TITLE: TESTING RESULTS FOR THE HCT-1400 SWITCH

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INTRODUCTION

The High Current Thyristor (HCT) -1400 was characterized for switching performance. This is a Soviet switching device that has recently become available to the U.S. community. Substantial claims have been made regarding the performance of this switch. In particular, the switch was claimed to be able to switch high currents, with very short risetime without any significant jitter. This is an independent evaluation of the high current thyristor.

The effort reported here was made possible by the teamwork of several organizations and demonstrates that complicated and challenging efforts can be accommodated through the Small Business Staff Member Program of the Industrial Partnership Office (IPO). The project ultimately resulted in a close teaming of technologist from AOT-9 (Accelerator Operations and Technology-High Power Electronics), DX-1, DX-3 (Detonation Physics), Moose Hill Enterprises, Inc. of Virginia and Reynolds Industries, Inc. of California to explore the commercial possibilities of a novel switch developed at IOFFE Institute, St. Petersburg, Russia. This project has been recognized by the Laboratory as an excellent example of DUAL-USE technology development with immediate value to the nation’s defense program. Reynolds Industries, Inc. has now taken the lead in providing American made switches using the Russian technology for use in United States commercial and military applications.
MEASUREMENT SYSTEM

The switch was tested in a low inductance circuit shown in Figure 1. The circuit layout was carefully constructed to minimize inductance in the output circuit.

HCT TEST CIRCUIT

![Test Circuit Diagram]

Figure 1. Test Circuit

MEASUREMENTS

The first set of tests was done with $R_{tot} = R_{load} + R_{shunt}$ of 0.250 ohms. The purpose of these measurements was to characterize the switch in a typical geometry that allowed direct comparison with other types of switching devices.

The output waveforms for different charge voltages is shown in Figure 2. The voltage was raised in approximately 100 volt increments to 1400 volts, the recommended upper
limit for the HCT-1400. This switch has been tested to higher voltage (1600 volts) at another facility to failure test for maximum performance (2). Charging voltages above 1000 volts require the use of an external diode to carry the reverse current that occurs after the first positive current pulse. The newer HCT devices incorporate an internal reverse diode inside the device. This is expected to reduce stray inductance of the circuit. These devices were not available during the test phase. The use of an external reverse diode branch can lead to confusion when used to measure circuit ring parameters. Typical procedure of measuring circuit Q are not valid with solid state devices like the HCT because the behavior after the first zero crossing is determined by the reverse diode and not by the HCT. New measurement protocol is required to correctly characterize solid state devices that do not have the same forward and reverse impedance characteristics. This is necessary to avoid damage to the HCT-1400.
Figure 2. Output Current for Various Charge Voltages
The jitter of the output pulse relative to the input trigger pulse to the HCT-1400 was also measured. Applications such as parallel triggered arrays of HCTs will require low jitter to maintain satisfactory risetime from the overall circuit. The jitter measurements were accomplished with a specialized 256 Giga-Sample / second transient digitizer. The output current of the HCT-1400 was differentiated to obtain a faster risetime signal that was compared to the input trigger pulse. The input trigger pulse was delayed and added to the HCT-1400 output pulse and then digitized. The jitter of the HCT-1400 was measured to be less than 20 picoseconds. The jitter may actually be better than the measured value because the differentiation assumes that the shot - to - shot output waveform does not vary.
RESULTS AND COMPARISON WITH OTHER DEVICES
The most equivalent switch presently produced in the west is a small triggerable spark gap. The triggered spark gap is a small vacuum gap with a separate trigger electrode. The trigger voltage has to be the same as the voltage to be switched, which adds to the circuit complexity. A triggered spark gap with the necessary trigger circuit was used in the same circuit to provide a direct comparison with the HCT-1400. The output circuit and output probes used for the measurements were the same as used with the HCT-1400. The output current for three charge voltages for each switch are compared in Figure 3.
Figure 3. Comparison of HCT-1400 and Spark Gap Performance
The triggered spark gap switch is designed to operate in the 2000 to 4000 volt regime and demonstrated less shot-to-shot reproducibility than the HCT-1400 when tested below the rated voltage. This is apparent in the spark gap traces and results in the thickness of the vacuum spark gap waveforms. Again, this is the closest performance switch presently available in the west. All of the spark gap based devices suffer from the same problems of aging with number of pulses and lifetimes of a few hundred pulses.

