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TWO-STAGE IGNITER TEST RESULTS: ELECTRICAL IGNITION OF LGP 1846

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APRIL 1991

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Test results from a two-stage, electrical liquid propellant igniter are described. Two critical areas are identified relating to the operation of the igniter. The first is the confinement of the liquid propellant in the ignition cavity and the second is the interaction of the gases venting from the precombustion chamber with the liquid propellant booster charge in the antechamber. The design modifications made to ensure proper operation are presented. Typical electrode gap voltage and current values ranged from approximately 1,000–1,500 V and approximately 175–185 A, respectively. The energy dissipated into the igniter ranged from 21–30 J, with only 10–30% of this energy due to the arc phase of the discharge. Typical maximum pressures were 502 MPa in the precombustion chamber and 329 MPa in the antechamber. The results of five tests staging up to the maximum booster charge are also presented. The average test chamber pressure rise time in these five tests was 3.55 ms, or about 5.4 MPa/ms in the test at maximum charge. A test successfully demonstrating arcless ignition is also presented. The performance with arcless ignition was comparable to that achieved in arc-based ignition tests.

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1. INTRODUCTION

The development of a practical liquid propellant (LP) based ignition system for medium and large caliber regenerative liquid propellant guns (RLPGs) is an important goal of the US Army's LP gun program. The main igniter development effort in the US is being conducted by General Electric Defense Systems Department (GEDSD), with supporting research being conducted at the US Army Ballistic Research Laboratory (BRL) and the Ernst-Mach-Institut (EMI), Germany. These programs have concentrated on developing small scale (30-mm caliber) igniters that can then be used as the first stage of an ignition system for a 155-mm RLPG (Giovanetti and Jardine, 1989; Klingenberg et al., 1989; Klingenberg et al., 1990a; Klingenberg et al., 1990b). In addition, GEDSD has developed large scale igniter design concepts (Giovanetti et al., 1988).

The guidelines for developing LP ignition systems were determined from tests performed by GEDSD using solid propellant igniters in 30-mm and 105-mm RLPG fixtures. It was determined that the best gun performance was achieved when the igniter supplied enough hot gas and burning propellant to raise the gun combustion chamber to between 17 and 21 MPa, with a rise rate of about 4 to 8 MPa/ms. These conditions would ensure that the start-up of the regenerative cycle, i.e., initial piston motion and propellant injection, was appropriate. A description of the RLPG is provided below.

The method of igniting the LP in the RLPG ignition system was chosen to be electrical discharge (DeSpirito and Knapton, 1988). This method offers favorable logistical advantages, such as a practical means of achieving multi-shot capability, reduced packaging size, and the availability of the power source on the vehicle. In addition, the feasibility of electrically igniting the class of LPs currently being tested was demonstrated in previous work by Carleton et al. (1986a; 1986b; 1987).

Preliminary test results from the Two-Stage Igniter were reported previously (DeSpirito et al., 1989a; DeSpirito et al., 1989b). These reports described the problems that were encountered relating to the ignition and successful staging of the igniter charge to that appropriate for a 30-mm RLPG scale igniter. The present report summarizes those problems and describes the changes that were made to overcome them. In addition, test results demonstrating the performance of the igniter is presented. Test results demonstrating "arcless" ignition, as was achieved with the earlier, Single-Stage Igniter (DeSpirito et al., 1987; Klingenberg et al., 1989; Klingenberg et al., 1990a; DeSpirito et al., 1990), is also presented.

2. EXPERIMENTAL

A detailed description of the experimental set-up can be found in the reports by DeSpirito et al. (1989a; 1989b). Therefore, only an overview of the hardware and test set-up will be presented here. The tests described in this report were performed with the igniter venting into a closed test chamber rather than a gun fixture. This test chamber simulated the initial free volume, 100 cm^3, of the combustion chamber of the 30-mm RLPG Concept VI RLPG at the BRL. The chamber was initially filled with air at atmospheric pressure.

2.1 Concept VI RLPG. The Concept VI RLPG and the typical location of the igniter is shown in Figure 1. The operation of the Concept VI RLPG is described in the literature (Mandzy et al., 1987), therefore only a brief overview will be presented here as it relates to the operation of the igniter. The upper half of Figure 1 shows the injection piston and the projectile in the "before firing" position, while the lower half shows the "after firing" configuration. The LP reservoir is initially sealed to prevent leakage of LP into the combustion chamber and to allow prepressurization of the LP reservoir. To begin the cycle, the igniter, whether solid or liquid, is fired and the pressure developed inside the igniter vents into the combustion chamber. The pressure thus developed forces the injection piston to the rear, breaking the chamber-to-reservoir seal, and injecting propellant into the combustion chamber. The injected propellant mixes with the igniter gases and burns, increasing the combustion chamber pressure further. The differential area (combustion chamber side/LP reservoir side) of the injection piston maintains higher pressure in the LP reservoir than in the combustion chamber. As a result, the liquid propellant continues to be injected from the reservoir, through the annular orifice formed by the inner diameter of the piston and the outer diameter of the center control rod, until the piston reaches the end of its stroke.

