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ELECTROSTATIC DISCHARGE TESTING OF ELECTROEXPLOSIVE DEVICES

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Electrostatic discharge (ESD) testing of electroexplosive devices has previously been regarded as single pulse, go/no-go testing, the emphasis being on the safety of the devices when exposed to human handling. For some components it has been found to be a destructive test; for others the test is performed 100% in production product-acceptance testing and is considered a nondestructive and nondegrading test if the component does not fire. Recent studies performed by R.J. Fisher at Sandia have resulted in a new model of the worst case human body electrostatic discharge that is more accurate than the model that is currently in use for testing electroexplosive components. In addition, recent requirements for no degradation or loss of reliability after multiple exposures (up to 100) have changed the go/no-go nature of the test. Several components have been tested to the new ESD model; results regarding both safety and reliability will be presented and discussed.

INTRODUCTION

Significant changes have recently occurred regarding the electrostatic discharge (ESD) requirements for electroexplosive devices (EEDs). These changes have resulted in a need for reevaluation and testing of existing devices as well as renewed interest in identifying and characterizing ESD failure mechanisms. The first change has been in the electrical-circuit used to simulate the human-body electrostatic discharge that EEDs are required to survive. The philosophy that has recently been accepted claims that, for ESD testing of electroexplosive devices, nominal values for human-body electrostatic parameters are unacceptable and instead, a combination of the worst-case parameters should be used[1,2]. Secondly, a change from emphasis only on the safety of EEDs when exposed to human-body ESD, to added equal emphasis on the functional reliability of EEDs following exposure to ESD has occurred. A device may meet the safety requirement of electrostatic discharge exposure, i.e. it does not fire when exposed to a human-body ESD pulse, but if it is degraded by the exposure such that it no longer meets functional and/or reliability requirements, it has not actually survived the exposure. The third change that has taken place involves the number of ESD pulses that an EED is required to survive. In the past, electroexplosive devices were required to withstand a single ESD pulse. Recently, requirements for EED ESD survival are being defined in terms of multiple pulses, with the actual number based on the number of opportunities for exposure presented by assembly, disassembly, and field operations throughout the stockpile life.

A chronological review of the history of EED ESD requirements and testing at Sandia National Laboratories follows, providing a convenient way of presenting these changes in more detail.

In 1973, a working group was formed at Sandia to address the lack of uniform practices and requirements with respect to ESD testing of EEDs. It was decided that all future explosive devices would be designed to withstand the discharge from a 600 pF capacitance charged to 20 kV and discharged through 500 ohms of series resistance. This decision resulted in a formal test specification being adopted in 1974. The specification defines electrostatic survival as the capability of an electroexplosive device to withstand a single ESD pulse without initiating, i.e. no explosive output occurs. The circuit parameters are defined as above: a 600 pF capacitor charged to 20 kV and discharged into the unit under test through a 500 ohm series resistor. This circuit is commonly known as the "Sandia standard man" and, until recently, has been the standard circuit used for ESD testing of electroexplosive devices. Based on the above definition of electrostatic survival, a test per this specification involves discharging the pulse into the device and checking for evidence of initiation. If the unit has not been initiated, the test is considered successful; no testing is performed following the ESD exposure to determine whether or not the device has sustained any damage or degradation.

In November of 1988, approximately fifteen years after this test specification was adopted, a report was published[1] recommending a new model for human-body ESD simulation for testing weapon system components. As mentioned earlier, the model consists of a combination of the worst case human-body electrostatic parameters, i.e. charging voltage, capacitance, and resistance. It also includes both a fast pulse simulating electrostatic discharge from the hand, and a slower pulse simulating discharge from the body. Figure 1 shows the circuit and a representative pulse.

At approximately the same time, in January of 1989, official requirements for components on a major weapon system were specified and included two ESD requirements, one regarding safety and one regarding reliability. The safety criteria was essentially the "standard man" test. The reliability requirement stated that components must function after experiencing a discharge, through a 1000 ohm series resistor, of a

300 pF capacitor charged to 8 kV. This was the first time that EEDs were formally required to remain functional following ESD exposure. However, the criteria was still in terms of a single pulse and the circuit specified was still the "standard man" and, for reliability, a less severe version of the "standard man." An exploding bridgewire (EBW) detonator was one of the devices that was subject to this new ESD requirement. The results of testing performed, to investigate the ability of this device to meet the requirement, are provided in the next section.

In September of 1989, new requirements for a commonly used hot-wire-initiated pyrotechnic actuator combined a reliability specification and the new model. The requirement stated "single or multiple exposures to static discharge from human handling (per the new model) shall not cause the device to function, nor shall it cause a reliability or performance degradation," and estimated that the unit could be exposed to forty ESD pulses during its lifetime. At the time, this component was being tested per the earlier test specification of a single "standard man" pulse with survival defined as no explosive output. The actuator had to be retested to demonstrate that it could meet the new requirement. The results of this testing are provided in the next section.

