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COMPARATIVE STUDY OF INPIStron AND SPARK GAP

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Abstract

An inverse pinch plasma switch, INPIStron, was studied in comparison to a conventional spark gap. The INPIStron is under development for high power switching applications. The INPIStron has an inverse pinch dynamics, opposed to Z-pinch dynamics in the spark gap. The electrical, plasma dynamics and radiative properties of the closing plasmas have been studied. Recently the high-voltage pulse transfer capabilities of both the INPIStron and the spark gap were also compared. The INPIStron with a low impedance Z = 9 ohms transfers 87 % of an input pulse with a halfwidth of 2 μs. For the same input pulse the spark gap of Z = 100 ohms transfers 68 %. Fast framing and streak photography, taken with an TRW image converter camera, was used to observe the discharge uniformity and closing plasma speed in both switches. In order to assess the effects of closing plasmas on erosion of electrode material, emission spectra of two switches were studied with a spectrometer-optical multichannel analyzer (OMA) system. The typical emission spectra of the closing plasmas in the INPIStron and the spark gap showed that there were comparatively weak carbon line emission in 658.7 nm and copper (electrode material) line emissions in the INPIStron, indicating low erosion of materials in the INPIStron.

Introduction

A compact and high power switch capable of giga-volt•ampere level operation is essential for the development of the compact pulser systems useful for beyond the-state-of-arts applications. For example a compact pulser requires that the final output stage switch should be able to transfer a train of 1-μs pulses with typically > 36kJ of energy at 1 megavolt and at the repetition rate of 10 Hz fed from a 4 - 6 Ω, fast pulse forming line (PFL). To date these requirements can be met only by a spark gap with a limited life.[1] Furthermore, the compact pulser requires a six-fold reduction in weight and a two-fold reduction in volume of the conventional pulser system. Therefore, the switch must be compact and of light weight. We reported earlier an INPIStron, a coaxial plasma switch, out-performed the conventional spark gap meeting the above requirements and thus uniquely qualified for the pulser. This presentation includes a report of recent investigation on the INPIStron pulse power-transfer characteristics in comparison with that of a spark gap.

Inverse-Pinch Plasma Switch, INPIStron

The INPIStron has a novel electrode geometry in contrast to the convnetional spark gap as shown in

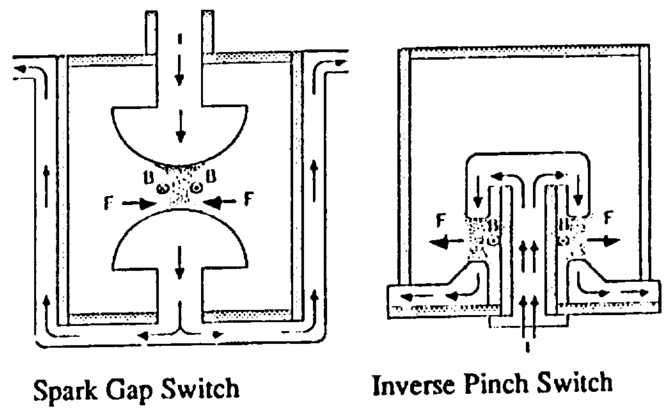

Fig. 1 Principal of inverse pinch switch and spark gap. (Trigger arrangement are not shown)

Fig. 1. The plasma dynamics employed in the INPIStron is an inverse-pinch , opposed to a z-pinch dynamics in the spark gap. Therefore the current sheet in the INPIStron is dispersed by the ponderomotive force F=J x B which quadratically increases with the total current since the self-induced magnetic induction B is proportional to J. Hence the INPIStron is capable of commutating ultra-high current without severe erosion of the electrode material. In earlier work a pulse train of 5×10^{10} V•A (i.e.25kV x 2MA) at 1 Hz has been transferred to a low impedance load via a single unit of this switch. Also the switch was operated with hold-off voltages up 250 kV and a design for 1-MV has been made.[1-3] The detailed configuration and characteristics of the INPIStron were reported elsewhere.[1-3] Fig. 2 is the cross section of a high current INPIStron coupled with a coaxial plasma-puff trigger unit employed in this study. The trigger unit was placed as "a cap" on the inner electrode and generated "a plasma-puff" in the annular discharge chamber when a high voltage pulse was applied. The electrical parameter used for testing the INPIStron and the reference spark gap used are listed in Table 1. Various methods for plasma puff