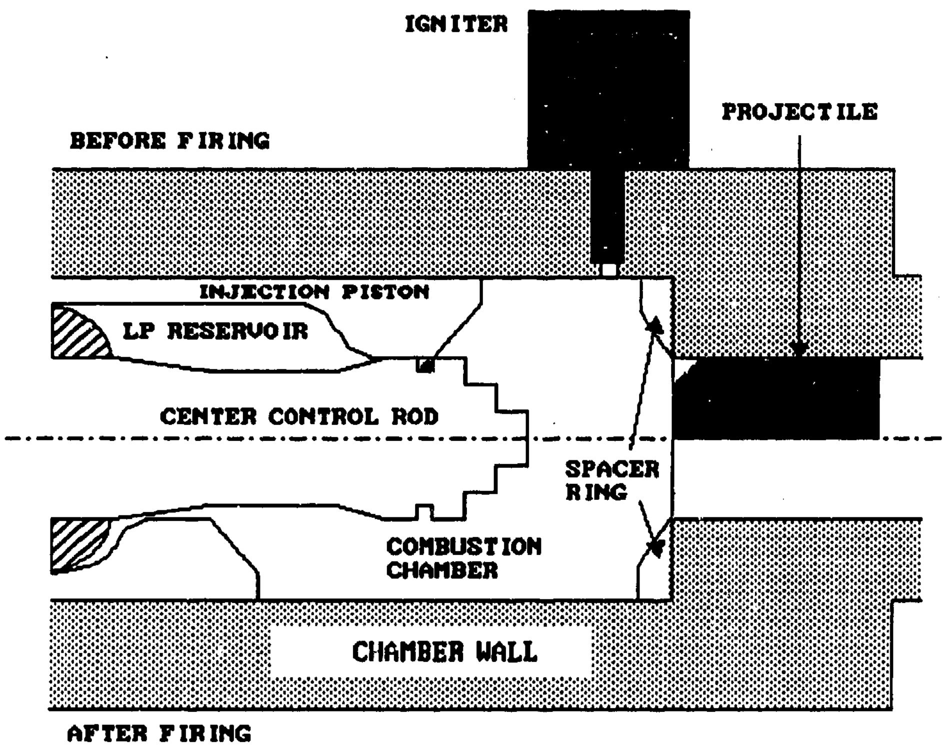

Figure 1. Concept VI Regenerative Liquid Propellant Gun.

It is important to control the venting of the igniter gases so that start-up of the regenerative cycle functions properly. For example, if the igniter is too powerful, the injection piston may move rearward too fast, resulting in a pressure wave within the LP reservoir. This could lead to the pressure in the LP reservoir dropping below that in the combustion chamber, possibly allowing hot gases to get into the LP reservoir and leading to ignition in that region. The result would be a "piston reversal," where the piston would move to the forward part of the combustion chamber, allowing the LP to burn in a "bulk-like" fashion. On the other hand, if the igniter is too weak, the propellant injected into the combustion chamber after the igniter is fired may not ignite properly, resulting in a "hang-fire." In this case, the piston could continue to move rearward due to the pressure from the igniter, injecting more LP into the combustion chamber. This LP could ignite at any time that the fizz-to-flame transition requirement has been reached, resulting in a faster than normal pressure rise rate. Neither of these scenarios would necessarily lead to catastrophic failure of the hardware, however, higher than normal pressures and some hardware damage would probably result.

2.2 Two-Stage Igniter. The Two-Stage Igniter, shown in Figure 2, consists of a precombustion chamber, an antechamber, and a vent tube for integrating into a test chamber or gun fixture. The diameter of the igniter body is 7.6 cm and the length of the assembly is about 30 cm. The electrical ignition of the LP takes place in the precombustion chamber, which is completely filled with 0.5 cm^3 of LP. A high current pulse is discharged between the center and outer electrodes. The theory of operation is that the combustion of the propellant in the precombustion chamber forces some unburned propellant and combustion gases into the antechamber containing an additional LP booster charge. This additional propellant then burns in the antechamber and vents into a test chamber. The reaction in the precombustion chamber is confined by an orifice that is a long, constant diameter tube, or "inertial column," which is initially filled with LP. The theory is that the inertia of the column of liquid will provide the required confinement of the reaction in the precombustion chamber during the early initiation phase.

