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# NONPRIMARY-EXPLOSIVE, HOT-WIRE DETONATOR

by

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ABSTRACT

A nonprimary-explosive, hot-wire detonator, employing the deflagration-to-detonation transition (DDT) process, has been developed. Pentaerythritol tetranitrate (PETN) is the explosive used. The assembly is nominally a 1-A/1-W/1-Ω system. The DDT process has been examined over a range of PETN specific surface values (3 000-14 500 $cm^2/g$) and pressing densities (1.0-1.4 $g/cm^3$). The reaction is sensitive to the degree of subdivision and the compactness of the explosive in which the transition takes place. It apparently happens better with PETN of small specific surface loaded at low density. Consistent transitions from burning to detonation occur in PETN pressings 9 mm or more in length, with diameters of about 2 mm. Increasing the charge diameter by a factor of 2 appears to allow a shortening of the required charge length by several millimeters.

## INTRODUCTION

Secondary explosives such as PETN can be ignited by a hot wire at low current and low voltage. If the confinement of the ignited explosive is restrictive enough and other criteria are met, the deflagration will build up (transit) into a detonation. This paper discusses developmental experiments leading to a functional explosive device and selected parameter studies on a hot-wire detonator (ER-345).

## DDT DEVELOPMENTAL STUDIES

ER-322 donor assemblies (Fig. 1) with Nichrome V bridgewires of 0.05-mm diameter and 2.5-mm length (room-temperature resistance of ~1 Ω), loaded to a density of 1.6 $g/cm^3$ with PETN of specific surface (S) 3 650 $cm^2/g$, were found to have an ignition-current threshold value of about 1 A over an environmental temperature range of -54°C to +74°C. All-fire voltage and current values at the low temperature are 2.5 V and 1.4 A. They are 2.0 V and 1 A at the high temperature. The all-fail current value at +74°C is close to 0.7 A. While these values vary slightly over this temperature range, it appears that this assembly is a nominal 1-A/1-W/1-Ω system.

An indication of the reproducibility in performance of this donor portion (ER-322) of the hot-wire DDT assembly is given in Table I. These data come from experiments using HMX instead of PETN as the donor explosive charge but should be representative of