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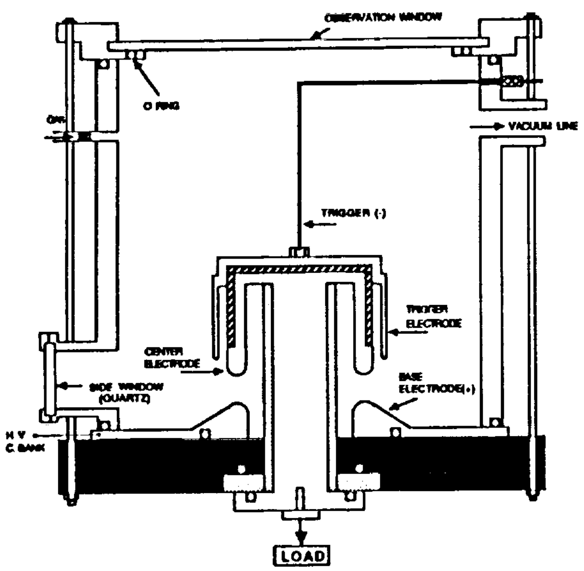

Fig.2 Detailed design of the inverse pinch switch

Table 1

Parameters	INPIStron	Spark-gap	Unit
Capacitance	8.21	8.21	μF
Capacitor energy	1.65	1.65	kJ
Operating voltage	20	20	kV
Cycle period	9.6	11.4	μs
Rise time	1.9	2.9	μs
Ringing frequency	104	88	kHz
Total circuit inductance	283	399	nH
Total resistance	25.35	27.01	mΩ
Switch inductance	17.6	147.8	nH
Switch Capacitance	219.9	14.7	pF
Switch impedance	8.94	100.27	Ω
Damping factor (R/2L)	4.47×10^4	3.38×10^4	Ω/H

initiation of the INPIStron have been tested and the range of working gas pressure that produce azimuthally uniform initiation of the switch were determined and reported elsewhere.[4] This experiment was performed on a system which comprised of a capacitor bank, a power supply, a Marx generator for a high voltage trigger pulse and a vacuum pump unit. The 3.6 kJ capacitor bank composed of 3 capacitors in parallel and a total capacitance of 6 μF was charged up to 40 kV. The trigger pulse with 30 ns risetime generated by the Marx generator was used for the initiation of breakdown for the INPIStron.

Diagnostics used were frame and streak photographs, and voltage and current probing at both low and high pressure side of the Paschen curve. The peak forward currents were obtained by using the oscilloscope trace of Rogowski coil voltage signals. The test results showed that the INPIStron was transferring the pulse power as expected from the circuit analysis when the "plasma-puff" initiation took place uniformly in the annular gap. At the Hampton University a single unit INPIStron is currently employed to replace multichannel spark-gap array used in past in a high energy capacitor bank and realized compactness, simplicity, reliability and cost effective operation. Compact high energy pulsers necessary for high power laser excitation, dense plasma production, weapons effect simulation, electromagnetic launchers and electric propulsion in space will similarly benefit from adoption of INPIStrons.

This presentation is the report of a recent study made with an INPIStron and a spark gap in order to compare pulse transfer fidelities and material erosion in an identical pulsed power system.

Comparative Study of Pulse Transfer Fidelity

Fig. 3 shows the experimental setup used for the study. The INPIStron and the spark gap were alternately inserted in the identical pulse circuit which consisted of a high voltage power supply, a pulse-forming Marx generator, a trigger pulse generator, and the two high-voltage probes connected to a fast-two-channel oscilloscope (TEK556).

The INPIStron and the spark gap housed in the same chamber had impedances of Z=9 ohms and 100 ohms respectively. The low impedance of the INPIStron is the result of coaxial current path with a small (near unity) aspect ratio and having a large relative dielectric constant ε of the insulator that surrounds the inner electrode. Since the transmission lines and the loads of ultra-high pulse power system are designed to have Z<10 Ω, the use of high-impedance switches such as spark gaps causes sacrifices in the pulse transfer fidelity