Figure 3 shows a close-up of the internal components of the Two-Stage Igniter. The igniter components are fabricated of PH 13-8 Mo Stainless Steel, teflon, and Macor glass ceramic. The center electrode assembly consists of the center electrode mounted in the body with teflon and Macor glass ceramic insulators. The center electrode is 1.5 mm in diameter and its length can be varied from 3.2 mm to 7.9 mm by using additional teflon spacers. All tests were performed with a hemispherical tipped center electrode. The diameter of the precombustion chamber is 4.8 mm, making the distance between the electrodes 1.7 mm. Three inertial column diameters were tested, 2.1, 2.3 and 2.6 mm. The "vent orifice bolt," shown in Figure 3, is used to prevent any unburned propellant that is ejected from the precombustion chamber from going directly out of the antechamber through the vent tube. The original vent orifice bolt design was modified to include the "afterburner" chamber used by Giovanetti and Jardine (1989). The afterburner, shown in Figures 2 and 3, is a small chamber between the precombustion chamber orifice and the antechamber. The afterburner traps any unburned LP that is ejected from the precombustion chamber and ensures that it ignites. The igniter is tested while in the horizontal position and the LP is loaded into both the precombustion chamber and the antechamber with a syringe.

2.3 Propellant. Liquid Gun Propellant (LGP) 1846 was used in all tests. The composition and physical and thermochemical properties of this propellant are listed in Table 1 (Freedman, 1988; Decker et al., 1987). It should be noted that LGP 1846 has a relatively high electrical conductivity, which enhances the feasibility of igniting the propellant without arc breakdown (Kirshner and Stiefel, 1968).

Table 1. Composition and Physical and Thermochemical Properties of LGP 1846.

Composition			Density,	Electrical Conduct.,	Flame Temp.,	Impetus,	Co-volume,	Frozen Gamma,
HAN[a]	TEAN[b]	H_2O,						
weight %			g/cm^3	ohm^{-1}-cm^{-1}	K	J/g	cm^3/g	(--)
60.8	19.2	20.0	1.43	0.076	2469	898.3	0.677	1.2225

[a]Hydroxylammonium Nitrate
[b]Triethanolammonium Nitrate

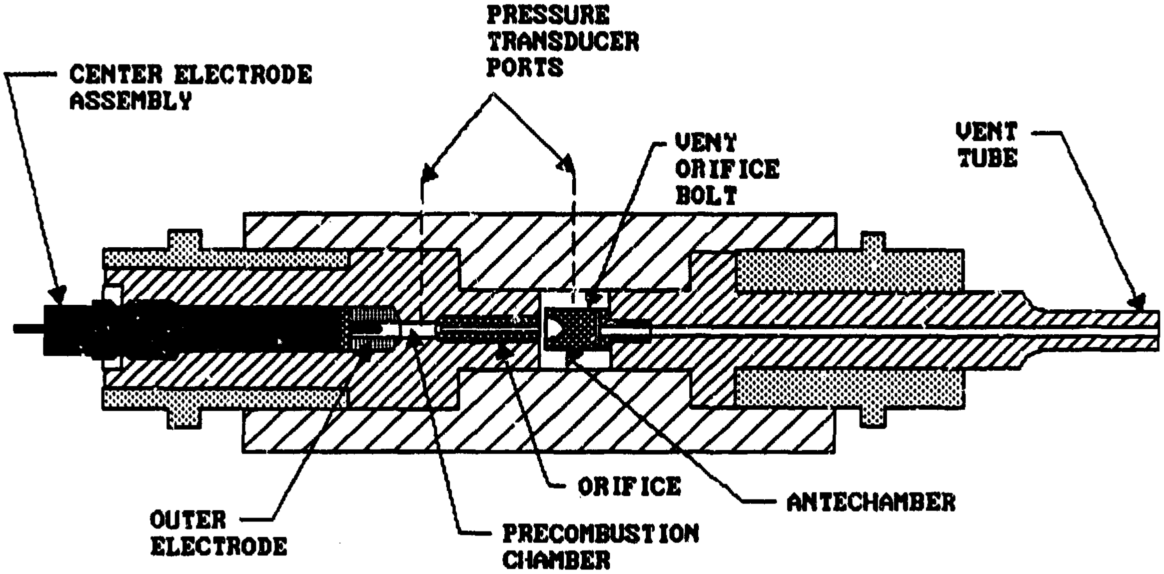

Figure 2. Two-Stage Electrical LP Igniter.

