

# HIGH AVERAGE POWER TESTS OF A CROSSED-FIELD CLOSING SWITCH\*

by

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## ABSTRACT

A triode version<sup>(1)</sup> of the crossed-field closing switch (CFCS)<sup>(2)</sup> has been successfully tested at average powers of up to 800 kW (40 kA, 40 kV, 12  $\mu$ s pulse width at 80 Hz) for burst durations of 30 s. Unlike most conventional spark gaps, the arc is initiated from a crossed-field glow discharge and occurs at random locations on a shot-to-shot basis. This uniformly disperses the heat loading and erosion over a relatively large electrode surface area which may then be cooled.

### The CFCS

The CFCS is shown in Fig. 1. All components exposed to the discharge are either OFHC copper,  $Al_2O_3$  or are thin walled metal backed up by water. The cathode is made of thin walled stainless steel in order to have a short magnetic field penetration time and also to maintain a low temperature differential between the plasma and the coolant. It forms the vacuum wall and is supported mechanically by vertical ribs which also serve as deflection baffles for the coolant flow. A fiberglass shell is wound over the supporting ribs to enclose the coolant passages. Finally, the magnetic field coil is wound over the fiberglass shell.

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\*Supported by the U.S. Army Electronics Command  
under Contract DAAB07-76-C-1313

# Report Documentation Page

Form Approved  
OMB No. 0704-0188

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1. REPORT DATE <b>NOV 1976</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>High Average Power Tests Of A Crossed-Field Closing Switch</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Hughes Research Laboratories 3011 Malibu Canyon Road Malibu, California 90265</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.</b>					
14. ABSTRACT <b>A triode version(!) of the crossed-field closing switch (CFCS)(2) has been successfully tested at average powers of up to 800 kW (40 kA, 40 kV, 121-Ls pulse width at 80Hz) for burst durations of 30 s. Unlike most conventional spark gaps, the arc is initiated from a crossed-field glow discharge and occurs at random locations on a shot-to-shot basis. This uniformly disperses the heat loading and erosion over a relatively large electrode surface area which may then be cooled.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

The slotted grid structure<sup>(3)</sup> is supported at four locations for mechanical stability. Two of the supports also serve as coolant pipes and electrical leads. The hollow Cu anode is cooled by flowing oil through the high voltage bushing.

Specially designed auxiliary systems which accompany the switch include: a trigger pulsing system with variable frequency capability ( $< 2$  J/pulse), pressure control system, a preionization system<sup>(4)</sup>, and a thermal control and monitoring system. The latter is designed to obtain absolute measurements of the thermal loading of electrodes. Testing was performed using a resonantly charged pulse forming network (1  $\Omega$  and 0.5  $\Omega$ ) and switching it into a matched load (Fig. 2).

### Experimental Results

The performance of the device has been characterized by a marked and steady improvement in its operating stability with increasing peak power. The test levels have thus far been limited to 30 s bursts at peak currents of 40 kA, peak voltages of 40 kV, 12  $\mu$ s pulse widths at a repetition rate of 80 Hz (Fig. 3). This yields an average power of 800 kW to the 0.5 ohm load at 40 A average current (1200 A rms). While one must exist, no indication of a fundamental upper limit in the switched power has yet been observed. During the entire test period, only one "kick-out" was detected. This was at an intermediate power level and may have been related to a failure in the auxiliary equipment.

The present average power limit is set by the power supply which was run well over its normal rating of 30 A average current. The resonant charging network voltage-recovery rate, however, was equivalent to 125 Hz operation. Repetition rates of up to 108 Hz were demonstrated using a 1 ohm load at 24 A average current (20 kA, 40 kV, 11.4  $\mu$ s pulse width) at an average power of 490 kW. The run time and the repetition rate were limited by overheating of the load and the voltage was limited by the PFN rating.

The thermal loadings of the three electrodes were monitored calorimetrically using the pumped coolant temperature rise. The net effective cathode voltage drop is found, by this means, to vary with the peak switched power, falling smoothly from  $400 \pm 25$  V at 29 MW to  $115 \pm 5$  V at 800 MW. No repetition rate dependence was observed. Similarly, it is found that the grid and anode voltages are  $78 \pm 6$  V and  $53 \pm 10$  V respectively, independent of the peak power or the repetition rate. This information is consistent with earlier, but less accurate, voltage drop measurements made on a diode version of the CFCS<sup>(2)</sup> operated in a single shot mode. The estimated temperature rise of either the anode or the grid following a 30 s run at 0.8 MW is about 90°C. The temperature rise of the cathode is lower  $\sim 25$ °C due to the high heat capacity of the cooling water in contact with the rear surface of the cathode. The e-folding time required to transfer the electrode heat to the thermal baths was on the order of 6-8 min.

Inverse clipping was observed on a few percent of the pulses. No obvious causal relationships with current, pulse repetition frequency, conditioning time, or pressure was seen, nor was any forward voltage recovery problem observed (either with or without inverse clipping).

