THE HIGH ENERGY LIGHTNING SIMULATOR (HELS) TEST FACILITY FOR TESTING EXPLOSIVE ITEMS

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ABSTRACT

Details of the High Energy Lightning Simulator (HELS) Test Facility for testing missiles, motors, ordnance, and explosive items is described. The HELS Test Facility is designed to simulate the high current, intermediate current, continuing current, and restrike current components of an idealized direct strike lightning waveform.

The HELS Test Facility has been in operation since May, 1988, and consists of four separate capacitor banks used to produce the lightning test components, two steel safety cages and steel barriers for retaining the item under test should it be ignited during testing, an earth covered bunker housing the control/equipment room, a charge/discharge building containing the charging/discharging switching, a remotely located blockhouse from which the test personnel control hazardous testing, and interconnecting cables. Since its construction, a variety of explosive items have been successfully tested.

Besides testing, the HELS Test Facility has also been utilized to manufacture an experimental additive for solid propellant material. The restrike current component generator is ideal for exploding metallic wire in a gas filled vessel to create the additive residue.

In addition to the HELS Test Facility, two other lightning simulator facilities are available for testing at Redstone Technical Test Center. The Simulated Lightning Effects Test (SLET) Facility is available for testing inert items and explosive items limited to Class 1.4 explosives. The Transportable Lightning Effects Simulator (TLES) is available for testing at remote locations or at locations other than Redstone Arsenal.

I. INTRODUCTION

One of the problems associated with simulated lightning testing of inerted missiles and inerted explosive items containing electrically initiated explosive trains is to determine the interaction of the propellants and explosives with the simulated lightning environment. There have been concerns raised in the past that propellants and explosive materials may be susceptible to the indirect effects (radiated fields) of lightning. The HELS test facility was designed and built to simulate lightning strikes on missiles and other explosive items which contain less than 100 pounds of detonable material up to several thousand pounds of propellant materials. The primary objective of testing at this facility is to determine whether

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a hazard exists to personnel or area equipment should the ordnance be struck by lightning. These tests may also be conducted on shipping containers containing live missiles or explosive items to determine if hazards exist in stockpile or shipping configurations. The secondary objective of this testing is to determine whether the ordnance suffers major damage which prevents its use or which requires extensive repairs before it can be used.

II. IDEALIZED DIRECT STRIKE LIGHTNING WAVEFORM

The test facility is designed to simulate components A (high current), B (intermediate current), C (continuing current), and D (restrike current) of the direct strike lightning idealized current test waveform shown in Figure 1 [1 and 2]. These components are intended to reproduce the significant effects of the natural environment and are therefore independent of vehicle type or configuration. The idealized component specifications are as follows:

High Current:	Peak current = 200 kA ± 10% Action integral = 2.0×10^6 A^2 sec ± 20 % Current rate-of-rise = 1.4×10^{11} A/sec ± 10% Time duration ≤ 500 μs
Intermediate Current:	Maximum Charge Transfer = 10 C Average Amplitude = 2 kA ± 10%
Continuing Current:	Charge transfer = 200 C ± 20% Average amplitude = 400 A Time duration: 0.25 sec ≤ T ≤ 1 sec
Restrike Current:	Peak amplitude = 100 kA ± 10% Action integral = 0.25×10^6 A^2 sec ± 20% Current rate-of-rise = 1.4×10^{11} A/sec ± 10% Time duration ≤ 500 μs

III. DESCRIPTION OF THE TEST FACILITY

The HELS test facility is specifically designed to conduct direct strike lightning testing of live, explosive missile systems and ordnance items. For small systems, the near strike lightning environment requirement can be accomplished at the small system test site. The explosive limits for the HELS test facility at the large system test site are 100 pounds of Class 1.1 explosive, 5000 pounds of Class 1.2 explosive, 15,000 pounds of Class 1.3 explosive and unlimited Class 1.4 explosive, while the small system test site of the HELS test facility has an explosive limitation of 40 pounds of Class 1.1 or Class 1.2 explosive. The HELS test facility is comprised of five distinct capacitor banks for simulating the