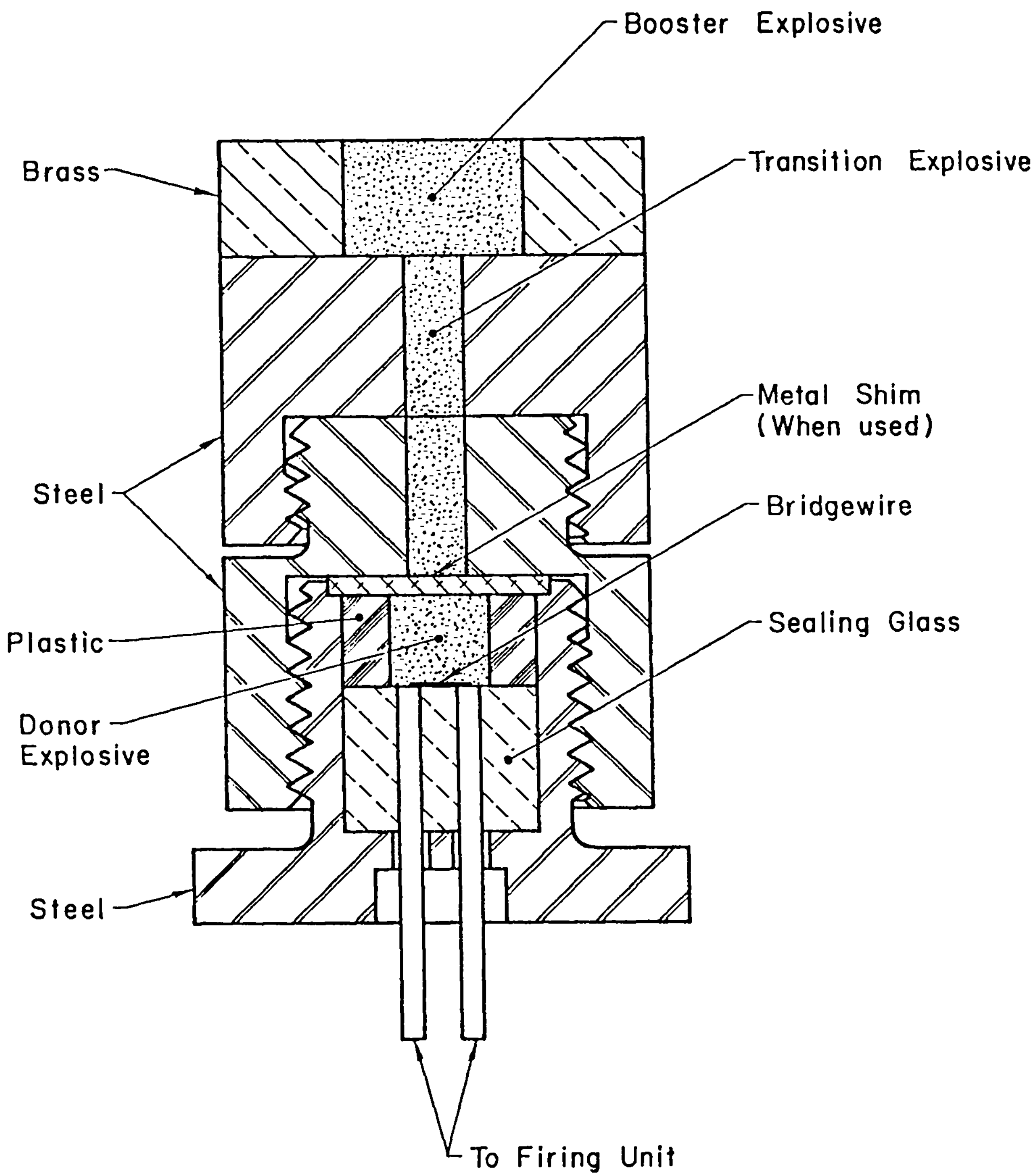


Fig. 1. DDT Assembly (ER-322 type).

TABLE I

REPRODUCIBILITY OF EXPERIMENTAL RESULTS

| Bridge Diam (mm) | Bridge Length (mm) | HMX Loading Density ($g/cm^3$) | Function Current (A) | Function Time (ms) |
|---|---|---|---|---|
| 0.051 | 1.7 | 1.64 | 2.18 | 3.06 |
| | | | 2.18 | 2.99 |
| 0.051 | 1.7 | 1.64 | 1.41 | 9.54 |
| | | | 1.39 | 10.18 |
| 0.051 | 3.1 | 1.64 | 2.77 | 1.92 |
| | | | 2.73 | 1.96 |
| 0.051 | 4.5 | 1.64 | 1.64 | 7.04 |
| | | | 1.60 | 7.79 |
| 0.038 | 1.55 | 1.64 | 0.87 | 12.32 |
| | | | 0.87 | 10.72 |
| 0.038 | 1.55 | 1.64 | 1.17 | 4.29 |
| | | | 1.17 | 4.11 |
| 0.038 | 1.55 | 1.64 | 2.43 | 1.19 |
| | | | 2.20 | 1.18 |
| 0.079 | 1.62 | 1.64 | 4.60 | 3.12 |
| | | | 4.68 | 3.28 |
| 0.051 | 1.7 | 1.56 | 3.15 | 1.27 |
| | | | 3.10 | 1.27 |
| 0.051 | 1.7 | 1.56 | 1.49 | 7.77 |
| | | | 1.47 | 8.07 |
| 0.038 | 1.55 | 1.56 | 1.35 | 3.22 |
| | | | 1.35 | 3.22 |
| 0.079 | 1.55 | 1.56 | 6.74 | 3.65 |
| | | | 6.74 | 2.94 |

PETN as well. The last column gives the value of the function time ($t_f$)--the time from start of electric current through the bridgewire until the explosive material ignites and the resulting burning reaches a self-sustaining reaction--over a range of bridgewire dimensions at two explosive loading densities. The current value when this functioning occurs is called the function current, $I_f$, and is shown in the fourth column. For a given value of $I_f$, $t_f$ appears to vary by several per cent.

