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AD-E403 135

Technical Report ARAET-TR-07017

## COMPETENCY DEVELOPMENT DETONATOR DEVELOPMENT AND DESIGN

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September 2007



ARMAMENT RESEARCH, DEVELOPMENT AND  
ENGINEERING CENTER

Armaments Engineering & Technology Center

Picatinny Arsenal, New Jersey

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**20070910286**

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-01-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden to Department of Defense, Washington Headquarters Services Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>					
1. REPORT DATE (DD-MM-YYYY) September 2007		2. REPORT TYPE		3. DATES COVERED (From - To) March to December 2005	
4. TITLE AND SUBTITLE  COMPETENCY DEVELOPMENT DETONATOR DEVELOPMENT AND DESIGN			5a. CONTRACT NUMBER		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHORS  Amy Wilson			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army ARDEC, AETC Energetics, Warheads and Environmental Technology (AMSRD-AAR-AEE-W) Picatinny Arsenal, NJ 07806-5000			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army ARDEC, EM Technical Research Center (AMSRD-AAR-EMK) Picatinny Arsenal, NJ 07806-5000			10. SPONSOR/MONITOR'S ACRONYM(S)		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) Technical Report ARAET-TR-07017		
12. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT  Detonator technology has not changed much over the last 20 yrs, yet it is fundamental in the use of explosives. Weapon systems are constantly changing yet the same detonators with the same designs are being used. Topics such as detonator loading, explosives characteristics, explosives development, and safety in handling and firing are included in this report. When discussing detonator design and development, specific topics include techniques for testing and building detonators, tooling required for pressing, industry's approach to loading, new detonator materials, and detonator design considerations.					
15. SUBJECT TERMS Detonators      Detonator design      Detonator loading      MEMS detonator					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  SAR	18. NUMBER OF PAGES 15	19a. NAME OF RESPONSIBLE PERSON Amy Wilson
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) (973) 724-7151

## **ACKNOWLEDGMENTS**

I would like to acknowledge Dr. Brian Fuchs for his guidance and expertise for this program. Sharing his knowledge of detonators is invaluable to a new engineer and competency development.

I acknowledge Dave Fair for his foresight in the training and development of new engineers in explosives systems and assuring the funding was available for this project.

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## INTRODUCTION

Detonator development and design is fundamental in the use of explosives. Detonator technology has not progressed much over the last 20 yrs, yet weapon systems are changing every day. In particular, the advances in new Micro Electro Mechanical Systems (MEMS) necessitate modifications of current detonators or new designs. To develop the detonators, new explosive formulations and updated explosive production technologies are required.

## OBJECTIVE

Sources of information for this report include visits to other research sites and manufacturers in addition to conferences such as the National Defense Industrial Associations fuze conference. Also, personnel within the U.S. Army Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, New Jersey such as Dr. Brian Fuchs, Neha Mehta, and Gerard Gillen passed on their knowledge of detonator development and design. Hands on training including detonator loading, explosives characteristics, explosives development, as well as safety in handling and firing provided a platform for regaining the knowledge necessary to establish detonator competency.

Some points addressed in this report include the following:

- Testing and building detonators
- Tooling design and procedures for detonator loading
- Industry approach
- New detonator materials
- Design principles
- Initiation capabilities of the MEMS scale detonator

## DETONATOR BACKGROUND

In a typical detonator, an explosive train is used. The explosive train generally consists of a sensitive material that is initiated and in turn initiates a less sensitive material with a higher output or detonation pressure. A number of steps may be used in the detonation train. This system allows minimal volumes of sensitive explosives to be used and maintain a high level of performance. A sensitive initiating explosive, such as lead azide or lead styphnate, is used since it has high ignition sensitivity and will initiate a secondary charge. A common explosive train consists of lead styphnate (easy to initiate using a hot wire) igniting lead azide, which in turn initiates a high performance explosive, such as PETN or RDX.

Non-electric initiators, such as non-electric blasting caps, are initiated by a spark or flame from a safety fuze. Another type of non-electric initiator, called stab detonators, function when a firing pin pierces the closure disc and penetrates the priming mix. This occurs to initiate the lead azide in the explosive train. By penetrating the priming mix, the compression results in heating and initiation.

