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Title:

MAGNETIC GAUGE MEASUREMENTS ON THE TWO-STAGE GUN: HOMOGENEOUS AND HETEROGENEOUS INITIATION OF HIGH EXPLOSIVES

Author(s):

Stephen A. Sheffield, Richard L. Gustavsen, Robert R. Alcon, and Lloyd L. Davis, DX-1
Los Alamos National Laboratory

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Magnetic Gauge Measurements on the Two-Stage Gun: Homogeneous and Heterogeneous Initiation of High Explosives[1]

Stephen A. Sheffield, Richard L. Gustavsen, Robert R. Alcon, and Lloyd L. Davis
Los Alamos National Laboratory
Group DX-1, MS P952
Los Alamos, NM 87545

Abstract

One of the reasons for building our gas-driven two-stage gun at Los Alamos was to be able to do shock initiation experiments on high explosives that were too insensitive to initiate with the single-stage gun. In past ARA meetings we have discussed the operation of the gun and the magnetic gauge measurement method. During the past couple of years we have done a number of magnetic gauge experiments on both liquid and solid high explosives. Shock initiation of high explosives depends on the nature of the material – whether it is homogeneous (liquid) or heterogeneous (pressed solid). In the solid explosives, mostly heterogeneous behavior has been measured. In the liquid explosive isopropyl nitrate, classic homogeneous initiation has been measured including the formation of a superdetonation in the shocked liquid. Experiments in both materials are discussed including the particle (mass) velocity profiles at a number of Lagrangian positions in the flow, progress of the shock front as measured by shock tracker gauges, and the position when the reactive wave reaches a detonation condition. The two-stage gun, in conjunction with the multiple magnetic gauging method, has proven very useful for generating new information in initiation experiments. Information from these experiments is of great value to modelers trying to determine the proper reaction rate models to use in simulations of the shock initiation process.

Introduction

One of the main research areas in our group is studying shock initiation behavior of high explosive (HE) materials. The best method of producing a shock in the HE is to use a gun-driven projectile with an impactor that imparts a well controlled and well known shock input to the sample material. For many years we have used a single-stage gun (capable of projectile speeds of 1.45 km/s) to provide this type of input to the more sensitive HE materials. However, this projectile speed is not sufficient to shock an insensitive HE (such as TATB) or a liquid HE to high enough pressures (and temperatures) to make them initiate during the times available to make diagnostic measurements in a gun experiment. Because of this several years ago we decided to build a gas-driven two-stage gun which would allow a sample size sufficient to do multiple magnetic gauging experiments and provide projectile speeds up to 3 km/s. This would allow us to do experiment with input shocks of sufficient strength to initiate quite insensitive materials. We have reported over the last several years various aspects of this

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[1] Work performed under the auspices of the U. S. Department of Energy.

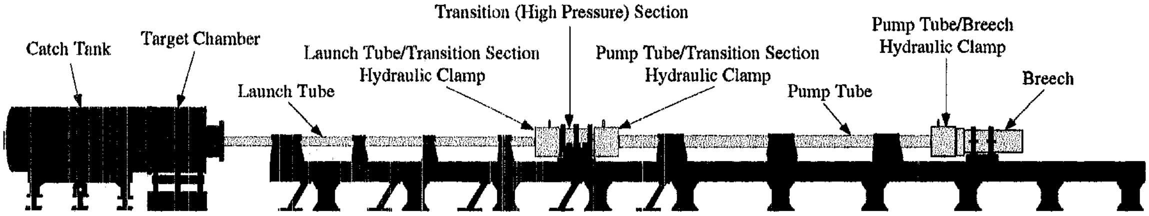

Figure 1. Schematic of the LANL gas-driven two-stage gun.

gun and the work being done using it.[1-7] We now have experiments completed that demonstrate the great value of this experimental tool in our work. This paper describes some of the important new work that has helped us understand the nature of shock initiation of explosives in terms of the heterogeneous or homogeneous nature of the explosive materials.

The paper is organized to give a brief description of the gun followed by a discussion about the experimental technique including the multiple magnetic gauge method. Then homogeneous and heterogeneous shock initiation of HE is briefly discussed to acquaint the reader with the rudiments of the models relating to them. Experimental data are presented that demonstrate the heterogeneous nature of the initiation in PBX 9502, a TATB based high explosive material. In addition, measurements made on isopropyl nitrate (IPN), a liquid explosive, are presented that demonstrate the homogeneous nature of the shock initiation of this material. These will be contrasted to provide a sense of the differences between these two HE initiation processes.

Two-Stage Gun

Our two-stage gun is a compressed-gas driven, two-stage light gas gun designed to perform shock initiation studies on insensitive HE (see Fig. 1).[1-7] It has a 100-mm diameter by 7.6-m long pump tube and a 50-mm diameter by 7.6-m long launch tube. The relatively large launch tube diameter was chosen to provide an experimental area large enough to allow 1-D multiple magnetic gauge experiments to be done. A gas breech, capable of operating at 15,000 psi, is the driver for the pump piston. Three large hydraulic clamps are used to clamp the breech to the pump tube, the pump tube to the transition section, and the transition section to the launch tube. Helium is used as the driver gas for both the launch projectile and the pump piston. The target chamber provides the needed room for an electro-magnet which produces a static magnetic field during an experiment. Projectile velocities up to 3 km/s have been obtained in shock-initiation experiments on HE.

