A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR--83-1573

DE83 014200

TITLE: EXPERIMENTAL INVESTIGATION OF EXPLOSIVE-DRIVEN PLASMA-COMPRESSION OPENING SWITCHES

AUTHOR(S): J. H. Goforth, M-6
R. S. Caird, M-6

SUBMITTED TO: IEEE Pulsed Power Conference, June 6-8, 1983, Albuquerque, NM

EXPERIMENTAL INVESTIGATION OF EXPLOSIVE-DRIVEN PLASMA COMPRESSION OPENING SWITCHES*

J. H. Goforth and R. S. Caird
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Summary

Plasma-compression opening-switch techniques are being developed for use in explosive-driven magnetic-flux-compression-generator applications. A new test bed for performing low-cost experimentation is described. Experiments with ~0.15 MA/cm linear current density in the switch have achieved resistance increases of a factor of 10 in a few hundred nanoseconds. Peak field strengths of 30 kV/cm are generated in these tests. Data are presented from preliminary tests that indicate reduced pressure in the plasma cavity enhances switch performance.

Introduction

Many schemes for producing multi-megampere current pulses with risetimes of a few hundred nanoseconds require an opening switch to provide time compression of a slower high current pulse. Fuse techniques for opening switches have been extended to very high current ranges[1,2] but have the disadvantages of having a limited ratio of total pulse length to opening time and not being an on-command switch. A switch capable of interrupting high current pulses of any length on-command was described by Pavlovskii, et al.[3] We are exploring the prospects of using this technique in our applications, which employ fast explosive driven magnetic flux compression generators as high current supplies.

These plasma compression opening switches depend on early stages of the current pulse to cause the formation of a plasma that has high conductivity during the conduction phase of the switch. One wall of the plasma cavity is a high explosive and, when detonated, the explosive by-products are introduced into the cavity at high pressures, increasing the plasma resistance. The physical mechanisms causing this resistance increase are a subject of this research. In addition, the research is aimed at characterizing and improving switch performance at current densities of interest.

We describe here a new test geometry that allows switch performance data to be obtained accurately and inexpensively. In addition, results of tests performed in the new geometry using capacitor bank and high explosive driven magnetic flux compression generators as power supplies are presented. Finally, results from experiments designed to explore switch mechanisms are presented.

New Test Geometry

Figure 1 illustrates the geometry introduced by Pavlovskii for plasma compression opening switches. In principle, this is the ideal arrangement for the switch. It has good field symmetry in the plasma cavity and good isolation between electrodes during the high voltage opening stages. It is also convenient in this geometry to couple the output of the switch to a coaxial load. It is, however, very expensive and time consuming to fabricate a switch of the type shown. As a result, it is not practical for

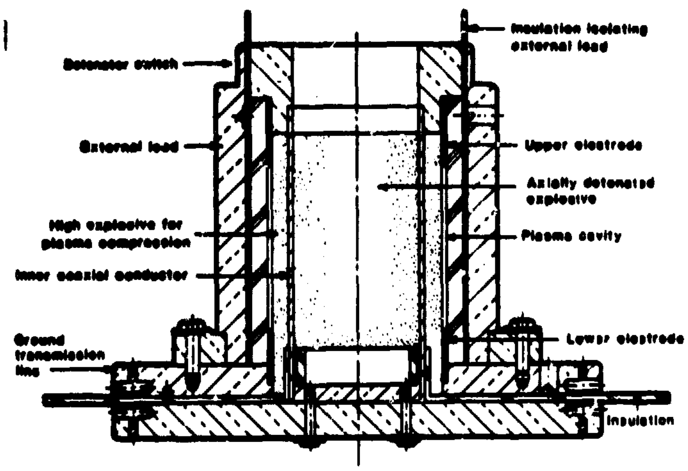

Figure 1. Plasma compression opening switch geometry introduced by Pavlovskii. Current flowing in the coaxial region returns to ground through the plasma cavity initially and through the external load after the detonator switches are actuated.

performing the fifty to 100 tests required to evaluate switch characteristics.