Hot-wire initiators use an electrical current to heat a wire that is in contact with the ignition material. The wire is heated to the materials ignition temperature to begin a burning reaction that propagates to the next material in the initiator.

Exploding bridgewire (EBW) detonators are similar to hot-wire initiators except that the explosive in contact with the wire cannot be ignited by the wire. The EBW initiates detonation directly by the impulse of the shock wave from exploding the bridgewire. To explode the bridgewire, high input power and high current are required.

Exploding foil initiators (EFI or Slapper) - The benefits of using an EFI is that the metal bridge is separated from the explosive, the explosive can be packed to high densities, and insensitive explosives can be detonated using this type of initiator. A high current firing pulse causes vaporization of the necked section of the foil. This section moves down the barrel and impacts the explosive pellet transmitting a shock wave into the explosive. This causes the explosive pellet to detonate.

Each type of detonator is valuable for different applications. Other aspects besides detonator output contribute to choosing a detonator for a specific application include reliability, and time to ignition. All of these aspects have to be considered when using detonators.

## **LOAD, TEST, AND RESEARCH NEW DETONATOR MATERIALS**

A detonator was developed by Tanner Research for the MEMS program. The detonators are being used in conjunction with a research effort at the Explosive Development Facility (ARDEC) in developing new lead styphnate, lead azide, and CL-20 formulations. In addition to loading and testing the detonators, the Explosive Development Facility is researching new explosive ink formulations for many applications including detonators. Initially, the detonators were loaded and tested with the same materials used at Stresau Laboratory, Inc for reliability testing of the Tanner detonators.

Many different ink formulations were mixed in small quantities. Each was spotted on a glass slide and viewed under a microscope to check for correct adhesion. Specifically, the lead styphnate was examined for a desirable volcano-like characteristic and for the absence of dark spots where the formulation did not adhere to the substrate. A volcano-like characteristic is indicative of the material collapsing onto the substrate, in most cases it means the formulation is completely adhered to the substrate.

A CL-20 based ink formulation (EDF-11) was chosen based on tests and observation of the material's physical characteristics. Also, many ink formulations of lead azide and lead styphnate were produced; one lead azide (PDI-002) and one lead styphnate (PDI-001) formulation was chosen for further testing. The new materials were tested in the same set of detonators from the MEMS program and functioned similarly to the reliability tests at Stresau.

The PDI-001 lead styphnate explosive ink was spotted onto the bridge head and allowed to dry. Next, the PDI-002 lead azide explosive ink was filled into the cavity on top of the DPI-001. The detonator was used to initiate an explosive train of the same newly developed formulations beginning with PDI-002, next a 50/50 mixture of PDI-002 and EDF-11, called PDI-003, then EDF-11. The test demonstrated the initiation capabilities of both the detonator and the new explosive formulations.



The newly developed explosive inks all functioned properly in the MEMS detonator. The PDI-001 was used as a sensitive explosive whose output initiated PDI-002 whose output was used to initiate the explosive train.

## DESIGN

In a simple detonator, a primary explosive is necessary to build up the detonation then transfer to a secondary charge. Also, a heating element is necessary to make the detonator function. In particular, the simple detonator was designed using the newly developed ink formulations and a hotwire to start the initiation of the lead styphnate formulation (PDI-001), transfer to the lead azide formulation (PDI-002), and build up to transfer detonation to the 50/50 mix of PDI-003, and then to the EDF-11 (secondary) column for greater output.

Since the explosives were recently developed, there was a lot of trial and error before the detonator worked properly. Originally, the 50/50 mix of PDI-003 was not part of the train. However, after some testing, it was determined that another material was needed between the PDI-002 and EDF-11 to continue the detonation through the entire train. The intermediate needed to have higher performance and could be less sensitive than PDI-002, yet more sensitive and with less performance than EDF-11. To fulfill this need, the design was modified and a 50/50 mix of PDI-003 was developed as an intermediate to complete the train (fig. 1).