Experimental Setup

Magnetic Gauging – Magnetic particle velocity gauging was first used in Russia in the late 1940's but was not reported in the literature until the early 1960's when Zaitzev et al.[8] and Dremin et al.[9] published several papers. We have used magnetic gauging at Los Alamos since the early 1980's; the method we use was developed by John Vorthman.[10-11] The gauges are part of a thin plastic membrane that can be embedded in a sample HE piece at an angle. This method has several advantages: a) the gauges don't shadow each other; b) the gauge leads are not susceptible to spreading and giving inaccurate voltages, c) an intricate pattern can be etched in the thin aluminum, d) the membrane is thin and nearly the same shock impedance as the solid HE; e) a large number of in-situ measurements at different Lagrangian positions can be made in the flow on a single shock experiment; and f) the experiments are relatively easy to build, i.e., the membrane can be glued in reasonably easily rather than requiring assembly of a mosaic of target pieces as has been used by others. Over the years a number of changes have been made to the technique – we will discuss the technique as it is used today.

Electromagnetic particle velocity gauging is based on Faraday's law of induction. For a conductor of length **L** moving with velocity **u** in a steady uniform magnetic field of strength **B**, the induced voltage in the conductor is, $V = \mathbf{L} \bullet \mathbf{u} \times \mathbf{B}$. In this equation, all quantities but the induced voltage V are vector quantities. If, by design, the vectors **L**, **u**, and **B** are everywhere mutually orthogonal, this reduces to the scalar equation, $V = LuB$. Furthermore, electrical leads to sense the voltage in the conductor **L** can be made to have zero induced voltage by placing them parallel to the plane defined by the vectors **B** and **u**. The experiments are designed so that this is the case.

Magnetic gauges are useful for measurements in non-metallic materials only. This makes them ideal for HE materials. Experiments must be designed to eliminate or minimize the movement of metallic objects that might perturb the magnetic field. However, the use of these gauges in initiating and detonating HEs, which are somewhat conductive, has been amply demonstrated and will be apparent in the data to be shown later.

Gauge Design – The gauge package is a membrane consisting of a 25 μm thick FEP Teflon layer with a layer of 5 μm of aluminum epoxied to it. It is then coated with photoresist, exposed with a mask in place, and then etched producing the desired pattern. Finally, another layer of 25 μm thick FEP Teflon is epoxied to the membrane to protect the thin aluminum gauge elements which are only 0.1 mm wide. A completed membrane is about 60 μm thick.[12] The gauge now being used is shown in Fig. 2.

Several changes have been made to the gauges for various purposes, including the use of one or more "shock trackers", changing the position and nesting of the particle velocity gauges, etc. On the two sides of the gauge and at the bottom center are ladder shaped elements in Fig. 2; these are the "shock tracker" gauges. The nine elements down the center of the pattern are the particle velocity gauges. They have different lengths so the give different voltage signals – this is taken care of in the data analysis. The gauges provide particle (mass) velocity measurements at nine different Lagrangian positions when the gauge membrane is installed in the sample at an angle as will be discussed later.

When the gauge membrane is mounted in a sample at an angle, the shock tracker gauges have a periodically varying effective length with depth. As the shock sweeps through the sample, the effective length (and thus the output voltage) changes with the position of the shock front. The voltage output is high/low when the shock front is traversing a region where the gauge length is long/short, respectively. From this a distance-time (x-t) plot can be obtained using the known position of each element in the

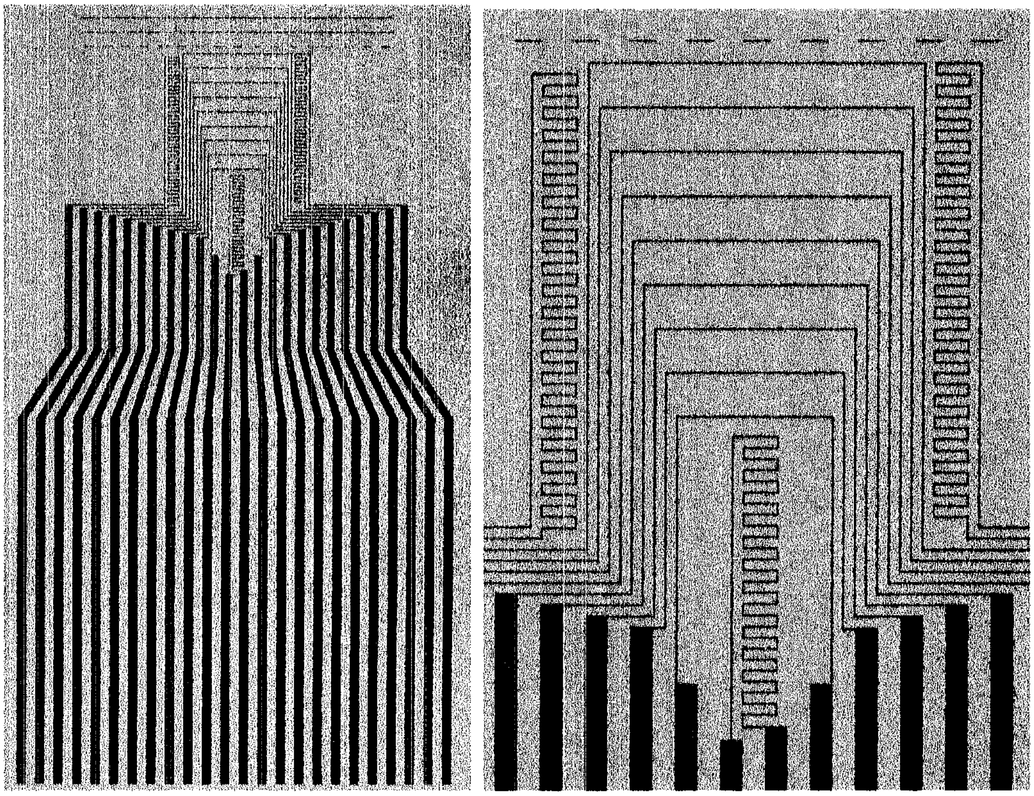

FIGURE 2. Gauge design presently being used. On the left is the complete gauge and on the right is the top of the gauge blown up showing the actual gauge elements – there are nine particle velocity gauges and three shock trackers.