The transition barrel portion of the hot-wire explosive device was made in two sections, loaded separately and then screwed together to form the cylindrical transition cavity. Each section of the transition barrel has a 2.5-mm inner diameter and 7.0-mm length, giving an overall 14-mm length. These barrels were loaded with PETN of three widely differing specific surface values (S = 3 650, 8 400, and 14 600 $cm^2/g$) at 1.0-$g/cm^3$ loading density. The DDT reaction took place in each. Dents were produced in 6061-T6 aluminum witness slugs attached to the downstream end of the transition barrels. No consistent variation in dent depth with PETN specific surface change could be found. It appears, however, that the PETN with the smallest S value (largest "average particle size") produced the deepest dent in the witness slug. The density of the PETN sample in the transition zone was also varied at constant powder specific surface. Dents were again observed in the

## TABLE II

## DDT IN ALL-PETN ER-322 ASSEMBLIES WITHOUT A BOOSTER PELLET

Donor: PETN $S = 3\ 650\ cm^2/g$ Density = 1.64 $g/cm^3$ Mass = 100 mg

| Transition Barrel | | | | | 6061-T6 Aluminum Witness Block Dent |
|---|---|---|---|---|---|
| PETN S ($cm^2/g$) | Mass (mg) | Density ($g/cm^3$) | Diameter (mm) | Length (mm) | Depth (mm) |
| 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.7 |
| 8400 | 72 | 1.0 | 2.5 | 14.0 | 0.5 |
| 14600 | 72 | 1.0 | 2.5 | 14.0 | 0.5 |
| 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.4 |
| 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.8 |
| 3650 | 100 | 1.4 | 2.5 | 14.0 | 0.8 |

aluminum witness slugs, showing that the DDT reaction had occurred. Table II gives both sets of data.

Booster pellets of PBX 9407 material (density = 1.6 $g/cm^3$) were substituted for the witness slugs to see whether the detonation produced in the DDT was strong enough to initiate a high-density, secondary explosive pellet. All systems detonated. The transition-zone PETN that was examined had an S value of 3 650 $cm^2/g$ and was pressed to 1.0-, 1.2-, and 1.4-$g/cm^3$ density. In these experiments we measured the diameter and the depth of the dent in a 2024 Dural witness block and calculated the estimated cylindrical volume. The data from these shots are given in Table III.

Over 40 complete assemblies were fired at low, ambient, and elevated temperatures. Aluminum (6061-T6) confinement shims (0.8 mm thick) were used between the donor and transition charges to enhance pressure buildup in the donor and provide more efficient compression in the transition charge. The detonator, however, will function quite satisfactorily without the confinement plate. High-density PETN and PBX 9407 pellets were the booster charges. All shots produced dents in 2024 Dural witness blocks, as evidence of detonation. Expansion of the transition barrel diameters clearly show the buildup to detonation takes place in the transition charges of PETN and not in the booster pellets. The cylindrical volume of the dents

## TABLE III

## DDT IN ALL-PETN ER-322 ASSEMBLIES WITH A BOOSTER PELLET

Donor: PETN $S = 3\ 650\ cm^2/g$ Density = 1.64 $g/cm^3$ Mass = 100 mg

Booster Pellet: PBX 9407 Density = 1.6 $g/cm^3$ Mass = 376 mg

| Transition Barrel | | | | | 2024 Dural Witness Block Dent | | |
|---|---|---|---|---|---|---|---|
| PETN S ($cm^2/g$) | Mass (mg) | Density ($g/cm^3$) | Diameter (mm) | Length (mm) | Depth (cm) | Diameter (cm) | Volume ($cm^3$) |
| 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.28 | 1.43 | 0.4 |
| 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.23 | 1.41 | 0.4 |
| 3650 | 100 | 1.4 | 2.5 | 14.0 | 0.21 | 1.54 | 0.4 |