Figure 2 illustrates a new arrangement we have devised for conducting switch evaluation experiments. This geometry complicates analysis by imposing electric field and current density in the plasma cavity that vary as 1/r, where r is the distance from the center of the concentric electrodes. It does,

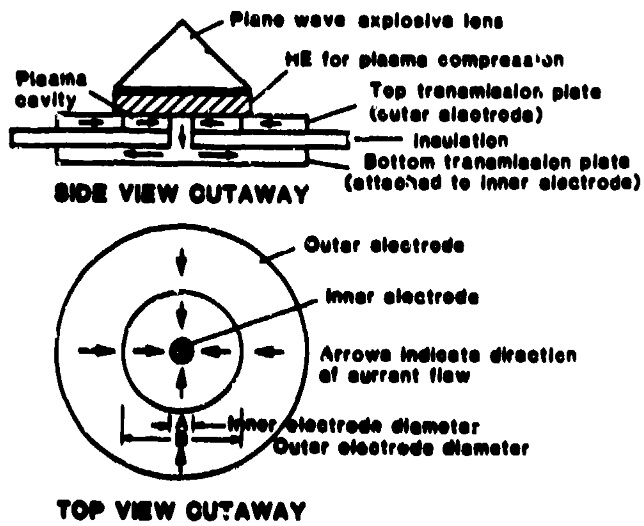

Figure 2. Cutaway sketches showing the side and top views of the new test geometry. Arrows indicate direction of current flow in both views. Dimension A is the diameter of the inner electrode and B is the diameter of the outer electrode.

* Work supported by the United States Department of Energy.

however, provide good field symmetry and good high voltage isolation between the electrodes at opening time. It is also inexpensive to build and operate in size ranges up to 30 cm diameter. (This 30 cm limit is imposed by the availability of good inexpensive explosive plane wave lenses for simultaneously detonating the plasma compression explosive.) The design is also adaptable to operation on the end of coaxial transmission lines or in the center of parallel plate transmission lines. It appears to be a straightforward problem to switch to a parallel load in the parallel plate geometry, but more difficult if the switch is on the end of coaxial electrodes. To date, we have made no attempt to use this switch for any purpose other than switch evaluation.

Experimental Results

Capacitor Bank Experiments

The power supplies used in our opening switch applications are explosive driven magnetic flux compression generators. These devices require an external initial field source, and for this purpose we have a conventional capacitor bank capable of delivering megampere currents with risetimes on the order of 20 μs. The most expedient way to perform small scale opening switch experiments is to use the capacitor bank as a primary power supply.

To test our new geometry in this manner, we scaled the switch size to operate at the 1 MA level. In scaling the switch, we take the distance (B−A)/2 to be the length of the plasma cavity, and the circumference (π/2) (B+A) as the average switch width. The plasma cavity depth is 0.30 cm in all tests. The length is used for computing average electric field strengths, and the width for determining an average value of current per unit width in the plasma. We chose A=1.27 cm and B=2.54 cm for our small scale experiments, which provides an average current density of ~0.17 MA/cm at a peak current of 1 MA.

The current history and current density are important factors in the operation of devices of this type and in the majority of our tests we have attempted to keep these two variables relatively fixed. Within this constraint, we primarily consider three parameters in evaluating switch performance. The first is the change in resistance when the explosive interacts with the plasma. The second is the rate of change of the resistance, and the third is the average field strength at peak switch voltage. Results from experiments using our new geometry reveal switch performance that is greatly improved in comparison with results obtained in previous small scale experiments using parallel plate geometry for the switch cavity.[4]

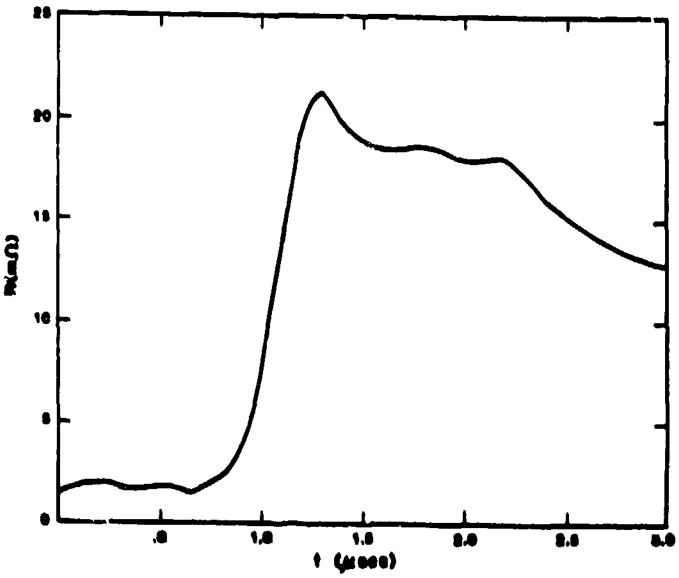

Figure 3. Resistance increase achieved in a typical small scale switch test.

