured with a Dynamo nitrogen flow meter. The pressure on the switch was measured with the MDC thermocouple gauge and controller. The pressure on the switch was allowed to equalize for approximately 30 min.

Figure 1 shows a plot of the self-break voltage (upper curve) and the minimum trigger voltage (lower curve). The best operation of the switch was around 190 mT.

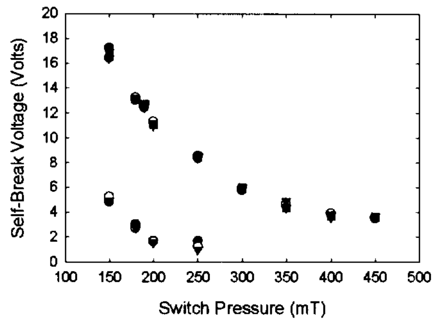

Figure 1. Self-break voltage(upper trace) and minimum trigger level(lower trace).

Over one thousand shots were taken on the low current test setup with a sub-hertz triggering system. The tests were conducted to show that the maintained voltage hold-off and switch was obtainable with the low flow of hydrogen. Three shots were taken at 10,000 volts on the high energy test setup, five minutes apart, as a test case for the switch lifetime tests to be conducted at Sandia

SANDIA HIGH CURRENT TESTS

The switch was tested on the Sandia test bed to determine the performance at substantially higher Coulomb transfer levels (145 C). The tests answered the basic questions about electrode erosion rate, and macro problems such as switch integrity at full current and heating issues. The tests at Sandia were conducted in two phases, first, macro effects were determined with stainless steel electrodes, and second, erosion data was measured with tungsten electrodes.

Experimental Setup

Sandia National Laboratories built a dedicated test facility for evaluating pulsed-power closing switches[3]. The Sandia test facility can evaluate candidate switches in a variety of configurations. The system consists of 25-sub-modules designed to supply 20 kA peak current each. High -current relays allow the selection of any number of sub-modules. Each module has its own pulse-forming components, so the pulse shape does not depend upon the number of modules selected.

The NIF charge voltage is 24 kV, but the facility allows testing at 6, 12, or 24 kV with 500 kA of peak current. This allows testing of a single radial pseudospark switch at 12 kV. The system operates under computer control, and automatically charges and fires the 6.4 mF, 24 kV, 1.8 MJ system every 3 minutes.

Tungsten Electrodes

A set of tests involved tungsten electrodes. Tungsten was chosen for its superior erosion properties[4]. It was impractical to have the entire electrode machined from tungsten from an economical as well as a mechanical standpoint. An electrode design was developed which used tungsten for the tips of the electrode only. The electrode tips were cryogenically pressed onto a stainless steel electrode body. The calculated lifetime of the electrodes was estimated at greater than 10,000 shots.

A summary of the high current shots taken on the tungsten electrodes is given in Table I. Two different bank configurations were used for the tests as indicated in Table I.

No pre-fires were recorded on the switch until shot 81, which had a pre fire level of 9000 volts. The system was recharged and the switch operated for another 54 shots at a level as high as 130 C. The switch then pre-fired approximately 5 times during the rest of the sequence shot 171. Although there were several pre-fires on the switch, none of them appeared to occur at the insulator. The problem appears to be the growth of rough spots on the electrodes. This problem will be fixed in the second design of the switch which will be operated at much less than the self-break voltage.

The final setup that was tested simulated the actual pulse shape of the NIF machine. Seven shots were taken on the machine at a level of 30 C and then all 25 modules were switched in for a peak current of 460 kA and 145 C. Nine shots were taken without any signs of problems. The switch then had a pre-fire. Six more pre-fires were recorded on the switch for the next 22 shots.

Table I. Summary of shots with Tungsten electrodes.

Shot #	Charge (kV)	# of mod	Bank config	Ipk (kA)	Charge (C)	Capacitance (uF)	Energy (kJ)
55 - 63	10	1	B	22.5	11	1000	50
64 - 69	10	3	B	68.8	30.4	3000	150
70 - 72	10	5	B	112.8	100	5000	250
73 - 109	10	10	B	220	100	10000	500
110 - 171	10	13	B	281	130	13000	650
172 - 178	10	5	C	99.9	28.6	2500	125
179 - 210	10	25	C	460	145	12500	625

The switch was disassembled and examined. The breakdown occurred due to roughness on the electrodes. This problem can be fixed by designing the switch to operate well below the self break level.

Erosion for the tungsten electrodes was significantly lower than what was observed for the stainless steel. As before, the erosion of the electrodes was estimated by measuring the electrode profile and calculating the missing volume. The eroded material is estimated at 0.0286 cm^3 for the inner electrode and 0.0398 cm^3 for the outer electrode At the measured erosion rate the switch would have lasted for 6,130 shots at 145 C / shot for no more than a 10% increase in electrode spacing. The electrode assembly was dismantled and the inner section of the outer electrode showed one location where it appears the plasma collapsed along the cryogenic joint between the tungsten and the stainless steel,. A typical current and coulomb trace for configuration B and C is shown in Figure 27 and Figure 28 respectively.

CONCLUSION

A uniform discharge was maintained for the long conduction phase of the current which was greater than 500 microseconds. This validates the radial discharge concept and the ability of the switch to be electrically triggered and still being able to maintain a uniform discharge. It was observed in laboratory that even during self-break the plasma discharge was uniform around the electrodes for long discharge times! The measured erosion rate of the feasibility device corresponds to a lifetime in excess of 6000 shots at 145 C per shot!

A uniform discharge was observed after the preliminary stage of testing on the switch. Over 1000 shots were taken on the switch during the comprehensive stage of switch testing. The energy level was above 30 kJ for more than 20 of the shots. Several thousands of shots were taken on the switch with the low current setup at rep-rates of greater than 10 Hz. Open shutter photographs were taken through one of the view ports showing a uniform glow during switching. The switch was disassembled and inspected after the high energy shots and there was no sign of localized hot spots within the switch. The results are very promising and it appears that the basic physics of the switch has been demonstrated. Being able to achieve a uniform discharge between the electrodes was the highest risk of the program and the key milestone for Tetra.

Voltage hold-off levels of greater than 28 kV were observed on the original configuration of the switch at pressures of around 120mT. Gas flow experiments on the switch yielded slightly lower voltage hold-off levels. The switch has reliably held-off 10 kV for greater than 30 minutes at 190mT,with gas flow. This was well below the self-break voltage of approximately 12kV.

Data indicates that the voltage hold-off of the switch can be improved to greater than 30kV, but this will require additional research in determining the proper gap width/height ratio. One iteration of changing the electrode spacing was tested as part of this program, and it was observed that the switch began to behave erratically. This amplifies the fact that simple iterations will not be productive and a more detailed analysis will need to be conducted.

The results of the measurements with gas flow show that the best operating voltage for the switch with the highest reliability is at 200mT and 10-12 kV hold-off voltage. Sandia agreed to accept the switch for testing at the 10 kV voltage level and at full switch current (500kA).

Two issues that still need to be addressed are: 1) protection of the insulator from metalization, and 2) higher self-breakdown threshold to reduce the chance of pre-fires. Metalizaiton of the electrodes can be addressed with the addition of an extra convolute on the switch electrodes which will act to protect the insulator. An investigation was done to increase the voltage hold-off by decreasing the spacing between the electrodes, the results were not as good as hoped. The voltage did increase slightly, but there were problems with breakdown in the proximity of the electrodes. The voltage hold-off should be improved by decreasing the hollow anode structure which would be easier to implement and is planed to be tested during future work on the switch.

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