shock tracker. This x-t plot provides a measure of what the shock front position is at a given time – thus the gauge is called a shock tracker.

The gauge membrane is installed in the sample at an angle, usually 30 degrees with respect to the sample front. The experimental design is somewhat different for the solid HE samples than for the liquid HE experiments because of the need to load and confine the liquid; these are discussed below.

Solid HE Experiments – Two solid HE pieces are machined with 30 degree angles on them as shown in Fig. 3. The gauge membrane is glued to the bottom piece with the gauge ends carefully aligned to a sample reference line. Then the top piece is glued on and the final assembly is lightly machined to make the top flat. When the membrane is installed at a 30 degree angle, the gauge ends are at depths ranging from about 0.5 mm to about 8 or 9 mm depending on whether the shot is for the single-stage or the two-stage gun. A "stirrup" magnetic gauge is usually glued to the front of the sample to measure the input particle velocity. An experimental assembly with this gauge in place is shown later.

Liquid HE Experiments – Since the liquid must be confined and the assembly must be designed so that the liquid can be loaded after it is built, there are considerable differences between the design of the liquid and solid HE experiments. The buildup for a liquid shot is shown in Fig. 4. The cell is made of three plastic pieces that are epoxied together. The PMMA base has a 30 degree angle machined on it and has a cutout for the liquid that is about 40 mm diameter by 12 mm high. The gauge membrane is put in an

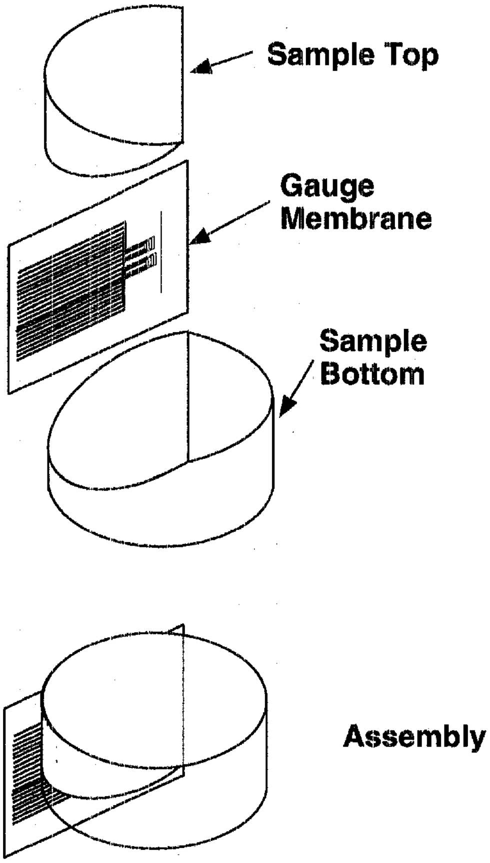

Figure 3. Solid HE sample assembly.

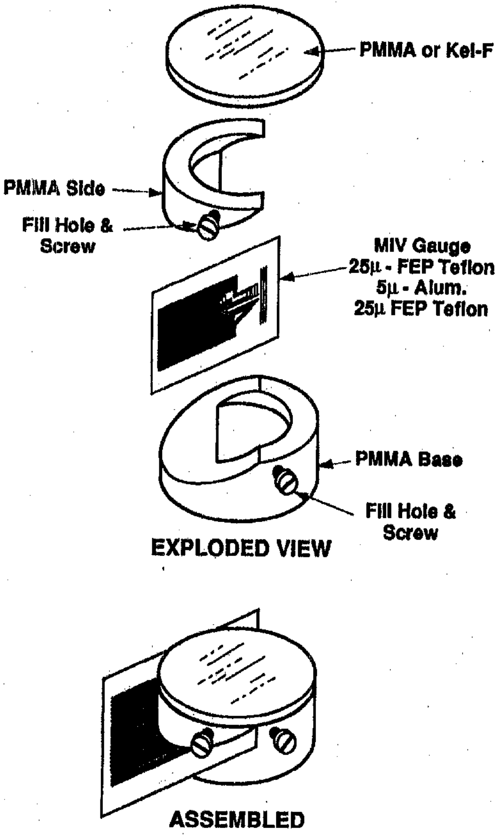

Figure 4. Liquid HE sample assembly.

apparatus to keep it taut as it is epoxied to the base. It is also carefully aligned to a reference line. Then the PMMA side piece, which has a matching cutout in it, is epoxied to the base. The gauge end is trimmed and this assembly is then carefully machined to make the top flat and parallel to the gauge ends. A cell top made of either PMMA or Kel-F is carefully prepared by lapping both sides flat and parallel and then gluing a stirrup gauge to the side of it that will be in contact with the liquid. It is then epoxied and screwed to the cell using nylon screws. There are fill holes in both pieces of the cell as shown in Fig. 4. The inside of the cell is painted with epoxy prior to assembly to keep the liquid from attacking the PMMA after it is loaded into the cell. Gauge end positions in the liquid are similar to those in the solid HE experiments.