Following the conduction of a total of over  $2 \times 10^4$  C of charge in about  $6 \times 10^4$  pulses, the anode of the tube was disassembled from the remainder of the tube and the interior of the device was inspected. No evidence of accelerated wear (or other possible life limiting effects) was seen. The site of the inverse clipping conduction was found to be localized at the anode upper shoulder. This created no obvious problems to the tube itself. Otherwise, the arc-track activity was spread out uniformly over the areas which were originally designed to handle the current. The tube was then reassembled and has since been operated for at least three more 30 s runs.

There are two practical limitations to optimum performance in an arbitrary system. The first is the thermal heat loading of the electrodes already described. This is tractable by conventional techniques and impacts the size, weight and duty cycle of the device. The second is the control of the He gas pressure. The gas pressure stability was found to be a function of the peak current. At currents below about 10 kA, the gas clean-up rate is rapid, presumably due to conduction taking place in a glow discharge mode. At higher currents, the clean-up rate is reduced. Relatively little clean-up was observed at the highest currents where the effective conduction voltage drop was low.

### Summary

The upper limits of the peak current, peak voltage and repetition rate have not yet been established. Since the maximum switchable power varies as the product of these three parameters, it is reasonable to assume that this power limit is in excess of the 0.8 MW reported herein.

### REFERENCES

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- <sup>2</sup>M.A. Lutz, R.J. Harvey, H. Alting-Mees, "Feasibility of a High Average Power Crossed-Field Closing Switch" IEEE Trans. Plasma Sci., PS4, 118, June 1976.
- <sup>3</sup>M.A. Lutz and R.J. Harvey, U.S. Patent Applications.
- <sup>4</sup>J.R. Bayless, R.J. Harvey, "Continuous Ionization Injector for Low Pressure Gas Discharge Device," U.S. Patent 3, 949, 260.