TABLE IV

DENT CHARACTERISTICS AS A FUNCTION OF ENVIRONMENTAL TEMPERATURE

| Dent Depth/Diam (mm) | Vol ($cm^3$) | Booster Material | Pellet Density ($g/cm^3$) | Environmental Temperature (°C) |
|---|---|---|---|---|
| 2.1/10.2 | 0.2 | PETN | 1.3 | -54 |
| 2.0/11.6 | 0.2 | PETN | 1.3 | +20 |
| 2.3/10.6 | 0.2 | PETN | 1.3 | +74 |
| 2.6/11.7 | 0.3 | PETN | 1.6 | -54 |
| 2.4/13.8 | 0.4 | PETN | 1.6 | +20 |
| 2.9/12.3 | 0.3 | PETN | 1.6 | +74 |
| 2.6/12.6 | 0.3 | PBX 9407 | 1.6 | -54 |
| 2.5/13.0 | 0.3 | PBX 9407 | 1.6 | +20 |
| 2.9/12.5 | 0.3 | PBX 9407 | 1.6 | +74 |

produced in the witness plate depends upon the density of the booster pellet. The data are given in Table IV.

NONPRIMARY-EXPLOSIVE (PETN), HOT-WIRE DETONATOR (ER-345)

The construction of the PETN-DDT, hot-wire detonator came about as a result of ad hoc testing. Once the approximate successful parameters had been defined, a prototype weapon detonator could be designed ab initio. The ER-345 (Fig. 2) is the result. The donor portion is the ER-322. The transition charge barrel is of a single piece of steel whose length and bore diameter can easily be modified. If the length/diameter ratio of this barrel is large, its loading generates a new detonator parameter, i.e., resultant explosive density gradients.

Detonators that had transition barrels 14 mm long with a 2.5-mm bore diameter were assembled. These dimensions met the criteria of more than enough length for deflagration-to-detonation buildup and at the same time provided a large (ca. 5) length/diameter ratio. The barrels were loaded in one and two pressing operations. The results of firing detonators so assembled are shown in Table V. Pressing Mode A is a single loading of 80 mg of PETN, pressed from the donor end. This produces the highest transition-barrel density at the donor end and the lowest at the booster-pellet end. Mode B is a two-step (40-mg each) pressing operation from the donor end. This procedure still provides the lowest density at the booster-pellet end, but the density in the tube no longer increases smoothly to the donor end. It has a high/low-density interface near the center of the barrel. Mode C gives the highest density at the booster-pellet end with a smooth decrease to the donor end. Mode D is similar to Mode B in that the density gradation from booster-pellet to donor end is no longer uniform. It differs in that Mode D has the highest resultant density at the booster-pellet end.

All detonators fired and gave dents in aluminum witness blocks. PBX 9407 booster pellets gave cylindrical dents of larger volume when they were initiated by the configurations with the highest density PETN at their end. We feel this is because of a faster and stronger buildup process in the transition barrel when the donor ignites lower-density PETN, as well as the booster pellet being initiated closer to its maximum detonation velocity, the higher the density of the

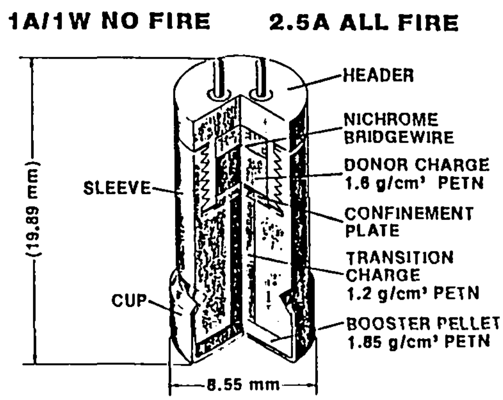


Fig. 2. All-Secondary, Hot-Wire Detonator.