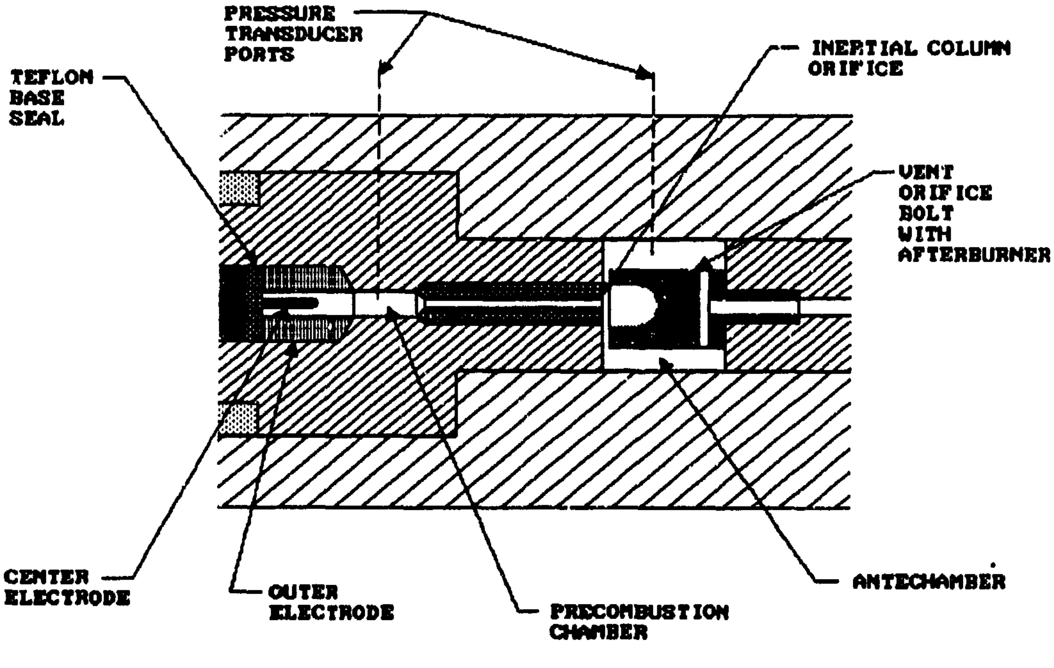

Figure 3. Internal Components of Two-Stage Igniter.

2.4 Instrumentation. The parameters that were measured in each test were the current and voltage versus time across the electrode gap and the pressure versus time in the precombustion chamber, the antechamber, and the test chamber. The pressures were measured with Kistler 607C4 pressure transducers and all data was recorded on a digital oscilloscope. The electrical power and energy dissipated were then calculated from the current and voltage measurements.

A high current pulse former was used to transfer the electrical energy to the igniter. The inductance, resistance, and capacitance of the pulse forming network of this device can be varied in order to change the pulse characteristics. For the tests described in this report the capacitance was 7 μF, the maximum available, and the inductance was 2.5 mH. The circuit resistance was approximately 2 Ω. The initial stored energy in the discharge circuit was 56 J. Two important characteristics of this device are that the maximum voltage across the load is limited to 2000 V and that an open circuit voltage is not allowed to remain on the load. If a large voltage exists across the load at what would be the end of the normal short circuit pulse for the circuit configuration (420 μs in this case), the pulse former will drain the charge from the circuit. This latter characteristic will be evident in the voltage traces presented in the next section, where the voltage drops to zero at about 420 μs, when an open circuit most likely exists across the electrodes because of combustion of the LP.

3. RESULTS AND DISCUSSION

Preliminary tests (DeSpirito et al., 1989a; DeSpirito et al., 1989b; Klingenberg et al., 1990a) identified two critical parameters in the operation of the igniter that needed special attention. Both of these were also encountered by Giovanetti et al. (1988; 1989) at GEDSD. The first critical parameter that was found in the operation of the igniter was the amount of confinement of the LP in the precombustion chamber. The confinement must be great enough to lead to the transition to sustained combustion or a misfire would result. The confinement of the LP can be increased by decreasing the diameter of the orifice of the precombustion chamber. However, we controlled the confinement of the LP in the precombustion chamber with the inertial column orifice described above. We used this method of confinement, rather than decreasing the diameter of a normal orifice, because we believed that we could achieve an increased amount of confinement while using a larger diameter inertial column. This was important because too small of an orifice could lead to extremely high pressures in the precombustion chamber. However, the confinement due to the inertial column is substantially reduced once the bulk of the liquid in the column has been ejected. Another parameter found to be critical to the operation of the igniter was the ignition of the booster charge in the antechamber. Our preliminary tests, without the afterburner described above, resulted in quenching of the combustion in the antechamber when an LP booster charge greater than 0.75 cm^3 was loaded. The installation of the afterburner provided the mixing and confinement needed for sustained combustion of the LP that was ejected from the precombustion chamber. The larger booster charges apparently provided too large of a heat sink for the amount of mixing that was ocurring without the afterburner. The methods we used to overcome these two problem areas and ensure the proper operation of the igniter were first applied by Giovanetti et al. at GEDSD.