The curve in Fig. 3 shows the resistance increase obtained in an experiment using the new small scale test device. The curve is typical of the results obtained in these capacitor bank experiments. The resistance increases by a factor of ~10 in a few hundred nanoseconds. The peak field strength for this test was ~30 kV/cm.

We have achieved good reproducibility from test to test with this small scale switch. As a result, we expect to be able to perform definitive experiments relative to fundamental switch mechanisms. Some preliminary experiments of this type are presented in a later section.

Explosive Generator Tests/Scaling

In order to ascertain the validity of our small scale test results when applied to larger devices, we have run a series of tests using parallel plate explosive-driven magnetic flux compression generators as the prime power supply for larger switch assemblies. We scaled two separate parameters for

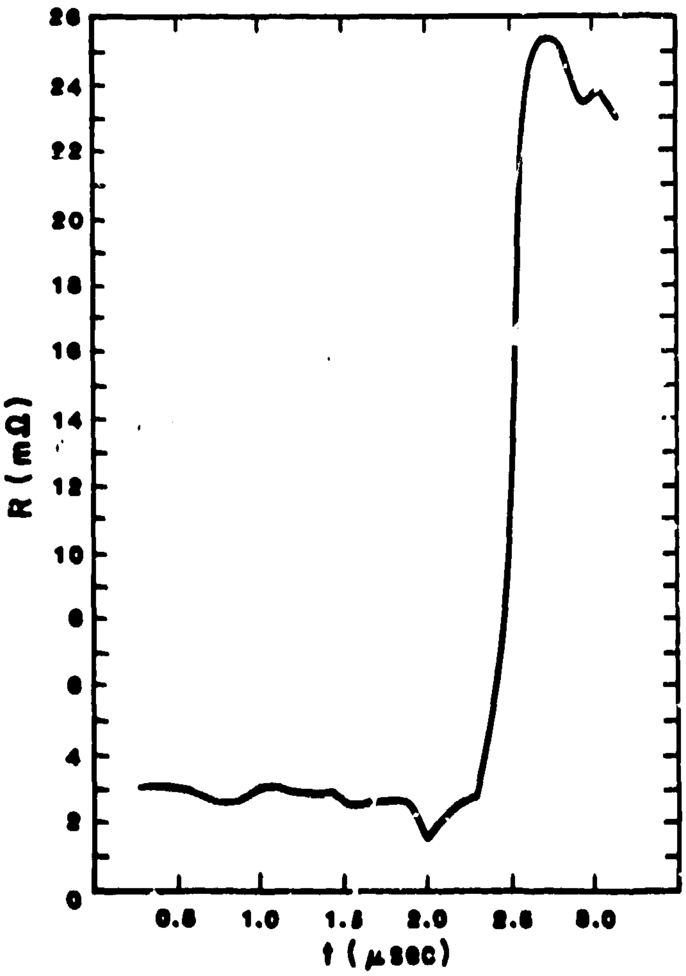

Figure 4. Resistance increase achieved in a scaled up switch test.

these tests. With A=2.5 cm and B=7.5 cm, the average circumference of the switch is 15.7 cm, allowing it to carry 2.5 MA at an average current density of 0.16 MA/cm. In addition, the ratio of length to circumference is ~0.16 for this switch as compared to ~0.11 in our small scale tests. Several other parameters also affect the switch resistance, but if switch resistance scales according to this ratio, the resistance of the larger scale device should be about one and a half times that of the small scale switch.

We have performed a small number of these explosive generator powered switch tests and the resistance curve from one of these is shown in Fig. 4. In this test, the current density was 0.16 MA/cm at switch time, allowing a direct comparison with small scale results. The resistance increases by a factor of ~10 in less than 500 ns in this test. The peak field strength is 24 kV/cm. Two such tests were performed at this current density with similar results. It appears that the switch can be scaled up to larger sizes without any severe adverse effects on switch performance.