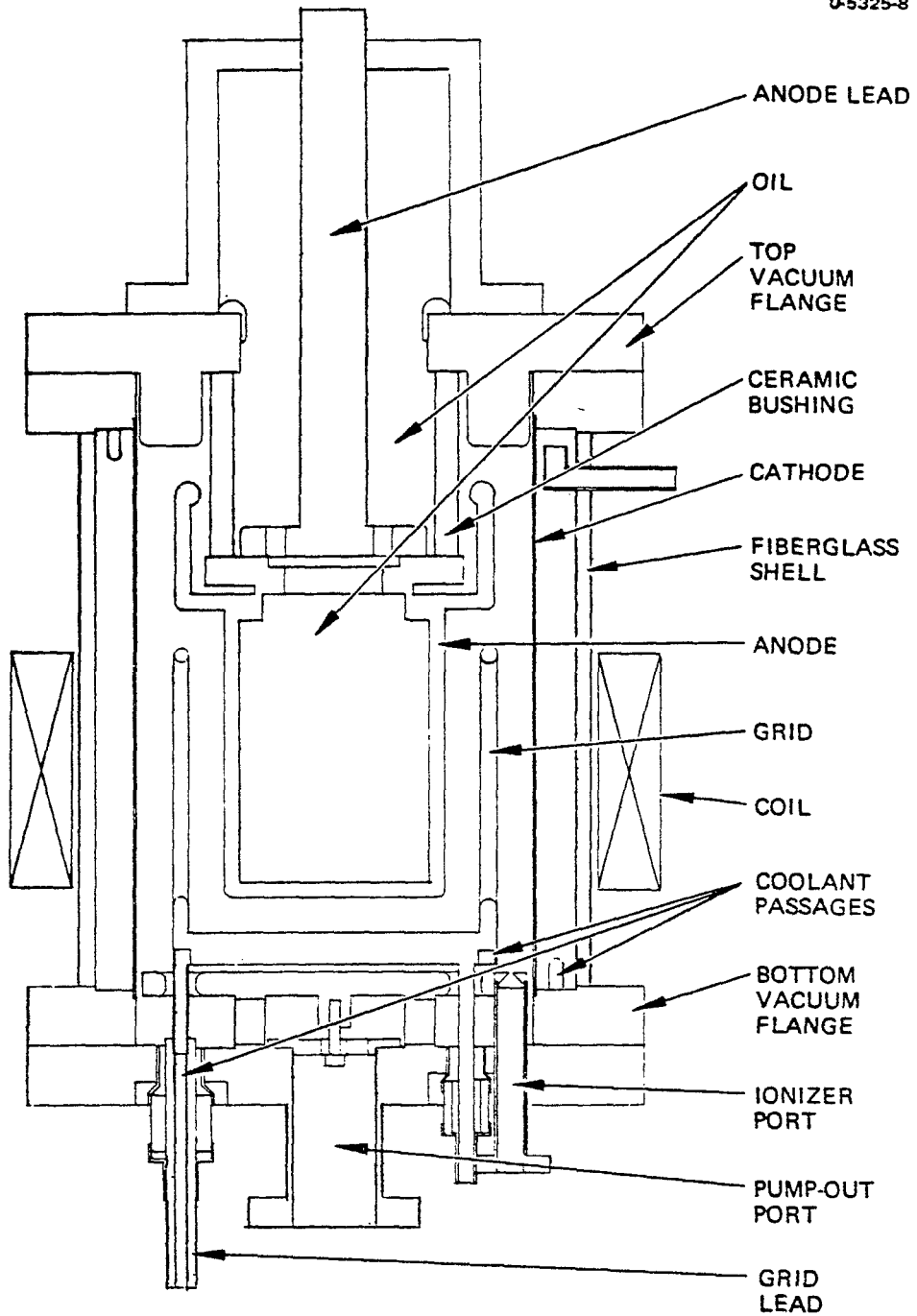


Fig. 1 High average power prototype CFCS design.

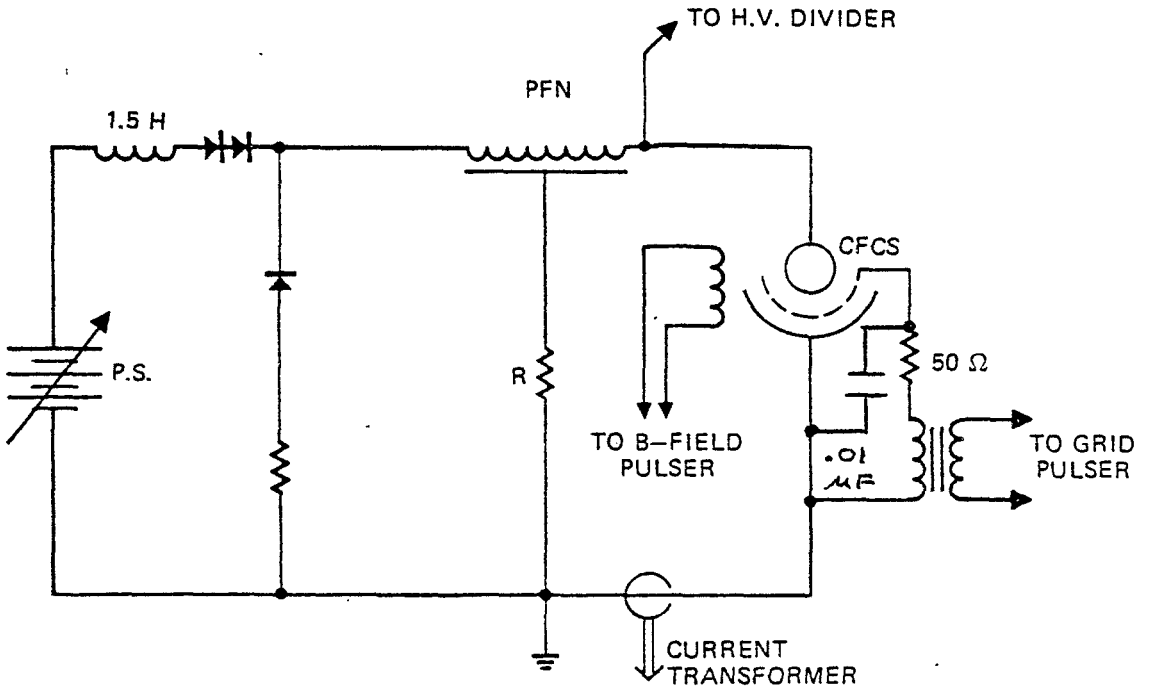


Fig. 2 Test circuit.

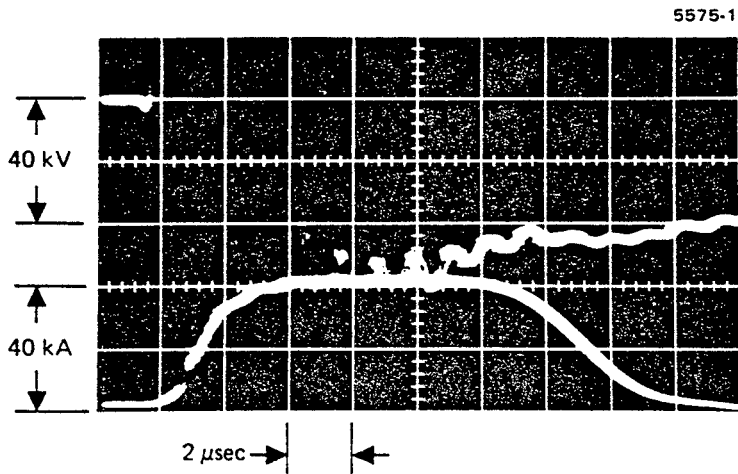


Fig. 3

CFCS operation at: 800 kW average power to load, 800 MW peak power, 80 Hz, and 40 A average current (1240 A rms). Upper trace: resistive divider (dc only) lower trace: switched current pulse wave form; 0.2 s exposure during 30 s run.