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LIGHTNING-RESISTANT, LOW-INDUCTANCE DETONATOR CABLES

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Lightning-resistant, Low-inductance Detonator Cables

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A lightning strike on a flat detonator cable in close proximity to a high explosive (HE) main charge poses a possible detonation hazard if the electrical explosion of the cable launches the dielectric cover coat of the cable at a high enough velocity to shock-initiate the HE. The detonator cable for the W87 system has been demonstrated to be incapable of initiating LX-17 main-charge explosive even for a 99 percentile negative lightning strike (1). The W87 cable is a relatively high inductance cable, unsuitable for use with low-inductance firesets. We have performed tests on a low-inductance cable designed for the W89 program, which show it to be marginal in its ability to withstand a lightning strike without the possibility of initiating a heated LX-17 main charge HE. A new cable design, proposed by R. E. Lee of LLNL has been tested and shown to be capable of withstanding a 99 percentile negative lightning strike without initiating LX-17 heated to 250°C.

Introduction

The purpose of the work reported here was to study the response of LX-17 (92.5/7.5% TATB/Kel F) insensitive explosive at 250°C to a simulated lightning strike exploding low-inductance cables. Earlier work (1,2) indicated that the W89-type cable might be marginal in its ability to withstand a lightning strike without initiating hot LX-17 in close proximity to the cable. A new, low-inductance cable design was shown to be capable of withstanding a lightning strike without initiating hot LX-17.

Experimental Arrangements

Electrical Circuit

The electrical circuit is shown schematically in Fig. 1. The 5.08-cm-long test cable sections were connected across a gap in a flat transmission line. A 56-μF, 50 nH capacitor bank, which could be charged to 40 kV, was discharged through the flat transmission line to explode the test cable.

Method for Heating HE Samples

A 5.08-cm-long, 2.54-cm-square sample of LX-17, mounted into a steel sample holder, 6.72-cm long with a wall thickness of 7.94 mm, was heated in a cylindrical heating oven. The sample holder was constructed from 7.94-mm-thick steel held together with steel machine screws. Thermocouples were mounted in several locations around the sample holder to monitor temperature.

The heating oven was constructed from two cylindrical heating bands mounted together to form a cylindrical oven. A programmable controller allowed the oven temperature to be ramped up to a desired level and maintained to allow the sample to reach equilibrium. Power to the oven was transferred through a high-voltage relay, which isolated the oven when the shot was being fired.

Firing the Shots

When the sample had equilibrated at the desired temperature, power to the heaters was interrupted by opening the high-voltage relay and the bank was charged to the desired firing voltage. The thermal capacity of the furnace and the steel sample container

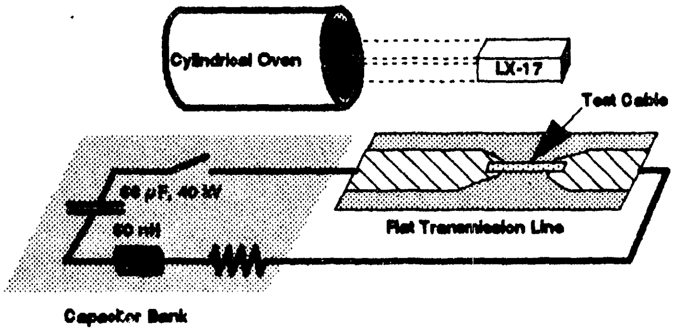

Figure 1. Schematic drawing of the electrical circuit and experimental arrangement for the cable tests.