The electrical characteristics of the igniter operation may be summarized as follows. The maximum current ranged from approximately 175 to 185 A and the voltage ranged from approximately 1000 to 1500 V. The energy that was dissipated into the igniter ranged from 21 to 30 J, with only 10 to 30 percent of this energy due to the arc phase of the discharge. Figure 4 shows typical electrode gap voltage and current traces (Test No. 1846-52) for tests in which arc breakdown occurred. The details of the characteristics of these traces are explained elsewhere by DeSpirito et al. (1987; 1989b). Note that the current trace in Figure 4 is scaled up by a factor of ten.

Typical precombustion chamber and antechamber pressure traces (Test No. 1846-52) are shown in Figure 5. Pressure oscillations were observed on both signals. The lower frequency (20 kHz) oscillation on the precombustion chamber pressure (solid line in Figure 5) appeared to be the longitudinal mode of the chamber, most likely caused by ignition at the base of the precombustion chamber. The higher frequency oscillations on both signals are most likely a combination of acoustical modes of the chambers and combustion disturbances. The oscillations have not posed any problems in our igniter testing and they will not be addressed here. The initial section of the signals were affected by interference from the current pulse, as evidenced by the negative values in Figure 5. Although this interference was minimized in our testing, it was not eliminated, resulting in a small error (<5%) in the first 500 μs of the pressure traces. After ignition of the LP takes place, the pressure in the precombustion chamber begins to rise rapidly. This pressure blows down into the antechamber where the booster charge (2.0 cm^3 of LP in this test) is ignited and begins to combust. The pressure in the antechamber blows down into the 100-cm^3 test chamber. The maximum pressures in this test, taken from filtered pressure signals (10-kHz, low pass), were 502 MPa in the precombustion chamber, 329 MPa in the antechamber, and 16 MPa in the test chamber.

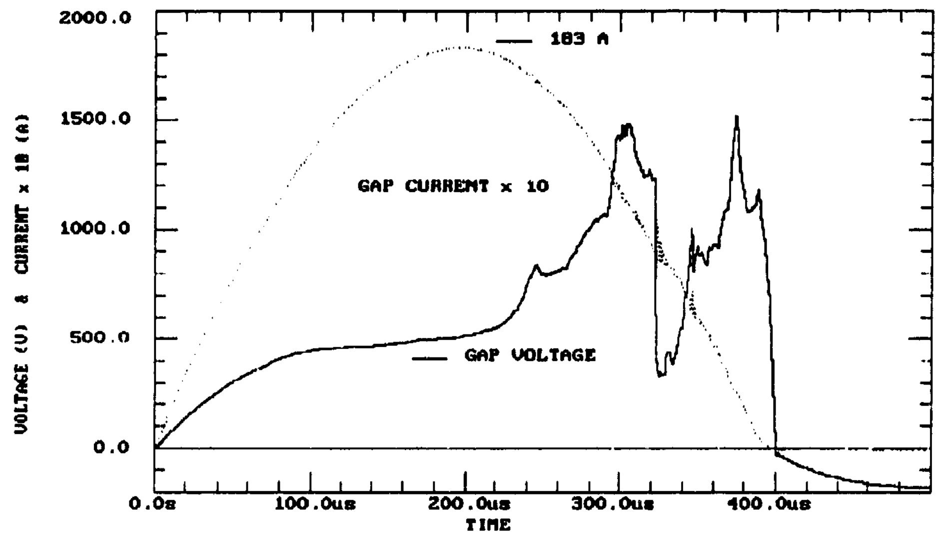

Figure 4. Electrode Gap Voltage (Solid Line) and Current (Dotted Line), Test No. 1846-52.

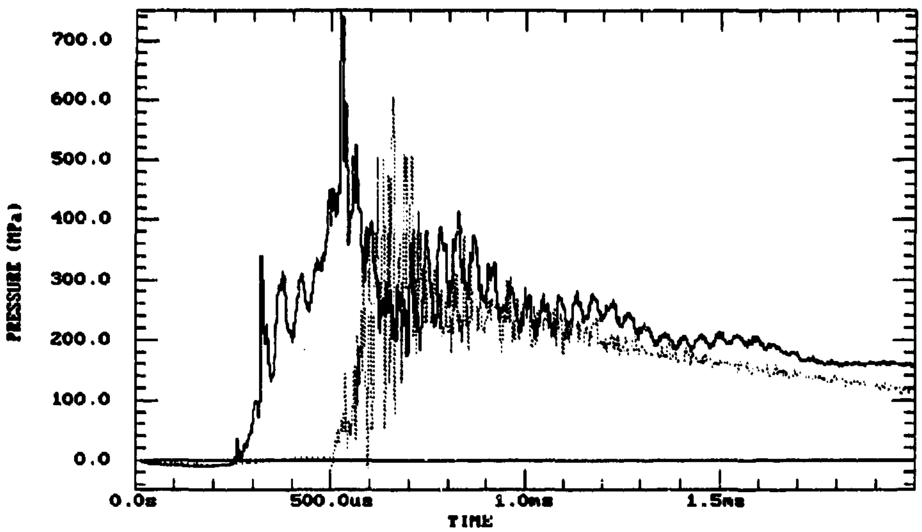

Figure 5. Precombustion Chamber (Solid Line) and Antechamber (Dotted Line) Pressures, Test No. 1846-52.