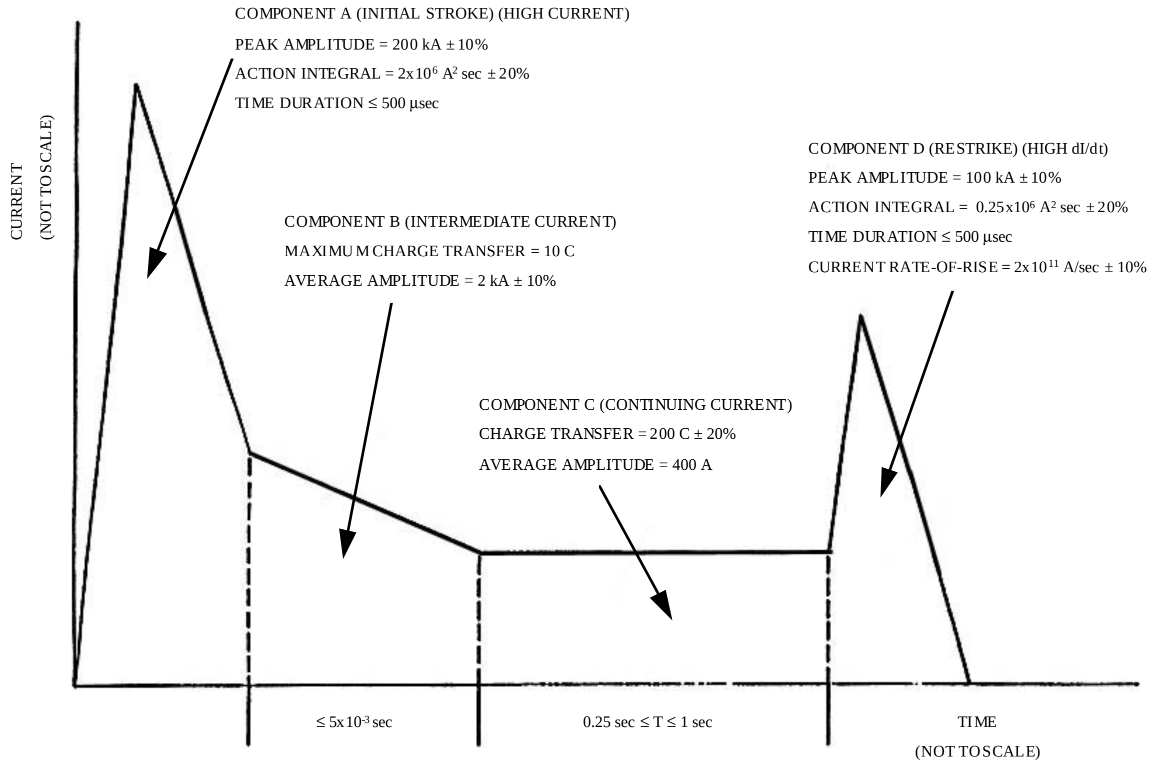

FIGURE 1. DIRECT STRIKE IDEALIZED CURRENT TEST WAVEFORM.

cloud-to-ground direct strike lightning, two steel safety cages and steel barriers for retaining the ordnance item should it be ignited during test, an earth covered bunker housing the control room, a charge/discharge building containing the charge/discharge switching, a remotely located blockhouse from which test personnel control the hazardous testing, and interconnecting cables (see Figure 2). The safety cages are designed to retain missiles and explosive items should they ignite during test. A smaller, removable secondary cage can be installed inside the larger cage to retain smaller test items. The high current and continuing current components are normally simulated simultaneously in one test event, and the intermediate current and restrike current components are simulated in separate test events.

A. HIGH CURRENT SYSTEM

The high current system consists of 480 capacitors each rated at 60 kilovolts (kV) and 1.875 microfarads (µF). It is constructed in 4 layers with 120 capacitors in parallel on each layer. Layers 1 and 2 are connected in series, as are layers 3 and 4. Each layer consists of 10 removable modules with 12 capacitors per module. Individual capacitors are fused in order to prevent the entire bank from dumping into a capacitor fault. Layers

1 and 2 and layers 3 and 4 are charged in parallel to approximately 110 kV and discharged