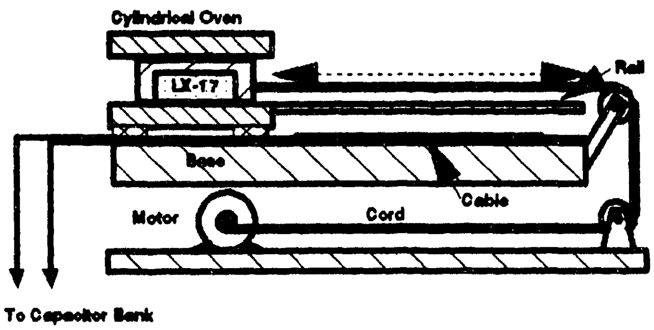

Figure 2. Schematic diagram of the apparatus used to heat the LX-17 and position the heated sample .

maintained the temperature while the bank was being charged. The sample, in its confining steel container, was pulled out of the oven by a string and pulley arrangement, as shown schematically in Fig. 2. The bank was then discharged through the cable (both conductors were connected in parallel). About 5 seconds was required to position the HE sample ~3 mm above the cable. The sample did not cool more than about 1°C before the shot was fired. Detonation spalls and shatters the steel container. If the sample does not detonate, the sample container is disassembled by the electrical explosion but otherwise is relatively undamaged.

Velocity Measurements

Cover coat velocities were measured for exploding W89 cables and for the new cable design using a Fabry-Perot laser velocimeter. The new cable design will be discussed below.

Experimental Results

Two cable designs were tested. The W89 cable is a low-inductance cable that was designed for the W89 program. The other cable was a new design, proposed by R. E. Lee of LLNL, which has low inductance but is designed to be incapable of initiating LX-17 in the event of a credible lightning strike.

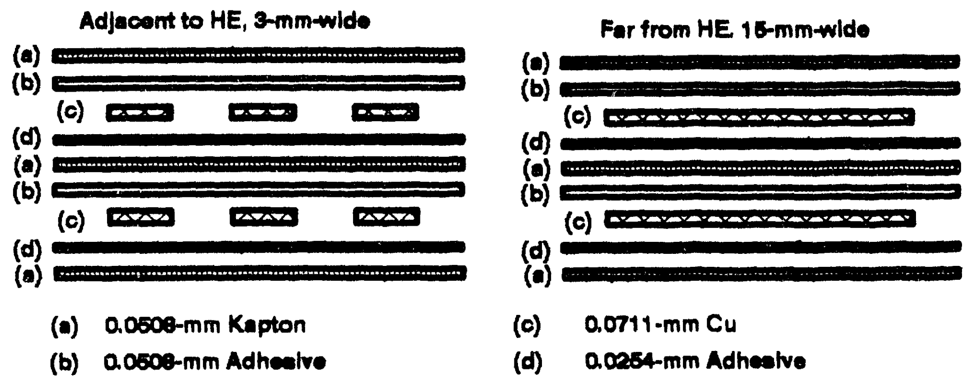

Figure 3. Cross section of new, lightning-resistant cable design.

W-89 Cable.

Low inductance is achieved in the W89 cable by using 15-mm-wide, 0.071-mm-thick copper conductors,. The W87 cable, with conductors of the same thickness but only 3.17-mm-wide, has nearly 5 times the resistance and inductance. The wide conductors are a detriment, however, if the cable should be struck by lightning. The dielectric cover coat launched by the electrical explosion would strike adjacent HE over a large area and could possibly initiate a detonation. The narrower W87 cable, on the other hand, has been shown to be incapable of initiating LX-17 explosive at 250°C when it is exploded at a burst current of 250 kA (1). One goal of our investigation was to see whether the W89 cable could initiate hot LX-17 at a burst current in the 250-300 kA range.

W89 Cable Cover Coat Velocity

Three shots were fired using 5.08-cm-lengths of W89 cable to measure the velocity of the dielectric cover coat. We had not exploded any W89 cables using the 56 μF, 40 kV capacitor bank, so the first shot was fired at 40 kV to determine current levels. The cable exploded at 720 kA with a cover coat velocity of 4.0 km/s after 2 mm of flight. This shot would probably have initiated hot LX-17, but the burst current was far in excess of the current from a credible lightning strike (the median peak current for negative lightning, the most common form of lightning, is 20 kA and the 99th percentile peak current is 200 kA. Median peak current for the rarer positive lightning strike is 35 kA.)