Overall Experimental Setup -- A picture of a solid HE experiment ready to be put in the gun is shown in Fig. 5. The leads from the gauges (up to 24 of them) are hooked to cables by using a computer card connector – the gauge leads have been positioned to fit the connector (see Fig. 2). The connection of these leads is shown on the right side of the figure. There are two leads for each gauge to allow for differential measurement of the voltage. This reduces the noise from extraneous sources. Also shown is the stirrup gauge and connection on the left side of the HE. In the case of a liquid sample, the stirrup gauge is on the underside of the cell front. It is hooked up and protected in the same way as in the solid HE experiment.

A schematic showing the target placement with respect to the magnetic field and the gun barrel is shown in Fig. 6. A non-metallic projectile impacts the target located in

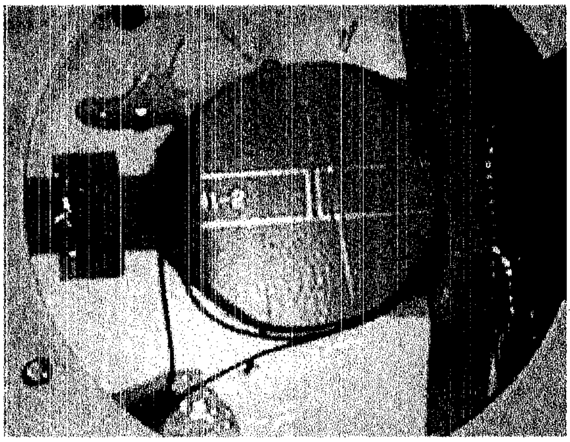

Figure 5. Finished solid HE target assembly showing the stirrup gauge membrane epoxied to the front of the target. As can be seen on the left side of the sample, the sample edge is rounded, the leads of the stirrup gauge are glued to the rounded edge, and the extra volume is filled with glue to minimize lead spreading and make the gauge record longer.

the magnetic field created by an electromagnet. The field is constant to better than 1% in the gauge region. Active gauge element lengths are typically between 5 and 10 mm long so, with a magnetic field of 750 to 1200 gauss, a voltage on the order of one to two volts is produced. The projectile is faced with an impactor to produce the desired input to the HE sample. Usually this is sapphire on the single-stage gun and Kel-F on the two-stage gun. When the projectile impacts the sample, a shock wave is driven into it. In the case of a solid HE target, shock goes directly into the HE. In the case of a liquid target, the shock goes through the cell front and then into the liquid HE.

In our experiments, we have eliminated all trigger pins – the digitizers are triggered off the gauge signals, usually with some logic so that any one of four signals can be the trigger. This eliminates much of the unwanted electrical noise and allows the gauge signals to be at baseline before the shock interacts with each gauge.

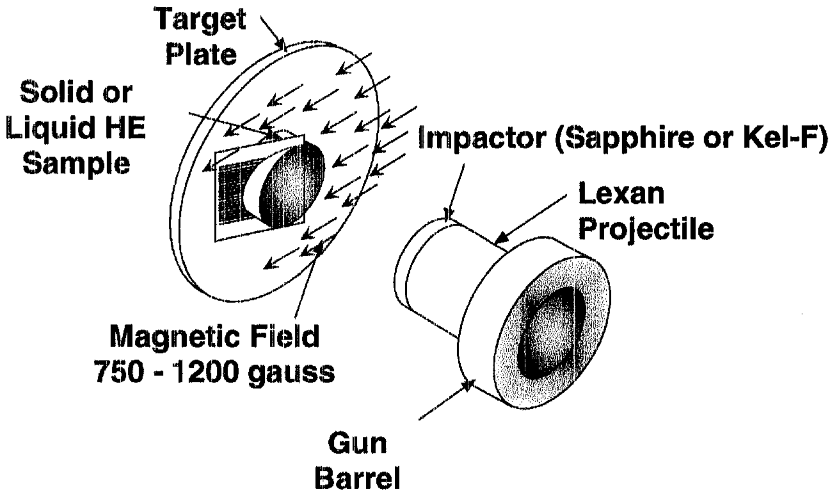

Figure 6. Projectile and Target configuration just before impact. Gauge ends are aligned so they are perpendicular to the magnetic field and gauge leads are parallel to the field. The field strength on the single-stage gun is 750 gauss and that of the two-stage gun is 1200 gauss.

Homogeneous/Heterogeneous Shock Initiation of HE

Initiation and detonation of HEs depend on the chemical and physical nature of the materials (e.g., molecular structure, density, charge geometry, confining materials, and various other variables). In terms of their physical nature, explosives are generally grouped into homogeneous and heterogeneous materials. Homogeneous materials are typically liquids or single crystals in which there are a minimal number of physical imperfections (e.g., bubbles or voids) that can cause perturbations in the input shock and the flow behind it. Homogeneous materials viewed with the macroscopic probes characteristic of detonation physics experiments appear uniform. In this paper the homogeneous HE is liquid isopropyl nitrate (IPN).