The switch most like the HCT-1400 in terms of high voltage performance (>1400 volts) is the vacuum triggered spark gap. The spark gap does not have the reproducibility or the lifetime of the HCT-1400. Presently available thyristors in the west are rated for much lower current. The highest current thyristor presently produced in the west is the GA-301. It was used as the trigger thyristor in the circuit. The HCT-1400 produced approximately 23 times more current than the GA-301. Figure 4 is a summary of the HCT-1400 output current for the various charge voltages previously shown in Figure 2. Note that the output current is linear with respect to the charge voltage on the capacitor of 0.0 microfarads. This indicates that the thyristor is still operating in a safe regime even at the highest voltage. In other test fixtures with higher value discharge capacitors, the HCT-1400 has produced up to four kiloampere peak current.

Figure 6 shows the performance of two HCTs stacked and switching a single 0.20 microfarad capacitor charge to 2,500 volts. The standard 0.250 ohm resistor load was used for the measurements. The risetime (10-90%) was about fifty nanoseconds. The extremely low trigger jitter of the HCTs allows for several new high power electronic circuits to be realized.

SUMMARY
The HCT-1400 has high current and high voltage switching capability not available from present western technology.
Figure 4. Peak Output Current as a Function of Charge Voltage.
Figure 5. Performance of a Two HCT Stacked Switch Module.
ACKNOWLEDGMENTS

The effort reported here was made possible by the teamwork of several organizations and demonstrates that complicated and challenging efforts can be accommodated through the Small Business Staff Member Program of the Industrial Partnership Office (IPO). Sue Fenimore, the IPO Project Leader, originated the Small Business Staff Member Exchange Program as a way for industry to take advantage of the unique resources available at the Laboratory. Her idea to bring outside researchers into the Laboratory and to learn measurement techniques and define new technology applications has proved to be invaluable to this activity. She has provided the guidance and the product oriented focus vital to having a successful industrial collaboration effort. Diana Baker, also of IPO, has continually worked with us and has substantially contributed to the value of this project. The project ultimately resulted in a close teaming of technologists from several different backgrounds and countries to make this effort a success. AOT-9, particularly Richard Wheeler, provided the electronics expertise and high frequency circuit design skills needed to build and test state of the art circuits incorporating the Russian switch. DX-1 worked throughout the effort to define areas of switch utility. Both Chris Quihis and Ernie Martinez provided guidance and support that was crucial to the successful conclusion of the project. The ultra low inductance circuits devised and built by Chris Quihis have proven the best approach to the output pulser circuit. Barney O'Meara, the President of Moose Hill Enterprises, Inc. of Virginia, made the vital contacts into Russia and was the first to recognize the intrinsic significance of a technology without a western equivalent. He has committed much time, effort and risk to his personal safety to prove that technology transfer and improvement of the Russian condition are actually possible through capitalism. Ed Malone of Reynolds Industries Inc. of California has been instrumental to the identification and exploration of the commercial possibilities of this novel device. Chase L. Leavitt, President and CEO of Reynolds Industries, recognized the potential for the device and has supported this effort with the finest business acumen we could have wanted. The switch was developed at IOFFE Institute, St. Petersburg, Russia. This project has been recognized by the Laboratory as an excellent example of DUAL-USE technology development with immediate value to the nation’s defense.
program. Reynolds Industries, Inc. has now taken the lead in providing American made switches using the Russian technology for use in United States commercial and military applications.
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