Although the actuator mentioned above was the first EED to be required to meet the combination of the three recent changes in ESD requirements, i.e. the new model, multiple pulses, and a reliability specification, several electroexplosive devices are now required to meet similar requirements. All new weapon systems are expected to call out the new worst case human body ESD model, and also require functionality and reliability of components following multiple exposures. Depending on the number of opportunities for exposure, devices are required to survive 10 to 100 pulses. A new test specification has been written to detail testing of EEDs to these new requirements. It calls out the new model and defines two types of failure, inadvertent initiation and degradation following single or multiple exposures.

TESTING AND RESULTS

Several EEDs have been investigated with respect to the new requirements described in the previous section. The details regarding the tester used to perform this "new model" ESD testing are given in Reference 3; however, it is worth mentioning here that much care is taken to ensure that the proper pulse is applied to the unit under test. The purpose of this paper is to describe the test plans that have been used to test specific devices, i.e. number of units tested, number of exposures per unit, ESD discharge mode (pin-to-pin or pin-to-case), as well as to present the results of the testing performed.

The actuator mentioned earlier is shown in Figure 2. It is a dual bridgewire hot-wire initiated device and contains approximately 100 mg of $TiH_{1.65}/KClO_4$ (titanium subhydride / potassium perchlorate), which is a common pyrotechnic material. Testing was performed to demonstrate that this device could meet the requirements, described earlier, of not functioning or being degraded when exposed to forty "new model" ESD pulses. Three groups of eighteen actuators each were used for the testing. The first group was subjected to eighty pin-to-case pulses, i.e. discharge from the three leads (shorted together) to the case of the device. The second group was subjected to eighty pin-to-pin pulses, i.e. discharge through one of the bridgewires. Eighty was used instead of forty to demonstrate a factor of two margin. The third group consisted of virgin units and was used as a control group. It should be noted that this device has a "spark gap" external to the charge cavity to prevent pin-to-case arcing through the pyrotechnic powder.

Electrothermal response (ETR) testing[4] was performed on each of the Group 1 and Group 2 actuators both before and after ESD exposure. ETR testing measures the thermal contact between the bridgewire and the pyrotechnic powder. For both groups the value of thermal conductance, usually denoted by γ (units are μWatts/K), increased by 6 to 15% indicating improved thermal contact at the bridgewire-powder interface following ESD exposure. Early development work on this actuator found the standard deviation of γ for a large number of units to be approximately 5%, which suggests that the 6 to 15% increase is not variability in the test method. The increase may be a result of localized melting of the pyrotechnic powder near the bridgewire, although no testing has been performed to confirm this possibility.

Following the ESD exposures, which did not initiate any of the actuators, testing was performed to determine whether or not the units had been degraded. The minimum functional requirements of interest are the all-fire and no-fire levels, the function time at the fire-pulse current, and the output of the device. Neyer Sensitivity[5] testing was chosen for determining all-fire and no-fire levels as well as function time. The output of these actuators is typically measured by a VEC (variable explosive chamber) test, in which the device is fired into an expanding volume and the resulting pressure vs. volume curve is required to fall within upper and lower limits. A hybrid of these two tests was used for this study. The Neyer Sensitivity software was used to determine the firing current for each unit tested. Also, each device was installed in a VEC tester when the fire pulse was applied so that, if the unit fired, output data was obtained.

The function time vs. firing current results of this testing are shown in Figure 3. Figure 4 is an expanded view of the data at the required fire-pulse current of 3.3 Amps. Both the pin-to-pin group and the pin-to-case group demonstrate an increase in function time, but both are still well within the required function time of 10 ms. The Neyer Sensitivity software was used to perform a statistical comparison between the three groups and calculated 57% confidence that Groups 1 and 3 were different populations and 97% confidence that Groups 1 and 2 were different. All of the VEC pressure-volume curves fell within the prescribed limits indicating no output capability degradation. Table 1 summarizes the results for the three groups tested as well as the requirements. This device appears to be able to meet the ESD requirement detailed earlier.

Table 1. Pyrotechnic Actuator Test Results and Requirements

	All-Fire Current (Amps)	No-Fire Current (Amps)	Function Time (ms) at 3.3 Amps	VEC Initial Pressure (MPa)	VEC Curve Exponent
Control Group	2.74	1.47	2.70	587	1.16
Pin-to-Case Group	2.80	1.47	2.97	588	1.16
Pin-to-Pin Group	2.48	1.88	3.09	577	1.12
Requirement	<3.00	>1.00	<10.00	425-750	1.00-1.30

A second device, a hot-wire-initiated detonator that contains approximately 60 mg CP and 11 mg HMX, was tested to a requirement of twenty "new model" ESD pulses[6,7]. The device is shown in Figure 5. Twenty units were each subjected to 20 pin-to-case pulses. These units were then tested to determine the variation of function time with firing current; the results are shown in Figure 6. The data indicates no evidence of degradation and suggests that this device would function reliably given the required fire-pulse of 3.5 Amps for 10 ms.

Another type of electroexplosive device that has been tested to the new requirement is hot-wire-initiated igniters. These igniters are required to survive only ten ESD exposures. Ten different igniters were tested[7]; a representative device is shown in Figure 7. Note that these devices have one of the leads welded to the case; the distinction between a pin-to-case discharge and a pin-to-pin discharge is not applicable. These igniters can be divided into two catagories, low energy and high energy, referring to the amount of energy required to fire the device.