Heterogeneous explosives are generally all other types; these are usually pressed, cast, machined, or extruded into the shapes or parts desired. Here, heterogeneous means a material that contains any kind of imperfections that can cause fluid-mechanical irregularities called "hot spots" when a shock or detonation wave passes over them. Such hot spots cause associated space/time fluctuations in the thermodynamic fields (e.g., the pressure or temperature fields) in the fluid. These thermodynamic variations affect the local chemical heat-release rate. When averaged over a sufficiently large space scale, such variations convoluted with the underlying chemical rate(s) produce an average heat-release rate that is a combination of chemistry and mechanics. Examples of conditions that cause hot spots are: i) void collapse, ii) shockwave propagation through irregular particles that cause complex shock interactions, iii) shockwave interactions between particles and voids that cause jetting, iv) plastic flow involving crystal breakage and shearing, and v) shock impedance mismatch between components of the explosive that cause shock reflections and interactions. In this paper, the heterogeneous HE is PBX9502, a TATB based plastic bonded explosive that is consolidated by pressing.

The experiments described in this paper involve the use of a gun-driven projectile to shock the HE, causing the HE to react and make a transition to a detonation; this is called a shock to detonation transition. The detonation is inherently a steady shock-induced reaction process.

Homogeneous shock initiation was studied in detail by Campbell, Davis, and Travis[13] and Chaiken;[14] these studies led to the classical homogeneous initiation model shown in the time-distance diagram on the left side of Fig. 7. The explosive is shocked and, after an induction period (that depends on the temperature generated by the initial shock), a thermal explosion occurs at the explosive/driver interface. This explosion produces a “superdetonation” (detonation in the explosive precompressed by the initial shock) which runs forward and eventually overtakes the initial shock. After the superdetonation overtakes the input shock, an overdriven condition results which eventually decays to a steady detonation. This model was modified by Sheffield, Engelke, and Alcon to include an evolution process for the superdetonation; a diagram showing this process is on the right side of Fig. 7.[15]

Heterogeneous shock initiation is considerably different in its nature because of the hot spot processes involved. It was also studied in detail by Campbell, et al.,[16] leading to much of the basic understanding that exists today. They showed that wave growth occurs

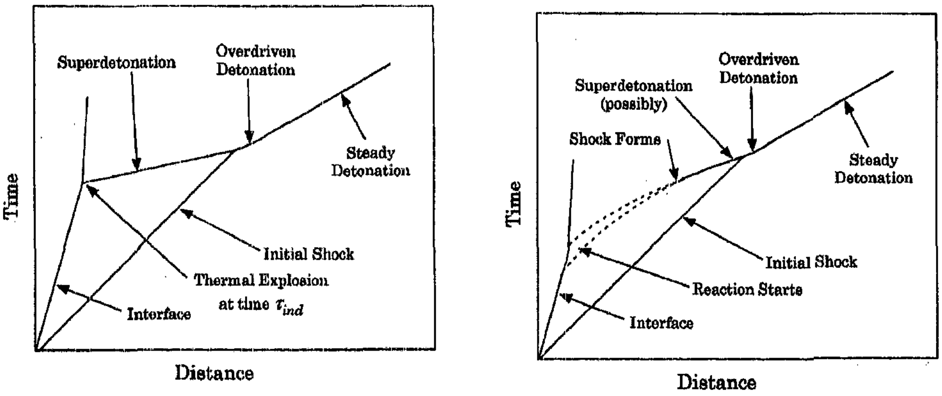

Figure 7. Homogeneous shock initiation diagrams showing the processes involved in making the transitions from a shock to a detonation. The left diagram was developed in Ref. 13 and the right one is a modification of this process described in Ref. 14.

at the front as well as behind the front. This leads to a relatively smooth growth of the initiating shock to a detonation, in contrast to the abrupt changes that occur in the homogeneous case. In this case, no overshoot in the detonation velocity is observed, indicating that the transition to detonation occurs at or near the shock front. This process is shown in Fig. 8.

Some HEs show characteristics of both homogeneous and heterogeneous shock initiation processes. They have growth in the front as well as the formation of a reactive wave behind the front. This reactive wave eventually overtakes the front and a steady detonation is formed. This is and indication that some reaction occurs new the shock front but that considerable reaction also occurs later. This undoubtedly has something to do with the nature and size of the hot spots formed when the initial shock moves over the material. An example of this behavior is shown in Fig. 9.

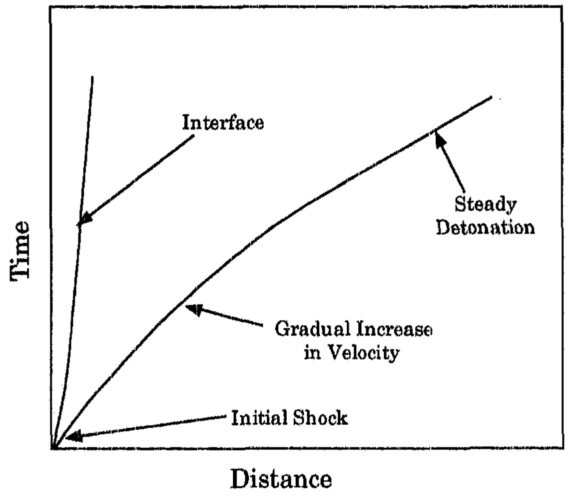

Figure 8. Schematic x-t diagram of a heterogeneous initiation process showing a gradual increase in shock speed until a steady detonation speed is attained.