The next shot was fired at a charging voltage of 25 kV. The burst current was about 300 kA and the velocity after 2 mm of flight was 2.6 km/s., which increased to 3 km/s at a 4-mm flight path.

We also made a velocity measurement at a charging voltage of 23 kV, but the velocity after 2 mm of travel was only 1.6 km/s. We decided to fire the HE initiation experiments at a charging voltage of 25 kV as a reasonable simulation of a credible lightning strike..

LX-17 initiation Experiments with W89 Cable

Two shots were fired at 25 kV with 5.08-cm-lengths of W89 cable spaced ~3-mm from LX-17 targets at 250°C. Neither shot resulted in a detonation. Burst current levels were about 300 kA. Both shots were "no go", as indicated by the recovered metal sample holder, which was disassembled by the force of the electrical explosion but whose parts were relatively undamaged (a detonation spalls and shatters the steel walls). The "no-go" is not surprising, because the measured cover coat velocity was only 3 km/s while the threshold for LX-17 at 250°C impacted by 10-mm-wide, 0.13-mm-thick Kapton strips is 3.3 km/s (2). The

LX-17 sample was pulverized by the impact of the exploding cable.

New Cable Design

A new cable design was proposed by R. E. Lee which reduces the hazard of HE initiation from the lightning strike. In the new design, the part of the cable which passes in proximity to the HE charge consists of three parallel striplines with conductor dimensions the same as the W87 cable. The rest of the cable is the same as the W89 cable. The section of cable which does not run close to the HE charge has the same cross section as the W89 cable. This cable combines low inductance with resistance to lightning. The currents in each of the three parallel branches which run close to the HE is one third that which would flow in a W87 cable struck by the same lightning. We have already demonstrated the W87 geometry to be safe, so with one-third the current there is no possibility that the new design could light LX-17. The cross-section for the new, lightning-resistant design is shown in Fig. 3 above.

Cover Coat Velocity for New Cable

Two shots were fired at 18 kV to measure cover coat velocity. Burst currents were ~250 kA. Because of differing cable cross sections, it was difficult to match the burst currents for the W89 cables exactly, but we felt that ~250 kA was still a good representation of a credible lightning strike. In both shots we measured a cover coat velocity of ~0.5 km/s, far below the shock initiation threshold of LX-17. The low velocity is a result of the current sharing between the three conductors. To achieve a burst current of 250 kA in each conductor, the cable would have to conduct 750 kA, a current beyond the range of even the most extreme positive lightning. It has been demonstrated that a burst current of 250 kA in a W87 cable will not initiate hot LX-17 (1), so it is clear that the new cable design has no chance of producing a detonation.

LX-17 Initiation Experiments with the New Cable Design

A shot was fired at 18 kV with a 5.08-cm-length of the new cable spaced ~3-mm from a LX-17 target at 250°C. No detonation was observed. Burst current levels were about 250 kA.

Summary and Conclusions

We have performed tests on two flat detonator cable designs to evaluate the effect of a direct lightning strike on the cable. Specifically, the concern is shock initiation of a main-charge, insensitive HE in close proximity to the cable during the electrical explosion of the cable. Experiments were performed on LX-17 with 6.35-mm-thick steel confinement on all sides except the side adjacent to the cable. To simulate the sensitization that would occur if the HE were heated in a fire, the LX-17 was heated to 250°C.

Using the W89 cable, two shots were fired at a burst current of ~300 kA and the cable did not detonate the hot LX-17. The measured cover coat velocities were ~3 km/s, which is uncomfortably close to the measured shock initiation threshold of 3.3 km/s for hot LX-17. For this reason, we conclude that the W89 cable design is marginal from a lightning-safety standpoint.

The new cable design yielded cover coat velocities of only ~0.5 km/s at a burst current of 250 kA. A shot was fired against hot LX-17 at the same burst current level and no detonation was observed. Because of the extremely low cover coat velocities observed with the new cable design, we conclude that there is no risk of accidental initiation by a credible lightning strike on the new -design cable.

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