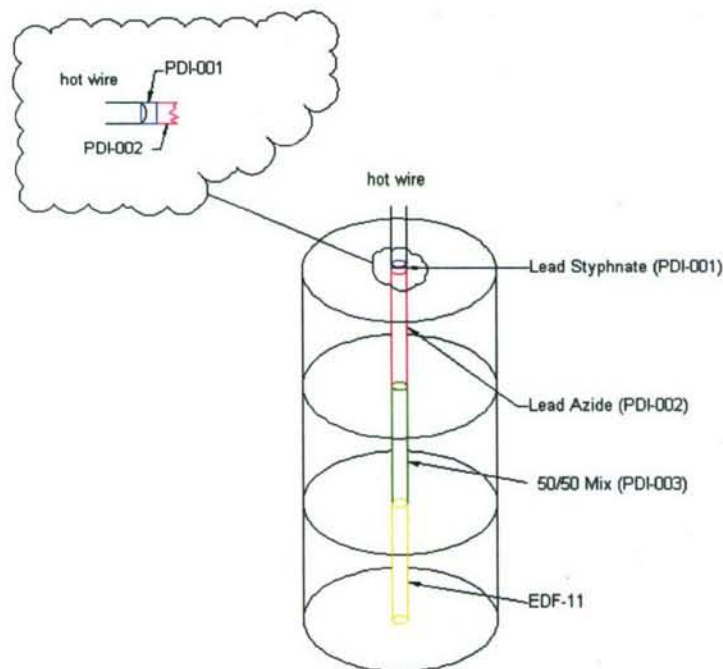


Figure 1  
Simple hot-wire initiator using newly developed explosive inks



Train:

Lead styphnate ink (PDI-001): Designed for easy ignitability by a hot wire, provides high sensitivity, a high level of uniformity, and sensitivity to heat

Lead azide ink (PDI-002): Designed to be initiatable from burning lead styphnate to rapidly transfer to a detonation

50/50 (PDI-003): Designed to be initiated by lead azide. Less sensitive than lead azide ink with a higher performance

EDF-11: Initiatable by PDI-003 with a progressively lower sensitivity and higher performance than the lead azide ink

### TOOLING AND LOADING PROCEDURES

No tooling is necessary for the loading of liquid explosives into the detonators from the Tanner Research project, but they could be loaded using an automated process. The process for loading is much easier than the previous method with the standard materials from Stresau. Both methods will be discussed.

#### Previous Method of Loading of MEMS Detonators

1. Place detonators in a plastic baggie
2. Place detonators and a flat aluminum plate to be used as a working surface inside an oven at -45°?
3. Once the items are cold, relocate to a suitable work area and place detonators onto the cold plate.
4. Add lacquer thinner (butyl acetate and n-amyl alcohol) to the ball milled lead styphnate.
5. Mix until the consistency is thick enough to load into the chilled detonator. Continue mixing or adding lacquer to maintain consistency during loading.
6. Using a wire, deposit some of the lacquered lead styphnate into the cavity of the detonator as a spot charge.
7. Allow the lacquered lead styphnate to dry before step 8.
8. Press an appropriately sized lead azide pellet on top of the spot charge to fill the rest of the cavity.

## **Liquid Loading of MEMS Detonators Method**

1. Using a previously prepared syringe filled with PDI-001, press on plunger to deposit a drop of material into the detonator cavity as a spot charge.
2. Allow the formulation to dry before step 3.
3. Using a previously prepared syringe filled with PDI-002, press on plunger to deposit material into the detonator to fill the cavity.
4. Allow the lead azide formulation to dry completely before firing.

## **Discussion of the Two Loading Methods**

The previous method using a cold plate made everything wet. This caused the risk of water in the cavity during loading. The process of mixing the lead styphnate with the lacquer was tedious. It was also difficult to keep the right consistency during loading. The lead styphnate has to be ball milled in both methods prior to mixing with either the lacquer or binder system of the new formulation. In the new method, it is timely to dry PDI-002 (approximately 4 hrs). Using the pressed lead azide, the detonator is ready to function immediately. However, when dealing with small volumes as in the MEMS scale detonators, pressing lends many challenges. Special tooling is necessary to withstand the pressures needed to keep the pellet together. For this testing, the lead azide pressed into pellets fell apart or delaminated and were placed inside the cavity piece by piece and pressed again inside the cavity, which was very time consuming due to the cavity's small size.