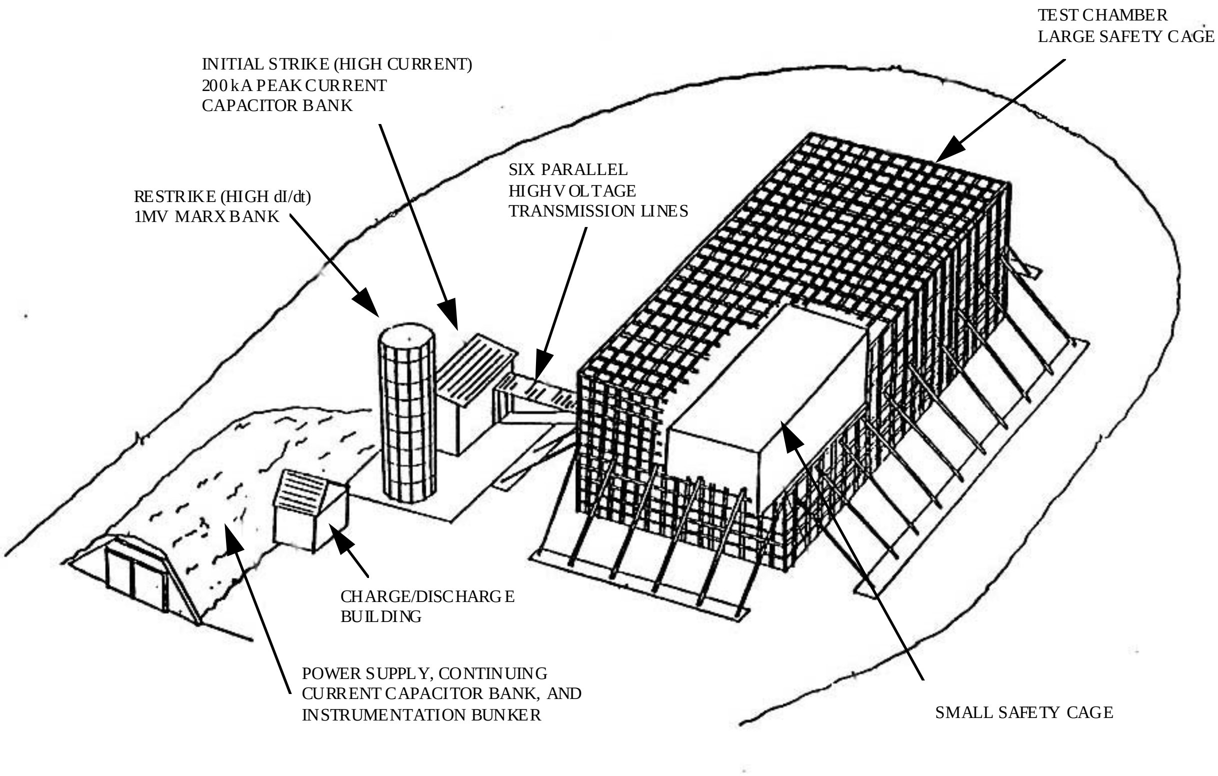

FIGURE 2. TEST FACILITY OVERVIEW

in series to form a two-stage Marx bank with an output voltage of 220 kV. The bank is activated by a triggered spark gap located between layers 2 and 3. An output isolation gap is located above layer 4 to isolate the test load from the bank. A damping resistor is also located above layer 4; it consists of 10 Franklin 60 kV, 240 kilojoule (kJ) resistors connected in a series-parallel arrangement, providing a total resistance of 0.52 ohms. The bank is charged by power supplies whose leads are routed through a switching system located in the Charge/Discharge Building, where charging and slow discharging of the bank can be accomplished by remotely operated pneumatic switches. A 2.25 µF, 300 kV peaking capacitor circuit is utilized in conjunction with the initial stroke capacitor bank to increase the current rate-of-rise time to 6.5 microseconds (µsec). The high current system can generate a 200 kA ± 10% peak current simulated component A waveform with a time to peak of 6.4 µsec into loads up to 4 µH. it delivers an action integral of 2.0×10^6 A^2 sec ± 20%.

The high current bank is activated by the pneumatically triggered spark gap, located between capacitor layer 2 and layer 3, about 20 milliseconds (ms) after the continuing current circuit is activated.

The high current/continuing current transmission lines must penetrate the safety cages, which are electrically conductive and grounded, without loss of current. This transmission system consists of six large parallel high voltage cables connected to ten smaller high voltage cables. The large cables penetrate the large safety cage and the smaller cables penetrate the secondary safety cage. The smaller cables can be routed within the secondary safety cage to the desired test location on the UUT. The center conductors of these cables are tied to a tungsten probe tip. During testing for these current waveform components, the probe tip is placed within one-eighth inch of the test item, and the current return path to the generator is through the coax shields. During the test, the UUT must be isolated from the ground plane and safety cage walls to assure that the entire current load returns via the coax shields.