As a final comment on scaling, we expect switch resistance just prior to compression to be dependent on the total current history, so we do not necessarily expect this parameter to scale in a test where the current history is different. Peak resistance, on the other hand, may or may not scale depending on the switching mechanism. A careful set of experiments dedicated to this point will provide valuable information for determining the mechanism important in the resistance rise. Specifically, if peak resistance is found to be a function of initial resistance, then the switch mechanism is likely to be pure compression at constant resistivity. If peak resistance is not a function of initial resistance, pure compression is surely not the sole switching mechanism. An interesting consequence of the switch mechanism being pure compression is that the ratio of final to initial resistance would be fixed for a given internal energy in the plasma.

Our primary consideration in this project is the operating characteristics of these switches at relatively high current densities. It is worth pointing out, however, that in a few experiments at current densities well below those cited so far, significant gains in peak switch resistance have been achieved. Figure 5 is a resistance plot from an explosive generator powered test using a switch with B=7.5 cm and A=2.5 cm. The current density in this shot was only 0.08 MA/cm, and the resistance increases by a factor of 19. The resistance rise occurs in ~600 ns, and peak field strength is 25 kV/cm. Reducing the current density apparently makes a significant improvement in switch performance.

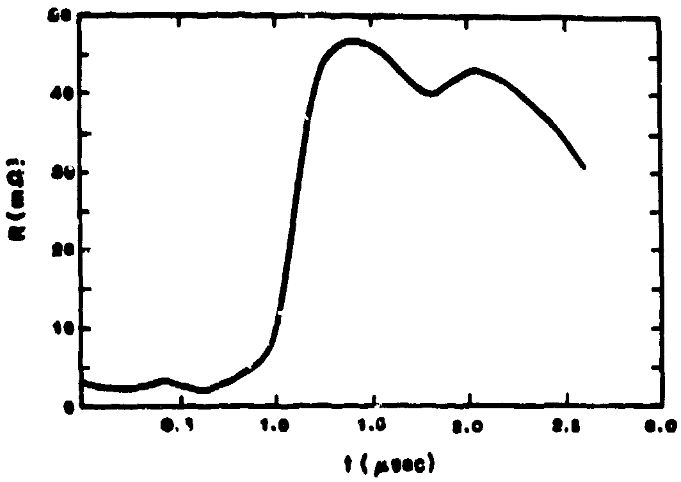

Figure 5. Resistance increase achieved in a scaled up switch test at reduced linear current density.

__Switch Mechanism Experiments__

A major goal of this research is understanding the physical mechanisms underlying the resistance rise observed in plasma compression switches. The new switch geometry provides an excellent test bed for performing definitive experiments, and we are proceeding with an experimental program to this end.

Our first efforts have been directed toward testing a switch model proposed by Greene et al.[5] Based on differing energy sinks during the plasma compression process, the model predicts improved performance in some circumstances. The first experimental series was to determine whether any difference could be detected experimentally in cases where the model predicted differences to occur.

A few preliminary experiments were dedicated to testing the prediction that plasmas formed from different gases initially in the cavity will produce different switch performance. The model predicts that a plasma having completely stripped ions will convert much of the energy of compression into thermal energy, thereby raising the plasma conductivity. A plasma of this type would make a relatively poor switch compared to a plasma in which an abundance of ionization states are available as energy sinks. To see if we could demonstrate this point, He and Xe were introduced into the switch cavity on separate experiments. These two gases were chosen with the notion that He might be fully stripped, but Xe would surely not be.

In our small scale hardware, the electrodes are separated by only 0.64 cm, which breaks down readily when the 15 kV charge voltage on the capacitor bank is applied. As a result, these tests were run with the simplest configuration achievable. The only materials involved in the test were the brass electrodes, the Teflon insulation, the PBX-9404 compression explosive and the gas in the cavity. In addition to He and Xe at atmospheric pressure, atmospheric air was used in an additional test for reference.

The tests proved inconclusive, as no measurable differences occurred between the tests with He and Xe, but no diagnostics were used to determine the ionization state in either shot. The performance of the switch using air in the cavity was slightly better than either of the other switches, however. Since another type experiment was available for testing the model, further tests of this type have been postponed.