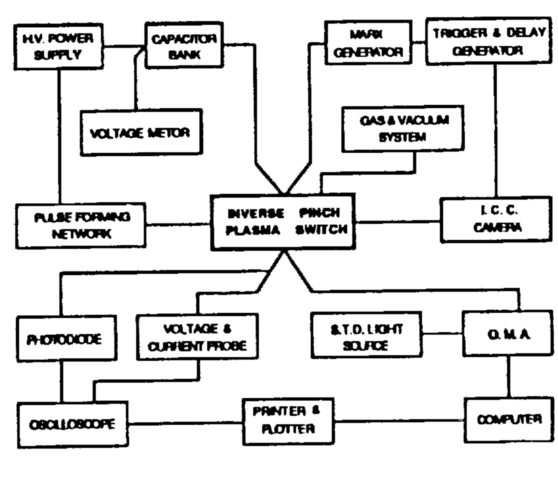

Fig. 3 Experimental set-up for INPIStron and Spark switch.

and the transfer efficiency.

The experiment was carried out to verify the above expectation with a train of real pulses with a 1-μs risetime from the pulse-forming Marx generator which had 13 stages of voltage multiplication. Because of large switching jitters (≈ 1 μs) among the switches (mini spark gaps) placed between stages when the Marx was elected, the output pulses contain multiple spikes as shown on the traces in Fig. 4. As indicated, Fig 4(A) was obtained with the INPIStron and Fig. 4(B) was with the spark gap reference. The upper traces represent the input pulse monitored at the input electrode (anode) and the lower traces represent the pulse at the output point on the switch electrodes (cathodes). The high-voltage probes used here were Tektronix model P6015 which had square-pulse shape and voltage calibrations. As shown, the peak power reduction through the switch for the INPIStron is 11% while that for the spark gap is 42%. No significant changes in the half width of the pulse are observed for both switches. The ratio of the input-and output-pulse energy (E =∫P•dt) or the pulse-energy transfer efficiency for the INPIStron is 87% while the ratio for the spark gap is 68%.

These findings are significant in that the choice of the output switch can influence the pulse-power system efficiency substantially. Replacing a spark gap with an INPIStron, as has done here, will result in an increase of greater than 50% in the output peak power. The equivalent circuit for the setup are shown in Fig. 5 which were simulated by PSPICE program and found a good agreement with the results shown in Fig. 4 except the noise spikes resulted from the pulse forming Marx pulser.

Spectra of Closing Plasmas

In order to assess the effects of plasma current density on the erosion of electrodes and insulators, emission spectra of INPIStron and the spark gap were compared. Fig. 6 is representative spectra obtained with an identical spectrometer-optical-multichannel analyzer system. The spectra (time-intengrated) indicate the color temperature of the argon plasma of approximately 4,000 K corresponding to the peak emission near 750 nm. The upper trace, which represents the emission spectrum of the spark gap, shows substantially higher irradiance of both continuum and line emissions in comparison to the lower trace for the emission from the INPIStron, indicating higher plasma temerpature and impurity content due to evaporation of materials in the spark-gap-plasma. (However the quantitative analysis of these spectra have not been done yet.)

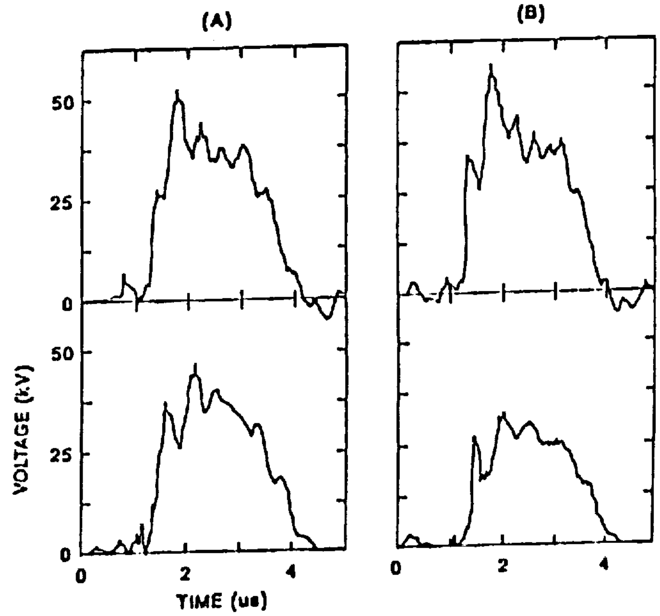

Fig. 4 Pulse transfer characteristics of (A) the INPIStron (B) the spark gap. The upper traces are the input pulses and the lower traces are switch outputs. This INPIStron performs with a better pulse shap fidelity and efficiency than that of the spark gap.