B. INTERMEDIATE CURRENT SYSTEM

The HELS intermediate current capacitor bank consists of 5 layers of electrolytic capacitors connected in series. Each layer contains 8 capacitors, each rated at 450 volts (V) and 3000 µF, in parallel. The total calculated capacitance is 4800 µF. The charge voltage is 2100 V. The intermediate current capacitor bank can generate a 2000 ampere (A) ± 10% average amplitude simulated direct strike component B waveform with a peak current of approximately 5800 A and 10 coulombs (C) of charge transfer. A Hipotronics Model No. 850/50/100 High Voltage DC Power Supply, rated for 50 kV or 100 kV and 100 mA, is utilized to charge the HELS intermediate current capacitor bank.

C. CONTINUING CURRENT SYSTEM

The HELS continuing current capacitor bank consists of two layers of electrolytic capacitors connected in series. Each layer contains 196 capacitors, each rated at 450 volts (V) and 3000 mF, in parallel. The total measured capacitance is 0.37 F and is charged to a nominal value of 750 V. The continuing current capacitor bank can generate a simulated component C waveform with 200 C ± 20% of charge transfer. A Hipotronics Model No. 801-5A High Voltage DC Power Supply, rated for 1 kV and 5 A, is utilized to charge the HELS continuing current capacitor bank. The charge leads are connected to the capacitor bank via a charge relay mounted on the bank. This bank is fired with a high voltage relay, triggered by a pneumatic switch, which triggers a high voltage relay to fire the high current bank. The current flows via connecting cables to the high current bank coaxial cables and thence to the UUT. An 8 mH inductive parallel circuit at the load stores the continuing current energy until the high current bank discharges and ionizes the air at the spark gap. This small, approximately one-eighth inch gap isolates the current from the UUT. After approximately 20 ms, the high current bank is fired and arcs across this gap, thus allowing the continuing current to flow from the parallel circuit to the UUT. Slow discharging can be accomplished by manually closing a switch on the bank, which places a large resistive load on the capacitors.

D. LARGE SYSTEM RESTRIKE CURRENT SYSTEM

The restrike current bank is an 18 stage Marx bank with a total capacitance of 0.9375 µF. Each stage, consisting of nine 60 kV, 1.875 µF capacitors in parallel, is normally charged to 42 kV to provide a total output voltage of 756 kV. The 18 stages are charged in parallel via a group of charge resistors by a 100 kV power supply. Charging is activated with a remotely operated pneumatic switch, located in the Charge/Discharge Building. The bank is triggered remotely by a pneumatic switch. The bank can be slowly discharged in the Charge/Discharge Building by switching in a large resistive load to ground.

Energy from the Marx bank is delivered to the peaking capacitor/spark gap assembly via a one-inch insulated conductor. The insulated conductor runs from the high dI/dt bank isolation gap to the top of the peaking capacitor/spark gap assembly large corona ring inside the large safety cage. The peaking capacitor bank has a total capacitance of 0.027 µF and a maximum voltage capability of 2.2 MV. The peaking capacitor bank consists of two parallel stacks of Maxwell capacitors. Each stack contains twenty-two 0.3 µF, 100 kV capacitors in series. The peaking capacitor circuit utilizes a large spark gap located above the secondary safety cage. This spark gap spacing determines the peak current and rate-of-rise of the test current waveform. A down-conductor, extending through the secondary safety cage, is attached directly to the test item.

The large system restrike Marx capacitor bank can generate a 100 kA ± 10% peak current simulated component D waveform with an average current rate-of-rise of 1.0×10^{11} amperes per second (A/sec) and a maximum current rate-of-rise of 1.4×10^{11} A/sec ± 20%. A Hipotronics Model No. 8100-250 High Voltage DC Power Supply, rated 100 kV and 250 mA, is utilized to charge the HELS large system restrike current capacitor bank.