Figures 6 to 8 show the precombustion chamber, antechamber, and test chamber pressures for five tests that were performed while staging up to the maximum booster charge of 2.5 cm^3. The pressures shown in Figures 6 to 8 were filtered with a 10-kHz, low pass digital filter. The second large peak on the precombustion chamber pressure, shown in Figure 6 at about 700 μs, is due to the blow back of the gases from the combustion in the antechamber. The antechamber pressure rise rate in Test No. 1846-47, Figure 7, is slower than that of the other tests because no afterburner was installed in that test. Figure 8 shows the pressure produced in the 100-cm^3 test chamber in the same five tests. The average test chamber pressure rise time (10-90%) was 3.55 ms, about 5.4 MPa/ms for Test No. 1846-53, in these five tests. The rise rate was within the desired range of 4 to 8 MPa/ms. The results of these five tests demonstrated very good overall operation of the Two-Stage Igniter. A repeatability series was not performed, however, the precombustion chamber pressures in these five tests were reasonably repeatable. However, the repeatability is most important in the test chamber and, to a lesser extent, the antechamber. A repeatability series is planned for future tests.

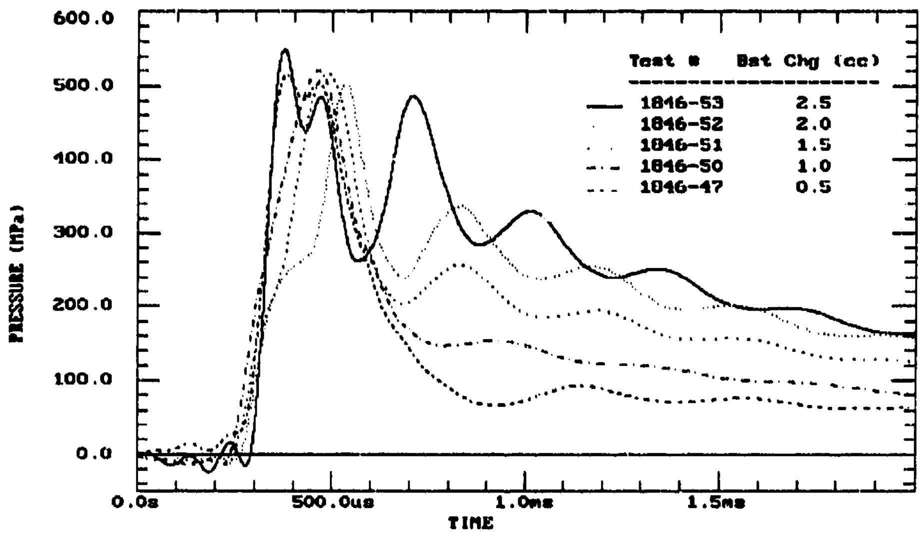

Figure 6. Filtered Precombustion Chamber Pressures.

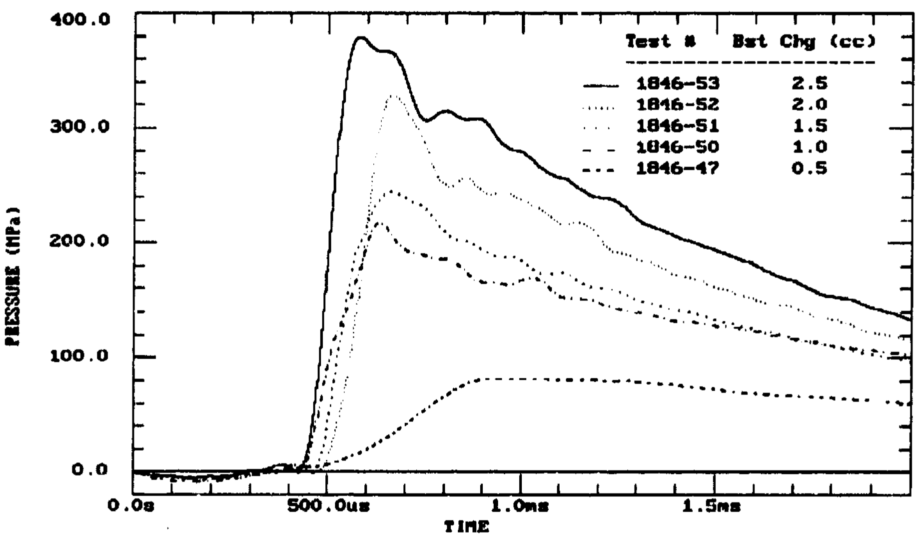

Figure 7. Filtered Antechamber Pressures.