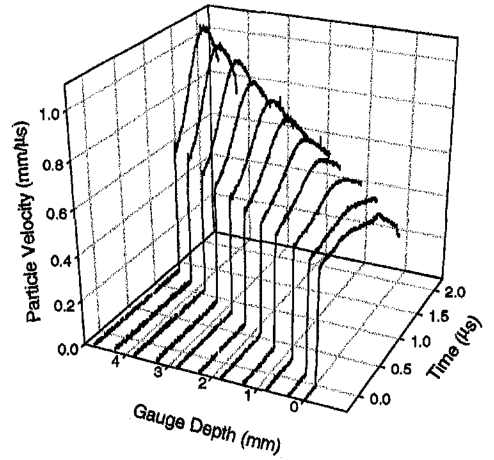

Figure 9. Particle-velocity measurements from a PBX9501 (HMX-based plastic bonded explosive). Gauges were from 0 to 5 mm into the HE. Notice there is some growth in the front and a lot of growth behind the front.

Homogeneous HE Initiation – Experiments on Liquid IPN

Liquid isopropyl nitrate [$(CH_3)_2CHONO_2$] (IPN) (see Fig. 10) is a rather low energy explosive because it does not have a good oxygen balance. It has been used in propellants or as a monopropellant. Liquid IPN was obtained from Aldrich Chemicals with a purity of 99 wt% IPN. It was used as received. IPN has an initial density at room conditions of 1.036 g/cm^3, a boiling point of 101--102 °C and a freezing point of 12 °C. It is a colorless liquid with a viscosity about like water. An estimate of the Hugoniot for this material was obtained using the universal liquid Hugoniot.[17] This empirical equation has the form $U_s = C_0\{1.37 - 0.37\exp(-2u_p/C_0)\} + 1.62u_p$ where U_s is the shock velocity, u_p is the particle velocity, and C_0 is the room condition sound speed – the only required parameter. It has been shown to provide reliable Hugoniot estimates for essentially all the liquids for which shock data are available. The room condition sound speed for IPN was measured to be 1.10 mm/µs. This was used to help calculate the input shock strength into the IPN.

Three magnetic-gauge gun experiments were completed. One was done on the single-stage gun (shot 1129) where the input was low enough that no reaction was initiated; it was used to confirm that the estimated Hugoniot was correct. Two higher pressure input experiments were completed on the two-stage gun (shots 2s-28 and 2s-29) to measure the details of the shock-to-detonation transition in IPN.

Shot 2s-29 will be discussed here. The projectile velocity was 2.97 mm/µs with a Kel-F impactor hitting a Kel-F cell front, providing a shock input of 8.9 GPa into the IPN. Particle velocity waveforms from this experiment are shown in Fig. 11. Several gauges failed in this experiment (including the stirrup gauge needed for an accurate measure of the input particle velocity) so only seven waveforms are shown. These records clearly show the initial shock followed by a building reactive shock that appears to have reached a steady state before overtaking the initial shock before the gauge G3 was reached. The overtake position was about 2.7 mm into the IPN.

The first four gauges give an initial shock particle velocity of about 1.73 mm/µs which is below the 1.89 mm/µs expected based on using the Hugoniot, the projectile speed, and the known Kel-F Hugoniot; it is about 8.3% low. The shock velocity measurement measurement obtained from the shock tracker was 4.5 mm/µs and provided additional support for the measured particle velocity being low. A lower measurement was expected because the shock impedance of the gauge is higher than that of the IPN. Previous work has shown that an impedance mismatch between the gauge membrane and the liquid sample causes 2-D effects in the flow (slippage at the gauge plane) which perturbs the measurement. Bdzil has shown this from a theoretical standpoint.[18] We have shown experimentally[19] that when the gauge is suspended in liquids, there are errors in the

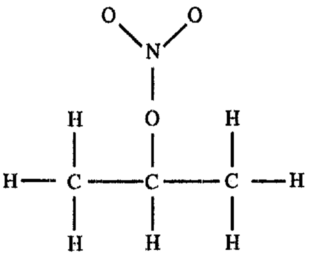

Figure 10. Chemical structure of isopropyl nitrate.

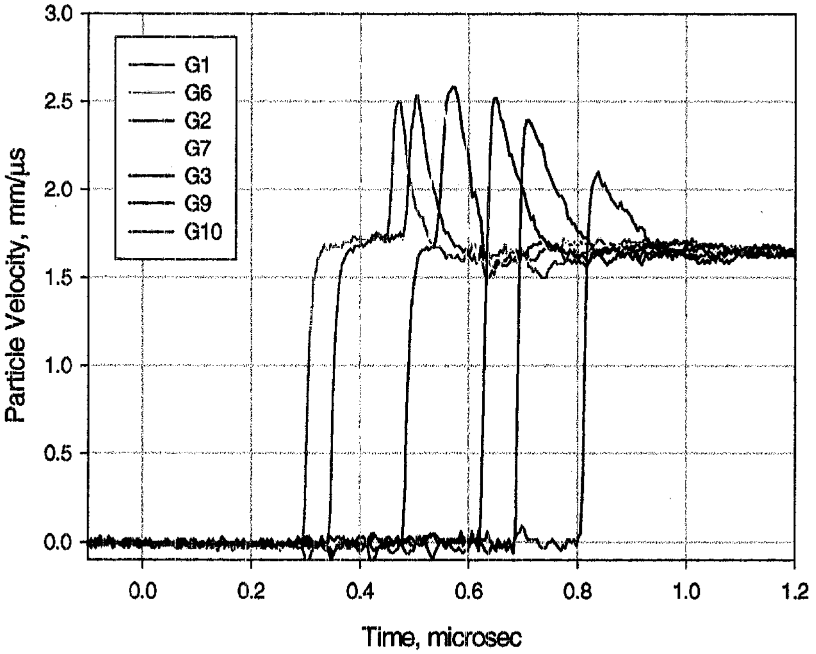

FIGURE 11. Particle velocity waveforms obtained from Shot 2s-29. Seven gauges are shown, all of them are in-situ in the IPN at positions from 1.3 to 4.5 mm deep. The other gauges (G4, G5, and G8) did not record properly for unknown reasons. The stirrup gauge also failed to work so the particle velocity input to the IPN was not recorded.