Six different "low energy" igniters were exposed to the "new model" ESD pulse and all units fired on the first pulse. Four of these devices contain barium styphnate, one contains boron calcium chromate, and one contains LMNR. All of these six types of igniters were subsequently tested per the "standard man" test and only the LMNR device ignited. The fact that the barium styphnate and boron calcium chromate devices survive the "standard man" test but fire from the new pulse indicates that, for initiation of these low energy igniters, the new model is more severe than the old standard man model and meeting this new specification may require major design changes. It should be noted that the low energy initiation capability of these devices is very desirable for some applications and it will not be trivial to design a device that will fire from a low energy fire pulse and survive the new model worst case ESD pulse.

Four additional igniters were tested. These four are classified as "high energy" and contain $Ti/KClO_4$ (titanium / potassium perchlorate) pyrotechnic. For each of the four types, ten units were each subjected to ten "new model" pulses; none of the devices fired. However, testing performed on these exposed units found that one of the four types had post-ESD all-fire and no-fire levels that did not meet specifications.

Additional data concerning reliability of EBW detonators following ESD exposure was collected by Hoke[8]. As mentioned earlier, the reliability requirement for this device was not stated in terms of the new severe ESD model. Three different types of EBW detonators were each subjected to one "standard man" pulse. Following exposure, both function time and threshold burst current increased, sometimes exceeding specification limits. More importantly, two out of forty of one type, five out of ten of a second type, and four out of twenty of a third type failed to fire when subjected to a normal fire pulse at ambient temperatures.

In summary, the limited amount of testing that has been performed with the new worst case model indicates that, while some devices can survive multiple pulses without significant degradation, other components, such as low energy igniters and EBW detonators, may not be able to survive even one pulse. Also, the fact that the barium styphnate and boron calcium chromate igniters fire from the new pulse but do not fire from the old pulse indicates that the new model truly is more severe and some devices that marginally survived the old model may not be able to meet the new requirement. This might necessitate design changes or, alternatively, very strict handling procedures to eliminate human handling ESD risk.

ONGOING AND FUTURE WORK

The results presented in the previous section provide evidence that the issue of ESD sensitivity of electroexplosive devices requires extensive further investigation. Although the human body ESD threat is now well defined, the actual mechanisms by which EEDs are susceptible to the threat are very poorly understood. Testing must be performed to identify and characterize ESD vulnerability and failure mechanisms. In addition, it is important to perform margin testing to assure that designs are not just marginally adequate but contain some factor of safety with respect to ESD protection. A variable parameter tester is currently being fabricated for performing this type of testing. The tester is essentially the new model tester, but the circuit parameters of interest can be varied as shown in Table 2. This testing will allow design engineers to characterize how well their design meets the new ESD requirement. For devices that survive the new model pulse, testing can be performed to determine at what more severe levels the device will begin to fail. For components that cannot meet the new requirement, a lower level threat that the device can meet might be determined.

Table 2. Variability of Parameters for EED ESD Margin Testing

Voltage		5 to 50 kV
Capacitance	C_B	50 to 2670 pF
	C_H	10 to 50 pF
Resistance	R_B	10 to 5000 ohms
	R_H	50 to 500 ohms
Inductance	L_B	0.1 to 1 μH
	L_H	0.05 to 0.2 μH

Ongoing investigations into optical initiation of energetic materials is of extreme interest. Conceptual designs for optically ignited explosive devices provide complete electrical isolation of the explosive material. Although the feasibility of optically initiating energetic materials has been demonstrated[9], extensive work in the area of designing, fabricating, and testing actual hardware remains to be done.