E. SMALL SYSTEM RESTRIKE CAPACITOR BANK

The HELS small system restrike Marx capacitor bank is an 18-stage Marx bank with a calculated total capacitance of 0.0556 µF. Each stage, consisting of 2 capacitors, each rated at 100 kV and 0.5 µF, in parallel, is normally charged to 80 kV to provide a total output voltage of 1.44 MV. Energy from the Marx bank is delivered to the peaking capacitor grid/spark gap assembly via bus wires. The peaking capacitor grid consists of two parallel, 50-foot diameter wire grids with a 20-foot high separation. Equation 1 can be used to calculate the capacitance (**C**) of the small system peaking capacitor grid where **S** is the

$$C = \frac{eS}{d} \ \text{F} \qquad \text{(Equation 1)}$$

area of each grid, **e** is the total permittivity and **d** is the separation distance between the parallel grids. Solving Equation 1 for the above noted parameters (converted to metric units) yields a calculated capacitance for the small system peaking capacitor grid of 265 picofarads (pF). The small system restrike Marx capacitor bank can generate a 50 kA ± 10% peak current simulated component D waveform with an average current rate-of-rise of 1.0×10^{11} A/sec and a maximum current rate-of-rise of 1.4×10^{11} A/sec ± 20%. A Hipotronics Model No. 850/50/100 High Voltage DC Power Supply, rated for 50 kV or 100 kV and 100 mA, is utilized to charge the HELS small system restrike current capacitor bank.

IV. DATA ACQUISITION AND SYSTEM CALIBRATION

Calibration waveforms for the high-current, continuous current, and restrike current components of the simulated lightning waveform are obtained by connecting a load of known impedance to the output of the generator and measuring the current that flows through it. Separate instrumentation is required for each of the lightning component waveforms. Instrumentation to monitor the high current and restrike component waveforms is identical, though, except for the attenuation/gain settings on the fiber optic receivers. The equipment used to generate and record these measurements is as follows:

A. HIGH CURRENT INSTRUMENTATION

A Pearson Model 1080 Current Probe (400 Amps/Volt, 200 kA max.) is utilized as the sensor for the high current waveform measurement. The current probe is installed on the center conductor of the High Current/Continuing Current Discharge Probe. The high current waveform measurement is telemetered via a Nanofast Model OP-300 Fiber Optic System (self-calibrating with a 1 volt, 1 MHz square wave signal). The signal can be recorded on a Hewlett-Packard Digitizing Oscilloscope (Model 54111D, 54200D, or 54510A) or a Tektronix Programmable Digitizer (Model 7612D or 7912A/D) and reduced on a Pentium based personal computer (PC).

B. CONTINUING CURRENT INSTRUMENTATION

An in-house designed 0.01 ohm Nichrome ribbon series resistor (100 Amps/volt) is utilized as the sensor for the continuing current waveform measurement. The Nichrome resistor is installed in-line with the continuing current transmission line. The continuing current waveform measurement is telemetered via a Meret Model MDL281-4-C Fiber Optic System. The signal can be recorded on a HP Digitizing Oscilloscope (Model 54111D, 54200D, or 54510A) or a Tektronix Programmable Digitizer (Model 7612D or 7912A/D) and reduced on a Pentium based PC. The continuous current measurement system is calibrated by flowing a known DC current through the series resistor and recording the output of the HP Oscilloscope.

C. RESTRIKE CURRENT INSTRUMENTATION

A Pearson Model 1080 Current Probe is utilized as the sensor for the restrike current waveform measurement. The current probe is installed on the center conductor of the

High Voltage Down Conductor. The current measurement is telemetered via a Nanofast Model OP-300 Fiber Optic System. The signal can be recorded on a HP Digitizing Oscilloscope (Model 54111D, 54200D, or 54510A) or a Tektronix Programmable Digitizer (Model 7612D or 7912A/D) and reduced a Pentium based PC.

V. CONCLUDING REMARKS

A simulated lightning test facility for testing live and inert missiles and components has been described. Although primarily designed for testing live missiles, this facility can be used to test other explosive items and inert hardware which could be susceptible to the effects of lightning, such as military vehicles and components, and aerospace hardware.

DISCLAIMER

Use of trade names or manufacturers in this report does not constitute an official endorsement or approval of the use of such commercial hardware or software.

REFERENCES

[1] MIL-STD-1757A, Lightning Qualification Test Techniques for Aerospace Vehicles and Hardware, 20 July, 1983.

[2] "Operating Procedures, Test Area 5 Large Missile Lightning Test Facility, MICOM Special Report SR-RD-TE-90-11, December 1989, prepared be Kenneth K. Mitchell COLSA, INC.