Another set of preliminary tests were performed to check the prediction that reducing the pressure in the switch cavity would improve switch performance. As in the previous tests, the applied voltage was used to break down the gas (air) in the switch gap. This did require, however, that pressure be above the critical point on the Paschen curve, and hence experiments were performed at 1.5 Torr, 20 Torr and atmospheric pressure. Data from these tests are presented in Fig. 6.

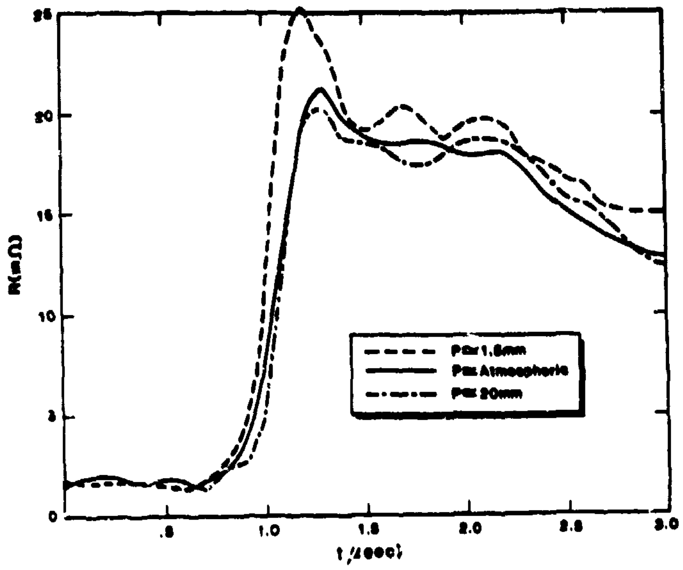

Figure 6. Resistance increases achieved in small scale experiments where the initial air pressure in the switch cavity was varied as indicated.

The figure shows that tests at atmospheric pressure and 20 Torr are very similar, but that the test at 1.5 Torr is measurably improved. The test at 1.5 Torr was repeated with a similar result. Apparently the effect of the reduced pressure is to enhance switch performance.

These experiments have not conclusively tested the details of the model, but do show trends that the model predicts. Further work will be required to test the model in a quantitative way.

Conclusion

A new test bed has been devised that gives reproducible results in a configuration that is simple and inexpensive to use. It appears that scaling laws determined from small scale testing in the new test bed can be applied to larger devices. As a result, experiments leading to a good characterisation of switch performance and mechanisms are now possible.

Our experiments, to date, indicate that resistance increases of a factor >10 are possible at linear current densities of 0.15 MA/cm, with risetimes of a few hundred nanoseconds. Lower current densities will provide larger resistance increases. Peak average field strengths of ~30 kV/cm can be expected. In addition, the tendency for better switch performance in an initially evacuated switch cavity has been demonstrated.

Acknowledgements

The authors wish to acknowledge the considerable efforts of our firing point crew, J. C. King, A. R. Martinez, D. T. Torres and D. Herrera, without whose support this report would have been impossible.

References

1. C. R. McClenahan, J. H. Goforth, H. H. Degnan, R. M. Henderson, W. H. Janssen and W. E. Walton, "200 kJ Copper Foil Fuses," Air Force Weapons Laboratory Report, AFWL-TR-78-130, 1980.

2. R. E. Reinovsky, D. L. Smith, W. L. Baker, J. H. Degnan, R. P. Henderson, R. J. Kohn, D. A. Kloc and N. F. Roderick, "Inactive Store Pulse Compression System for Driving High Speed Plasma Implosions," IEEE Transactions on Plasma Science, Vol. PS-10, No. 2, p. 73, 1982.

3. A. I. Pavlovskii, V. A. Vasyukov and A. S. Russkov, "Magnetoimplosive Generators for Rapid-Risetime Megampere Pulses," Sov. Tec. Phys. Lett. Vol. 3, P. 320, 1977.

4. J. H. Goforth, R. S. Caird, R. F. Benjamin, D. J. Erickson, C. M. Fowler and B. L. Freeman, "Fast Explosive-Driven Opening Switches Carrying High Linear Current Densities)." To be published in Proceedings of Third International Conference on Megagauss Magnetic Field Generation, June 1983.

5. A. E. Greene, J. H. Brownell, T. A. Oliphant, G. H. Nickel and D. L. Weiss, "Computational Simulations of Explosive-Driven Plasma-Quench Opening Switches." To be published in the proceedings of the Fourth IEEE Conference.