measured particle velocity. These errors range from 10% high for liquids with a high impedance (such as diiodomethane) to 10% low for low impedance liquids (such as nitromethane). If the impedance of the liquid is the same as the gauge, the gauges read the correct particle velocity, i.e., the measurement difference depends on the impedance difference between the gauge and the liquid. Since the IPN has a substantially lower impedance, the waveform being 8.3% low was expected. This was born out in the low input experiment (shot 1129) which also had a particle velocity this low – in this experiment the stirrup gauge measurement was good and it measured the correct particle velocity. In any case, the waveforms in liquid HEs provide a qualitative picture of the initiation process and they can probably be altered (using the stirrup gauge measurement as a base) to make them nearly correct. In all the experiments we have done on solids this has not been a problem presumably because of the lack of slippage at the gauge plane.

Using the gauge waveforms to determine the speed of the second reactive wave, it was possible to estimate the speed of the superdetonation to be about 8 mm/µs. It was not possible to obtain this speed from the shock tracker because the initial shock and the superdetonation were both causing changes in voltage at the same time rendering the record confusing in this region. After the superdetonation overtook the initial shock, it was possible to again use the shock tracker to determine speeds. After overtake the overdriven detonation had a speed of 6.3 mm/µs which slowed to a steady speed of 5.34 mm/µs by the end of the shock tracker. This value for the steady detonation speed of IPN is in agreement with other measurements of the detonation velocity. As mentioned earlier, the position of overtake was 2.7 mm into the IPN. All these measurements confirm that the homogeneous model shown in the right side of Fig. 7 is the correct model for IPN.

They also show that IPN develops a steady superdetonation; this is the first time this has been confirmed by in-situ gauges. This experiment demonstrates the usefulness of the two-stage gun and the multiple magnetic gauge method in measuring the details of a homogeneous initiation process.

Heterogeneous HE Initiation – Experiments on PBX9502

PBX9502 is a plastic bonded explosive composed of 95 wt% TATB (triamino-trinitobenzeme) and 5 wt% Kel-F plastic binder. It is pressed to about 98% theoretical maximum density by heating and quite high pressing pressures. After being pressed into a billet, it can be machined to the shape desired. This is inherently a heterogeneous material because it contains different impedance materials, grain boundaries, and voids so it is expected that it would have a heterogeneous nature to its shock initiation process. It is a very insensitive HE and cannot be initiated in our single-stage gun. As mentioned earlier, this was the main reason for building the two-stage gun.

A number of multiple-magnetic-gauge gun experiments have been completed on PBX9502 but we are only in the last year able to do experiments that are very good on this material on the two-stage gun. There are a number of reasons for this: a) projectile velocity measurements are becoming more routine as the design is refined; b) a lot of projectile/target tilt at impact due to various problems with cleaning the launch tube and the projectile design have been eliminated; c) the gauge has been redesigned to minimize the effects of tilt; and d) we have quit using any electrical pins in the experiments to eliminate noise problems that perturb the gauge signals.

The shot that will be discussed is shot 2s-57. It consisted of a Lexan projectile with a Kel-F impactor hitting the PBX9502 sample at a speed of 2.76 mm/μs, producing an input pressure of 13.5 GPa into the PBX9502. The PBX9502 top and bottom pieces had densities of 1.893 and 1.886 g/cm^3, respectively. Gauges were at Lagrangian positions of 0.0, 1.17, 1.96, 2.75, 3.54, 4.33, 5.11, 5.91, 6.70, and 7.48 mm into the HE. Particle velocity waveforms obtained from this experiment are shown in Fig. 12.

The reacting wave attained a detonation condition at about the position of the last gauge, i.e., the distance to detonation for this experiment was about 7.5 mm. The other gauge waveforms show an evolving wave that is growing quite a bit in the front but still has some reaction after the front as evidenced by the small hump. This indicates that the initial shock is causing considerable reaction but some reaction continues after the shock has passed. This behavior is indicative of a mixed homogeneous/heterogeneous reaction but with quite a lot of reaction resulting from the heterogeneities. This can be contrasted with the waveforms shown in Fig. 9 for PBX9501 in which the growth behind the front was much more pronounced that the growth in the front.