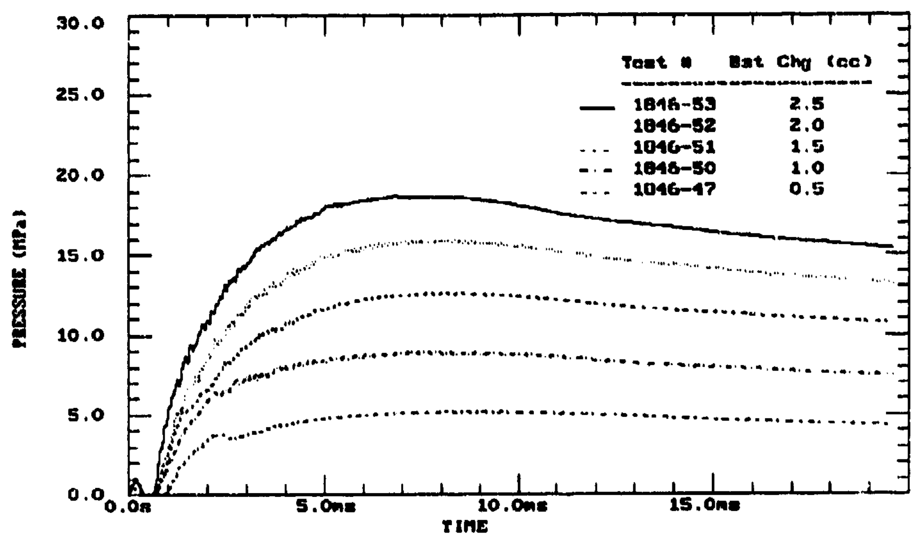

Figure 8. Filtered Test Chamber Pressures.

Before performing a repeatability series, tests to ignite the LP without forming an arc during the electric discharge through the propellant were conducted. This type of "arcless" ignition was demonstrated previously (DeSpirito et al., 1987; Klingenberg et al., 1989; Klingenberg et al., 1990a; DeSpirito et al., 1990) and, if it could be shown to be repeatable, it would be the desired mode of ignition because of the potential of reduced electrode wear. Figures 9 to 12 show the results from Test No. 1846-57, which successfully demonstrated arcless ignition. A booster charge of 1.0 cm^3 was used in this test. The pressures shown in Figures 10 to 12 are compared to those obtained in Test No. 1846-50, which were also performed with a 1.0 cm^3 booster charge but involved ignition with an arc breakdown. Figure 9 shows the electrode gap voltage and current. No arc was observed, as would be evidenced by a decrease in voltage like that shown in Figure 4. The voltage drops to zero at the end of the pulse, about 400 μs, because, as described above, the pulse former circuitry drains the charge from the circuit at the normal short circuit pulse width. It can be seen from Figures 10 to 12 that, although there is a delay in the precombustion chamber and antechamber pressures during arcless ignition, the resulting pressure in the test chamber is comparable. The delay in the time at which the rise of pressure in the test chamber occurs, Figure 12, would not pose a problem because the pressure rise rate is the more important parameter. The relatively long delay (about 500 μs) of the ignition of the LP booster charge in the antechamber (Figure 11) could be controlled by the design of the afterburner chamber (Figure 3). The size of the afterburner chamber and the gap between it and the inertial column orifice has been shown to allow some control of the ignition of the booster charge (Giovanetti et al., 1989).