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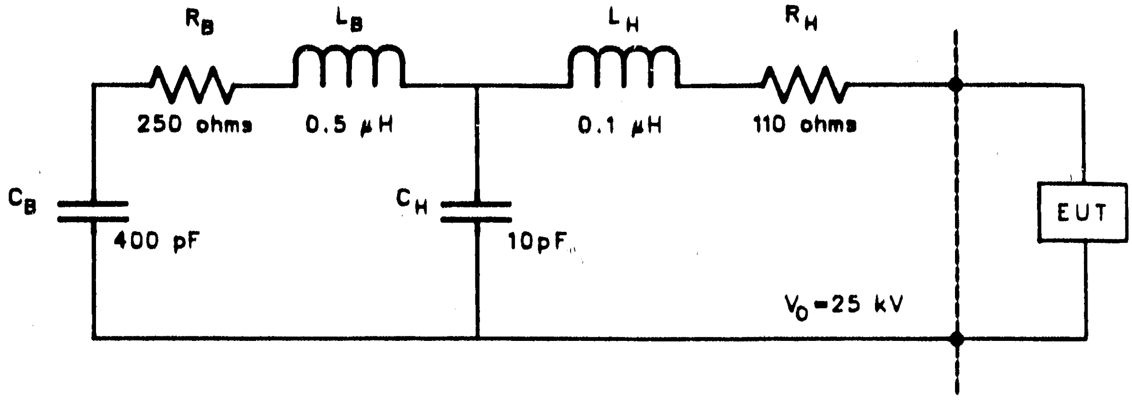
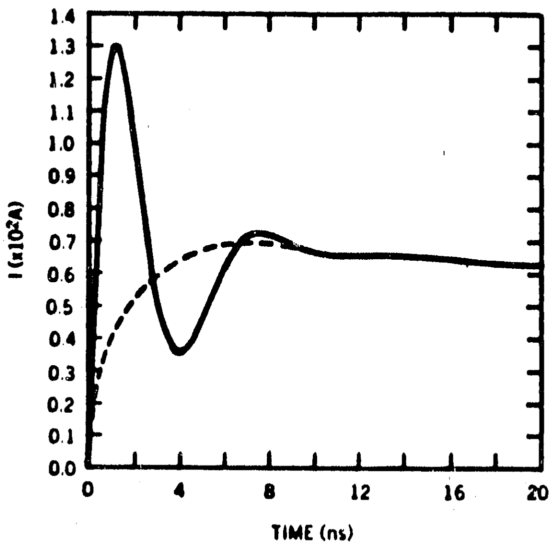
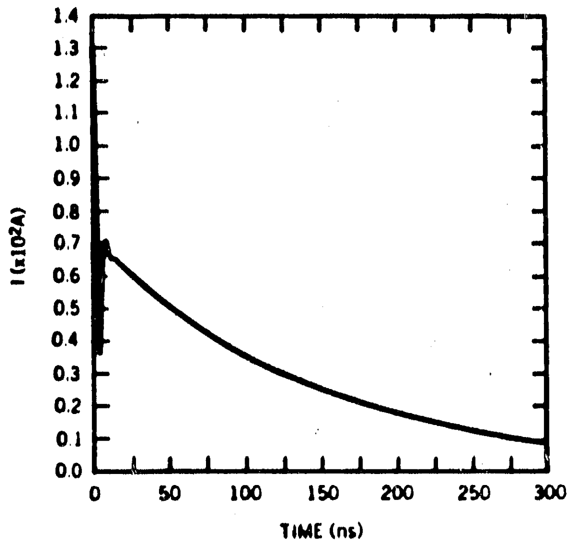


(a)



(b) Early Time



(c) Full Duration

Figure 1. Worst Case Human Body ESD Simulation (Reference 1)