TABLE V

EFFECT OF PETN TRANSITION-ZONE PRESSING MODE ON ER-345 BOOSTER-PELLET DENT DIMENSIONS

| Mode of Pressing | Dent Dimensions Diam/Depth (cm) | | Vol ($cm^3$) |
|---|---|---|---|
| A | 1.3 | 0.2 | 0.3 |
| B | 1.4 | 0.2 | 0.3 |
| C | 1.5 | 0.2 | 0.4 |
| D | 1.5 | 0.2 | 0.4 |

Pressing Mode A: One PETN pressing from donor end, 80 mg.
Pressing Mode B: Two separate PETN pressings from donor end, 40 mg each.
Pressing Mode C: One PETN pressing from booster-pellet end, 80 mg.
Pressing Mode D: Two separate PETN pressings from booster-pellet end, 40 mg each.

initiating PETN. A density discontinuity in the middle of the transition barrel seems to have little or no effect. As a result of these tests, all barrel-loading operations follow pressing Mode C (threaded end down).

## ER-345 PARAMETER STUDIES

ER-345 detonators were fired with five different transition-barrel lengths and three column diameters. The PETN ($S = 3\ 650\ cm^2/g$) loading-density range was 1.0-1.4 $g/cm^3$. The data are shown in Table VI. Only the results from barrels with a 2.5-mm bore are complete enough to analyze. These data indicate that the 50%-fire and all-fire lengths are near 7 and 9 mm, respectively, in this loading-density range. The few experiments with smaller transition-explosive diameters do not indicate that a significantly shorter charge length can be used. Five-millimeter-long assemblies still fail most of the time. An increase in charge diameter may be helpful; however, 3/4 of the 5-mm-long detonators at a low loading density functioned properly with a bore diameter of 3.8 mm. Experiments with PETN S values as high as 28 000 $cm^2/g$ indicated best performance (with 9-mm-long transition barrels) was with the larger-particle explosive loaded to the lowest density.

TABLE VI

EFFECT OF TRANSITION-BARREL DIAMETER, LENGTH, AND PETN DENSITY ON FIRING PERFORMANCE OF ER-345 DETONATORS

PETN: S = 3 650 $cm^2/g$

| | Diameter = 2.0 mm | | Diameter = 2.5 mm | | Diameter = 3.8 mm | |
|---|---|---|---|---|---|---|
| Density ($g/cm^3$) | F | Dent Vol. ($cm^3$) | F | Dent Vol. ($cm^3$) | F | Dent Vol. ($cm^3$) |
| **Transition-Barrel Length = 5 mm** | | | | | | |
| 1.0 | -- | -- | 0/5 | -- | 3/4 | 0.3 |
| 1.2 | 1/3 | 0.3 | 0/5 | -- | -- | -- |
| 1.3 | -- | -- | 3/4 | 0.3 | -- | -- |
| 1.4 | -- | -- | 0/5 | -- | -- | -- |
| **Transition-Barrel Length = 7 mm** | | | | | | |
| 1.0 | -- | -- | 5/7 | 0.3 | 2/2 | 0.3 |
| 1.2 | 4/4 | 0.3 | 6/10 | 0.3 | -- | -- |
| 1.3 | -- | -- | 0/3 | -- | -- | -- |
| 1.4 | -- | -- | 1/5 | 0.3 | -- | -- |
| **Transition-Barrel Length = 9 mm** | | | | | | |
| 1.0 | -- | -- | 3/3 | 0.3 | 2/2 | 0.3 |
| 1.2 | 3/3 | 0.3 | 8/10 | 0.3 | -- | -- |
| 1.3 | -- | -- | 3/3 | 0.3 | -- | -- |
| 1.4 | -- | -- | 5/5 | 0.3 | -- | -- |
| **Transition-Barrel Length = 11 mm** | | | | | | |
| 1.0 | -- | -- | -- | -- | -- | -- |
| 1.2 | -- | -- | 5/5 | 0.3 | -- | -- |
| 1.3 | -- | -- | -- | -- | -- | -- |
| 1.4 | -- | -- | 5/5 | 0.3 | -- | -- |
| **Transition-Barrel Length = 14 mm** | | | | | | |
| 1.0 | -- | -- | -- | -- | -- | -- |
| 1.2 | -- | -- | 10/10 | 0.4 | -- | -- |
| 1.3 | -- | -- | -- | -- | -- | -- |
| 1.4 | -- | -- | -- | -- | -- | -- |

F = Fraction assemblies achieving detonation.

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