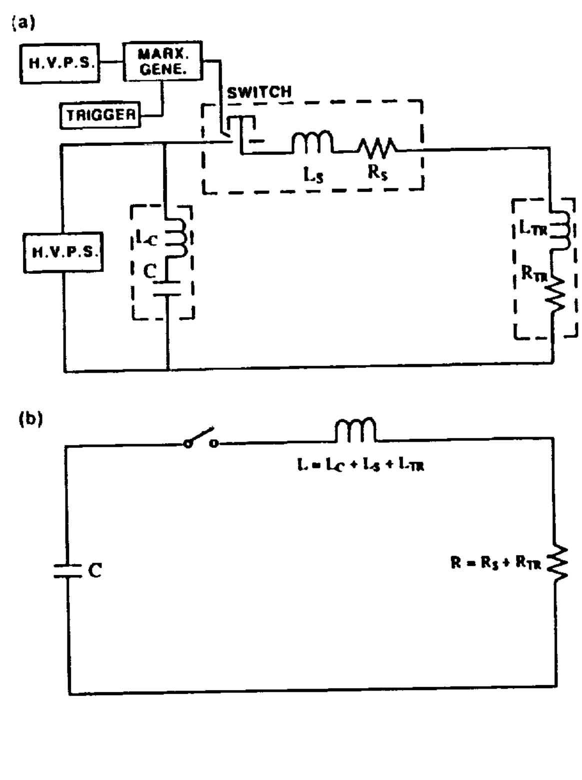

Fig. 5 Schematic (a) and equivalent (b) circuit of the system.

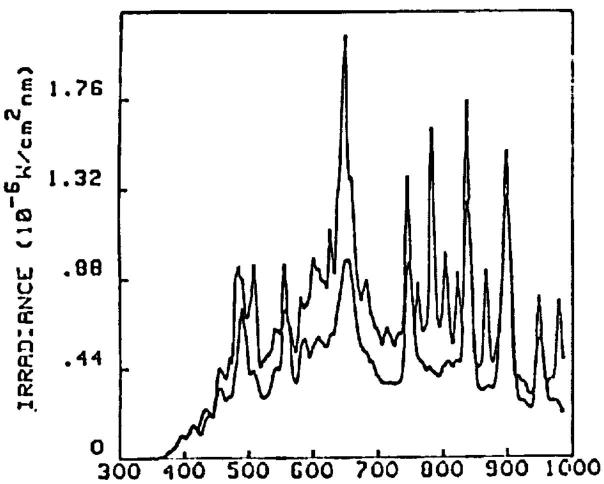

Fig. 6 Line emission from INPIStron and spark gap for comparison. Upper trace is for a spark gap trace for INPIStron.

Summary and Conclusion

An extended study of the INPIStron for the pulse transfer fidelity and efficiency revealed the INPIStron as the superior performer over that of the reference spark gap. Also material errosion, compared with the emission spectra of the closing plasmas in the two switches showed considerable differences which indicate the low current density and low material erosion in the INPIStron. These findings again confirm the superiority of the INPIStron already found with respect to other parameters of high power switching such as the voltage hold-off, the Coulomb transfer, the lifetime, material erosion, and the repetition rate.

Acknowledgments

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References

1. J. H. Lee, S. H. Choi, D. D. Venable, K. S. Han, and S. H. Nam, "Characteristics of Switching Plasma in an Inverse-Pinch Switch," Eighth IEEE Int. Pulsed Power Conference, San Diego, CA June 16-19, 1991 (Digest of Tech. Papers, IEEE Cat. No. 91CH3052-8, P.904)
2. S. H. Nam, S. H. Choi, and K. D. Song, "Design for Megavolt Inverse-Pinch Plasma Switch," Nineteenth Power Modulator Symposium, San Diego, CA June 1990 Paper 8.20.
3. J. H. Lee, S. H. Choi and K. D. Song "Preliminary Test for Megavolt Inverse-Pinch Plasma Switch," Nineteenth Power Modulator Symposium, SanDiego, CA June 1990, Paper 8.20.
4. E. H. Choi, K. S. Han, D. D. Venable, J. H. Lee, "Characteristics of Plasma-Puff Trigger for an Inverse-Pinch Plasma Switch," Spring Meeting of the American Physical Society, Wash. DC, April (Bull. APS 35, 1051 (1991)).