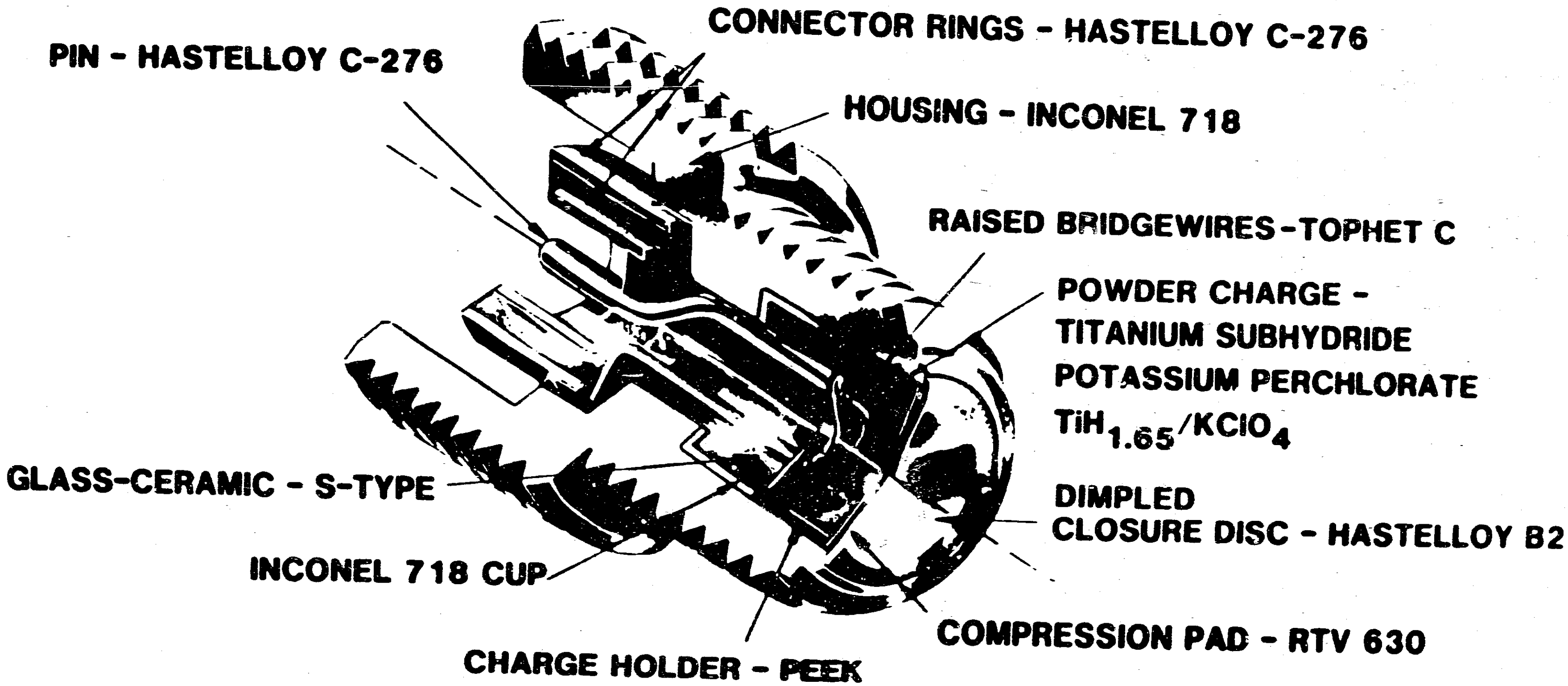


Figure 2. Hot-wire Initiated Pyrotechnic Actuator

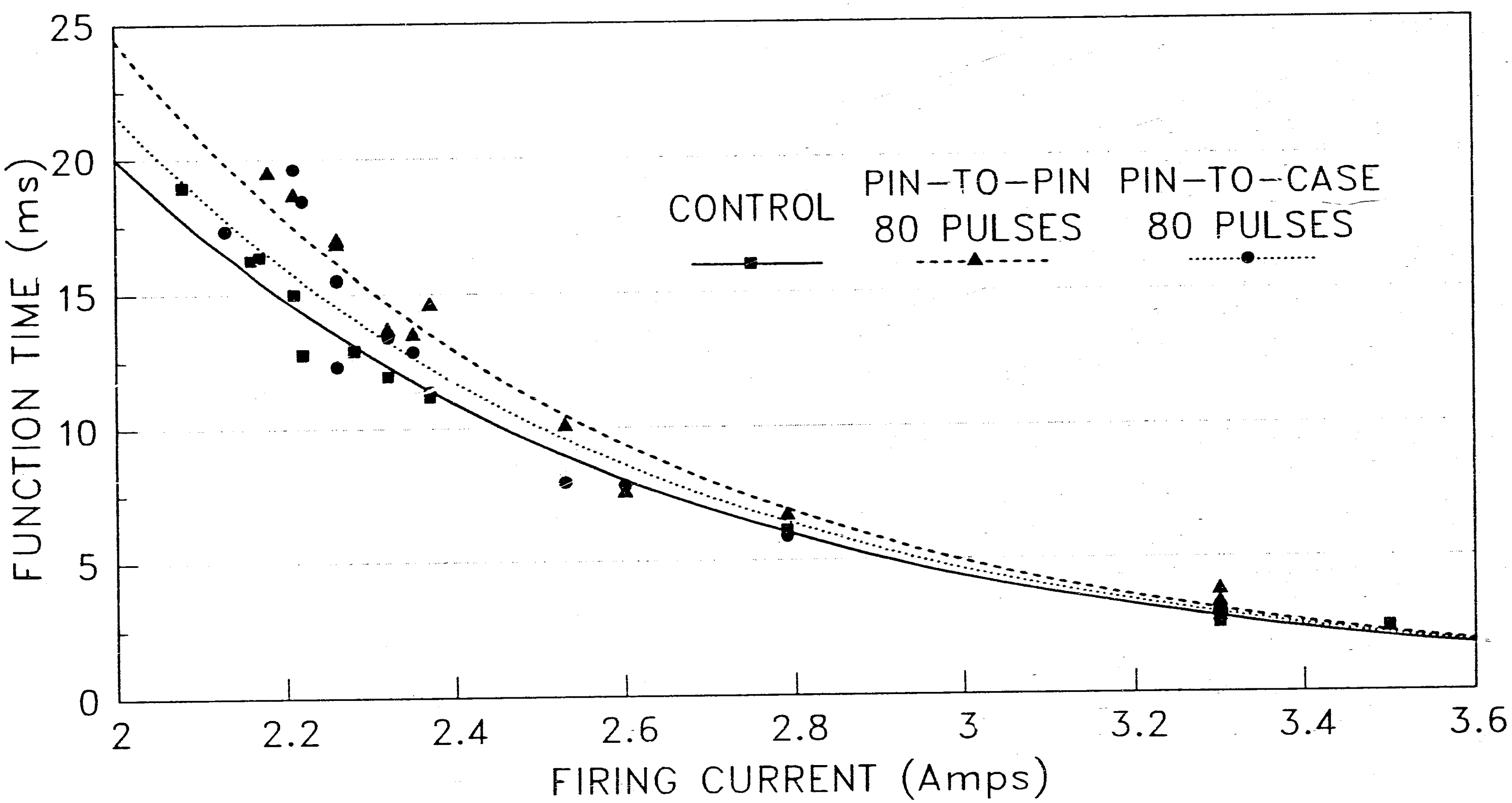


Figure 3. Effect of ESD Exposure on