In the new loading method, the material will remain suspended within the syringe for many days (settling studies have not been done) and can be pushed through pen tips down to 25 gage. The easiest way to load a detonator using the liquid explosives is using a pneumatic machine programmed to deposit a predetermined amount of material into the cavity. This loading method can be performed at room temperature and no additional mixing is required for loading. In comparison to the previous method, this method reduces human exposure to the explosives and allows the loading process to be more consistent.

## **INDUSTRY APPROACH**

Several tours were taken in conjunction with this research. Trips were taken to Stresau Laboratories, Action Manufacturing, and Ensign Bickford Aerospace and Defense (EBA&D). These facilities were selected to observe the research and production of detonators in industry. Action Manufacturing primarily does production and very little, if any, research. In contrast, EBA&D and Stresau do both research and production.

In combination with Tanner Research and Small Business Innovation Research Phase II program, an EBW detonator was developed to use on MEMS scale devices. An EBW includes a three material explosive train including a spot charge of lead styphnate, a lead azide charge, followed by an output charge such as CL-20 or RDX. A trip was taken to Stresau Laboratory in Wisconsin to observe reliability testing of the given detonators. The trip included the following participants: Dr. Brian Fuchs (ARDEC), Mark Gelak (Adelphi), Dr. Amish Desi (Tanner Research), and Amy Wilson (ARDEC). The discussion focused on detonator testing



and problems associated with loading and firing the devices. Problems with the lead styphnate spot charge were discussed. Currently, lacquered lead styphnate is being used. They experience loading problems such as separation of the lead styphnate mixture, and wicking along the sides of the cavity. Therefore, constant mixing and careful hand application is required.

In addition to the discussion, a tour of the facilities provided some insight into the detonator production process. Most of the production at Stresau Labs is done by hand using pneumatic presses. It was also observed how bridgewires are automatically welded in the manufacturing of detonators.

The primary concerns that were stressed included lead styphnate settling problems, as well as lead azide supply problems. At Stresau, the lead styphnate is ball milled to decrease particle size. It is then used in the lacquered formulation. The fact that the supply of lead azide is diminishing is also an area of concern for Stresau.

A trip to Action Manufacturing in Pennsylvania provided another aspect of detonator production in contrast to Stresau Labs. Attendees of this trip included Dr. Brian Fuchs, Gerard Gillen, and Amy Wilson all from ARDEC. Action is more automated in their processes than Stresau. However, hand assembly does exist at the facility for some processes. Action uses pneumatic presses functioned by hand when manufacturing detonators with quantities less than 10,000 and completely automated machinery such as the Iowa and Jones loaders for larger jobs. Also, pelletizing machinery, in-process testing, and packaging were observed.

One area of interest was the Action designed machine to automatically spot charge M100 detonators with a lead styphnate formulation that will not settle for approximately a week. This trip provided an insight of where detonator production is going, problems that still exist, and the current technologies available.

One final trip to EBA&D in Simsbury, Connecticut provided knowledge of non-electric initiators in contrast to Action Manufacturing. Attendees of this trip included Dr. Brian Fuchs and Amy Wilson (ARDEC). EBA&D gave a tour of their shock tube manufacturing facility and the production of non-electric blasting caps to the final assembly of the shock tube and non-electric blasting cap. The assembly process is automated; however, it involves a lot of human interaction between stages of assembly. EBA&D also uses pneumatic presses for loading purposes in addition to automated pressing stations.

By visiting Stresau Laboratory, Action Manufacturing, and EBA&D and observing their processes, it provided a better understanding of how detonators are produced in mass quantities and the challenges associated with those processes. Also, the challenges encountered in the loading processes of both small and large quantity items outlined in this paper are similar across the three facilities.

## SUMMARY

In conclusion, general information of detonator design and development has been summarized in this report. Even with current knowledge, things are always changing and research is continuous. By joining industry and the U.S. Army Armament Research, Development and Engineering Center, there is much to be gained in the area of detonator research. In addition, the new explosives and new detonator technologies discussed may one day be the basis for initiating upcoming weapon systems.



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