The x-t diagrams produced the data from the three shock trackers and the arrival times at each gauge are shown in Fig. 13. They show a gradual increase in speed until a steady detonation is reached at a position about 7.5 mm into the PBX9502. The data from the three shock tracker gauges are nearly on top of each other, indicating that there was not a large tilt at impact on this experiment. When this plot is compared to the diagram in

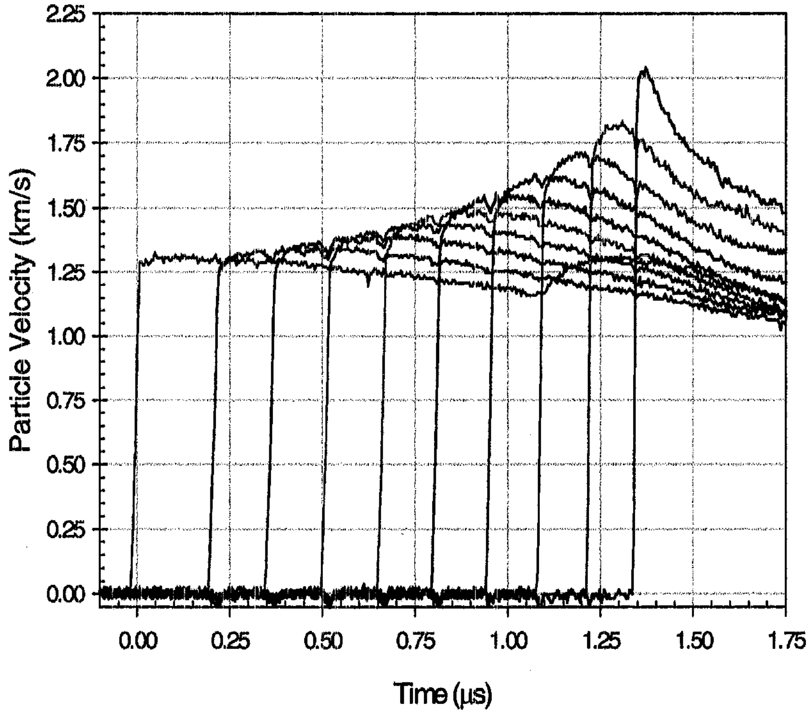

Figure 12. Particle velocity wave profiles for shot 2S-57 in PBX 9502. The first gauge is the stirrup gauge. The profiles are presented in their as recorded condition.

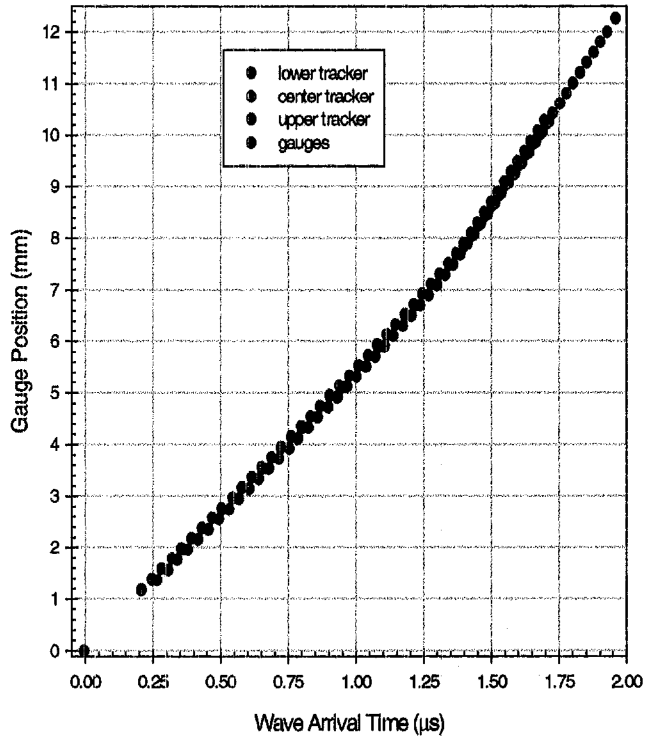

Figure 13. Wave arrival times vs. position for shot 2S-57. Green points are from the particle velocity gauges, red points are from the shock tracker located in the center of the target, and dark blue points are from the shock tracker located on the lower half of the target, and light blue points are from the shock tracker on the upper half of the target.

for heterogeneous initiation shown in Fig. 8, there is obviously a lot of similarity. We take this to mean that PBX9502 has a distinctly heterogeneous nature to its shock initiation process.

The detonation speed obtained from the shock tracker data in Fig. 13 was 7.9 mm/μs; the advertised detonation speed of PBX9502 is 7.7 mm/μs. This measurement is about 2% high which is about the accuracy of magnetic gauge measurements. The distance to detonation measured in this experiment can be compared to other data that exists (mostly based on explosively driven wedge tests) and it agrees quite well. We have shown that using the magnetic gauge method, it is possible to measure initiation differences due to changes in density as small as 0.005 g/cm^3. This is better than any other known method.

These experiments on PBX9502 have provided important new reactive waveform information that is useful to modelers developing a reactive model for this material. The particle velocity profiles, with reactive growth both in the front and behind the front, provide a considerable constraint on the model being used to simulate the experiments.

Summary and Conclusions

It is clear that the two-stage gun provides an important experimental tool to provide well defined inputs for shock initiation studies of insensitive HEs including TATB based materials and also liquids. The experiments reported in this paper are representative of the high quality of the shock initiation data that is being routinely produced using this gun. Information relating to both homogeneous and heterogeneous initiation processes has been obtained and has led to increased understanding of both of these processes. It is apparent that in the case of solid pressed explosive, the behavior has both a heterogeneous and homogeneous nature to it, i.e., there is growth both at the front and behind the front. The x-t diagram is much like that expected for a heterogeneous HE. In the case of the liquid IPN, the shock initiation process is classical homogeneous behavior and does include a steady superdetonation process in the preshocked IPN. The experiments in both the PBX9502 and the liquid IPN have provided important new information to corroborate presently accepted reactive wave code models.

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