Function Time for Pyrotechnic Actuator

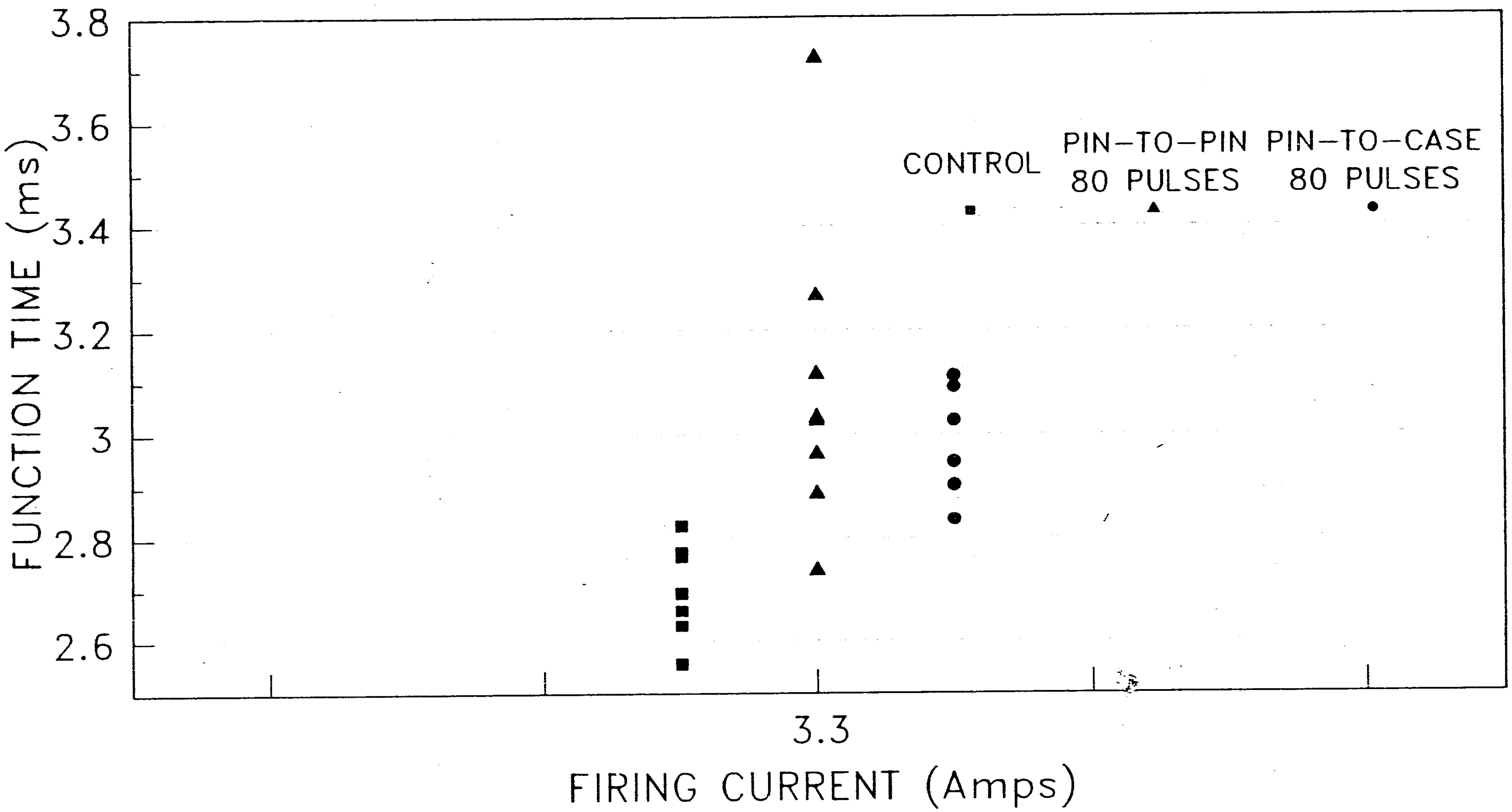


Figure 4. Effect of ESD Exposure on Function Time at Required Fire-Pulse Current of 3.3 Amps

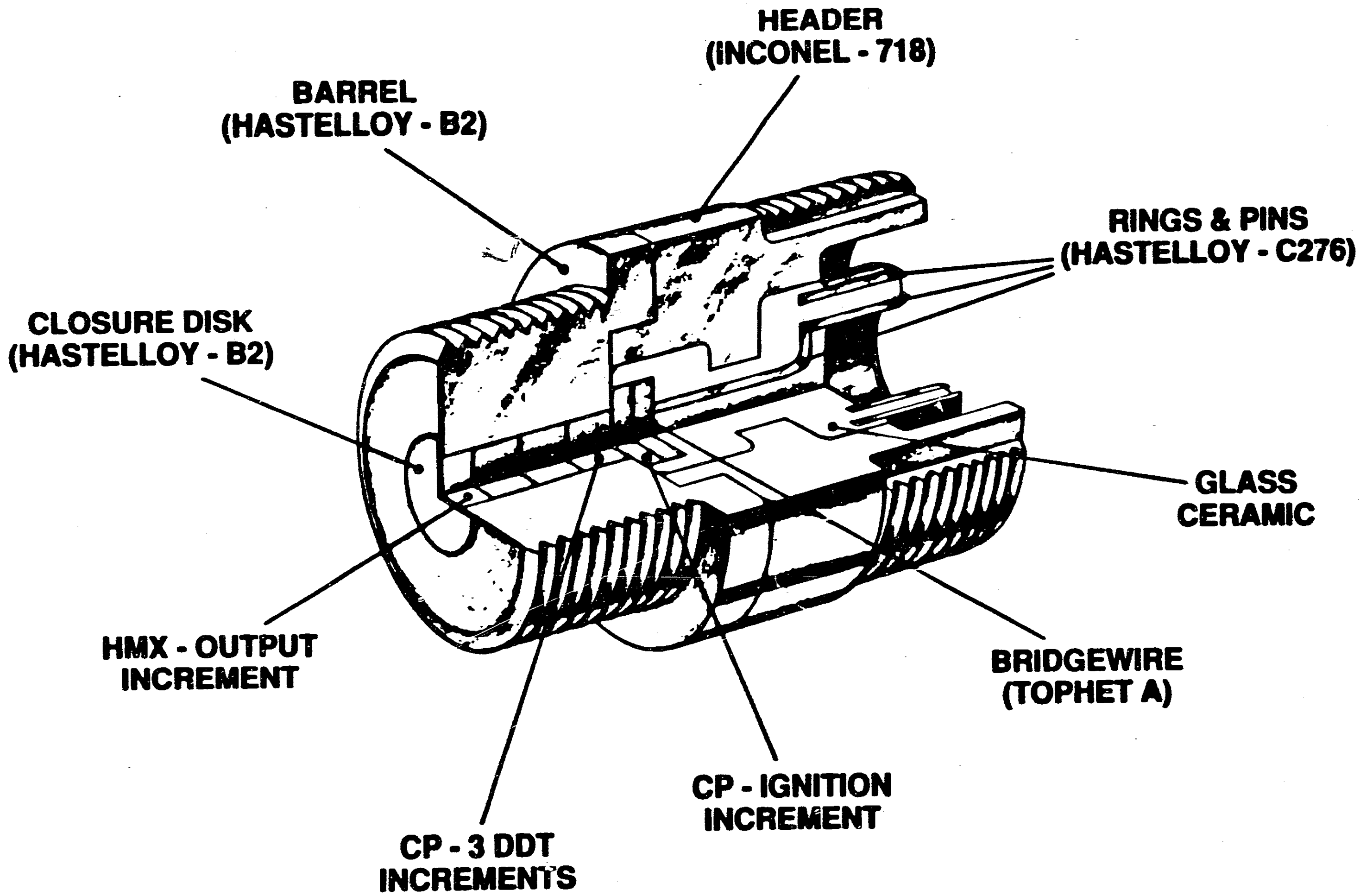


Figure 5. Hot–wire Initiated Explosive Detonator

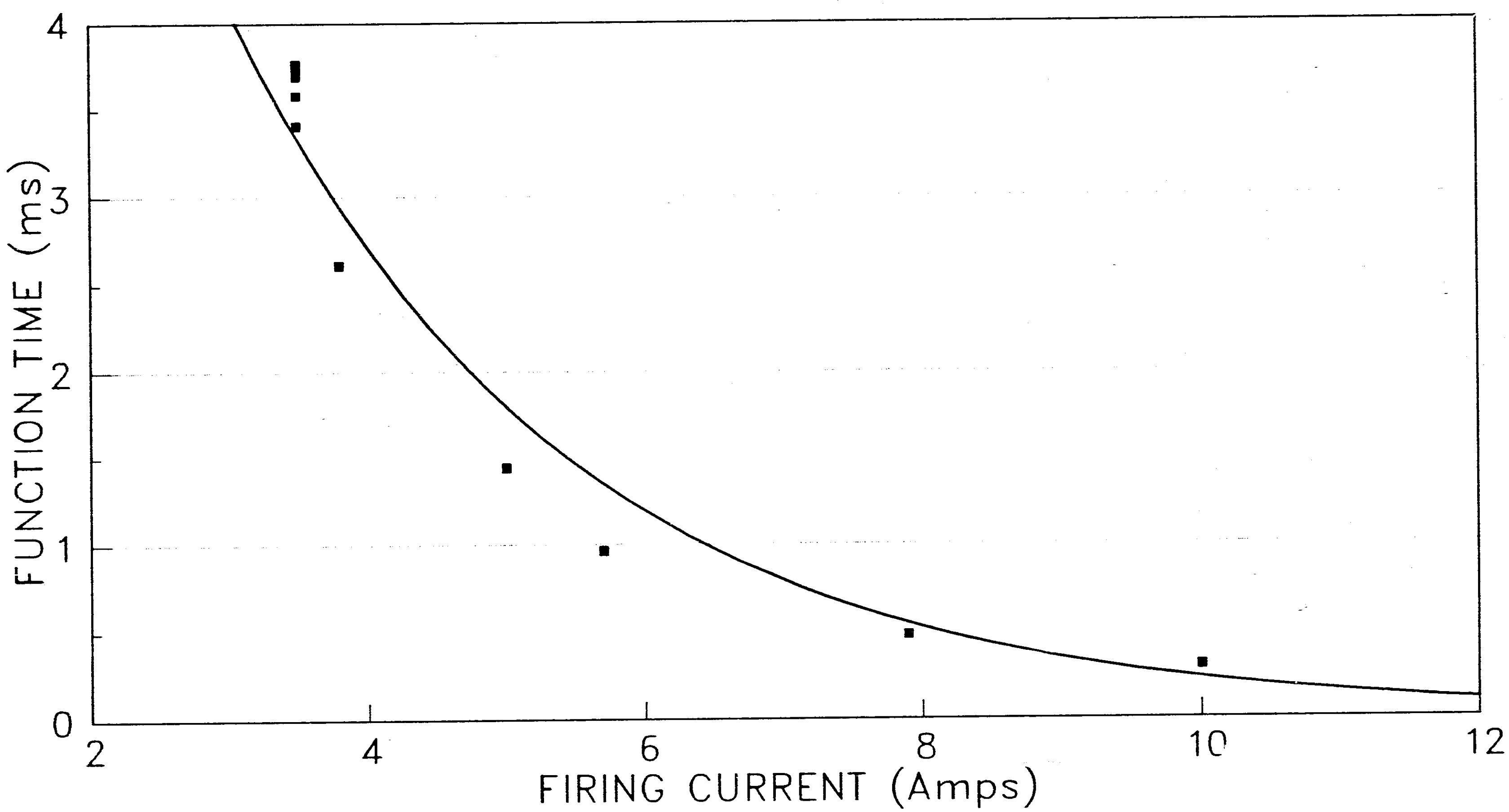


Figure 6. Function Time vs Current for Detonators Following ESD Exposure

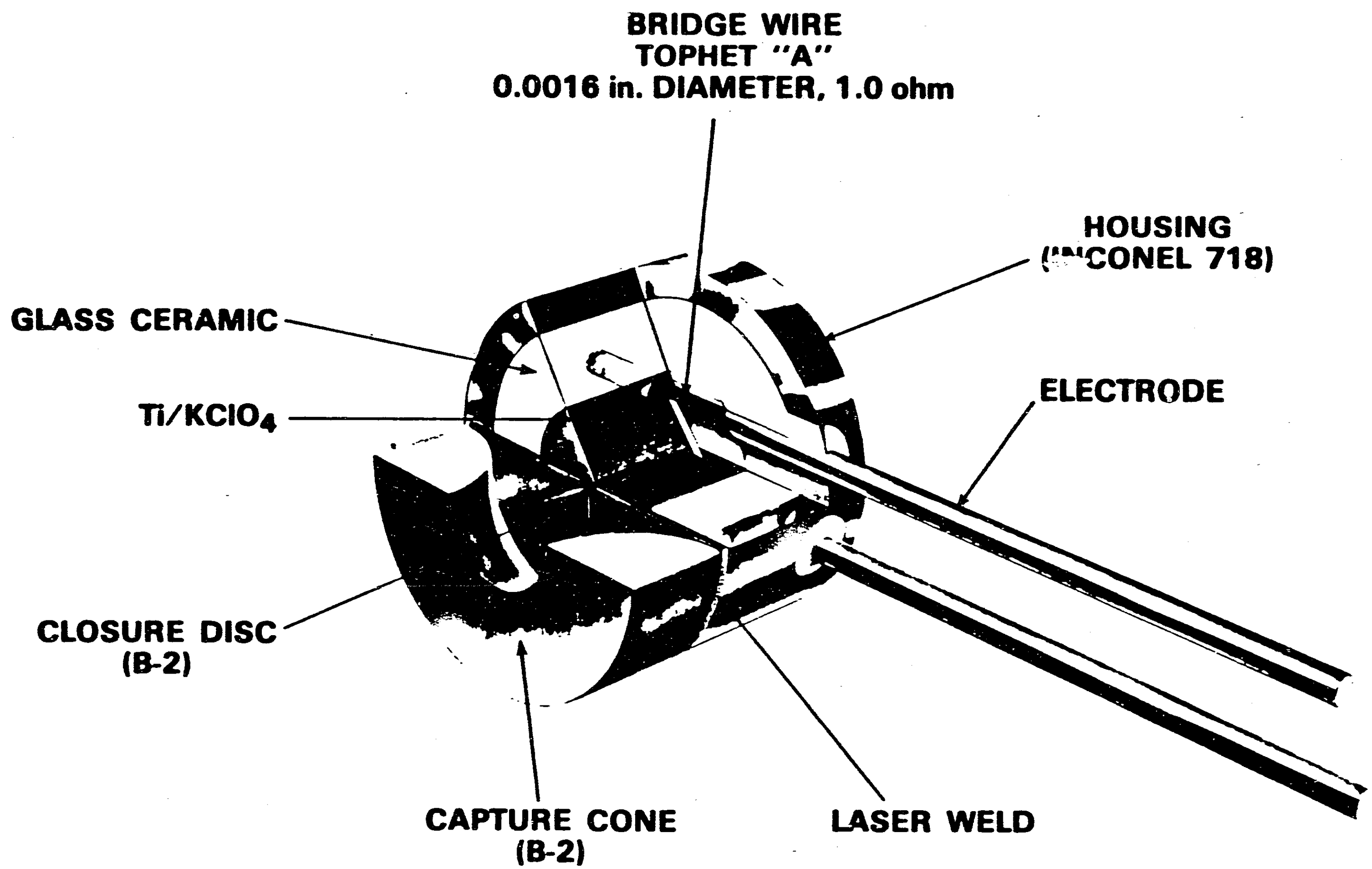


Figure 7. Hot–wire Initiated Igniter

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