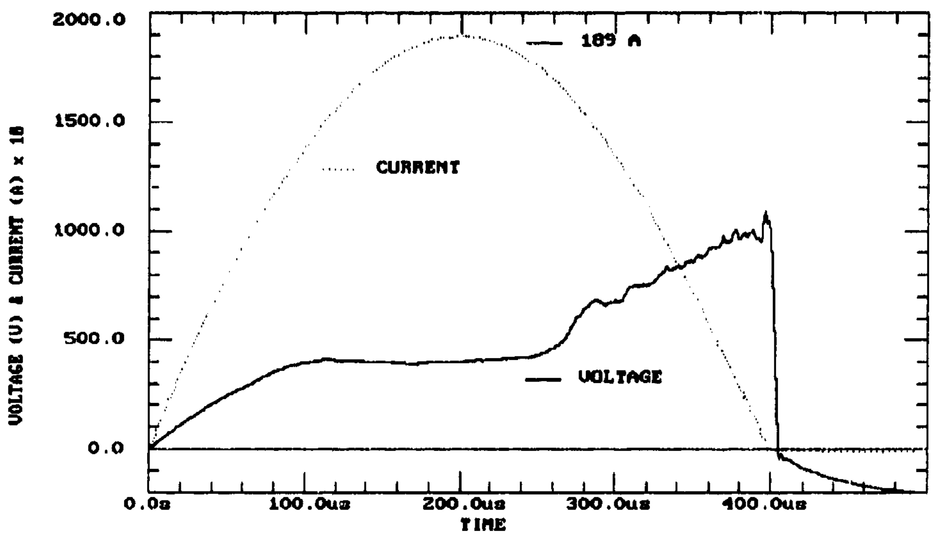

Figure 9. Electrode Gap Voltage (Solid Line) and Current (Dotted Line) in "arcless" ignition test. Test No. 1846-57.

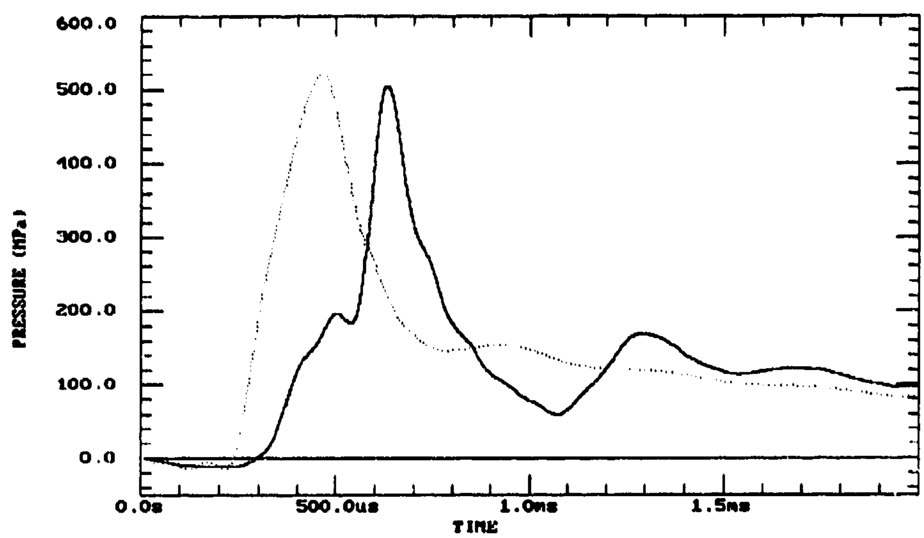

Figure 10. Precombustion Chamber Pressure in "arcless" ignition test. Test No. 1846-57. (Solid Line) and test with arc breakdown. Test No. 1846-50 (Dotted Line).

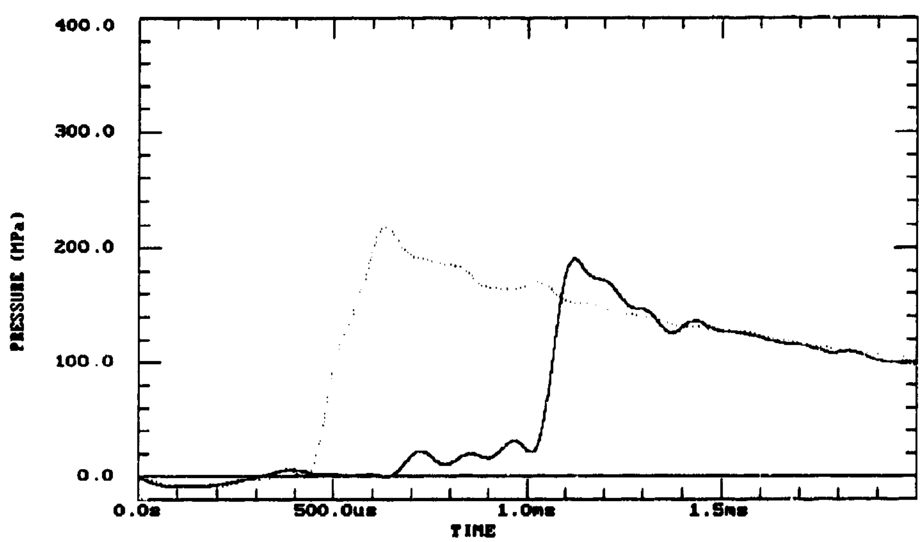

Figure 11. Antechamber Pressure in "arcless" ignition test. Test No. 1846-57. (Solid Line) and test with arc breakdown. Test No. 1846-50 (Dotted Line).

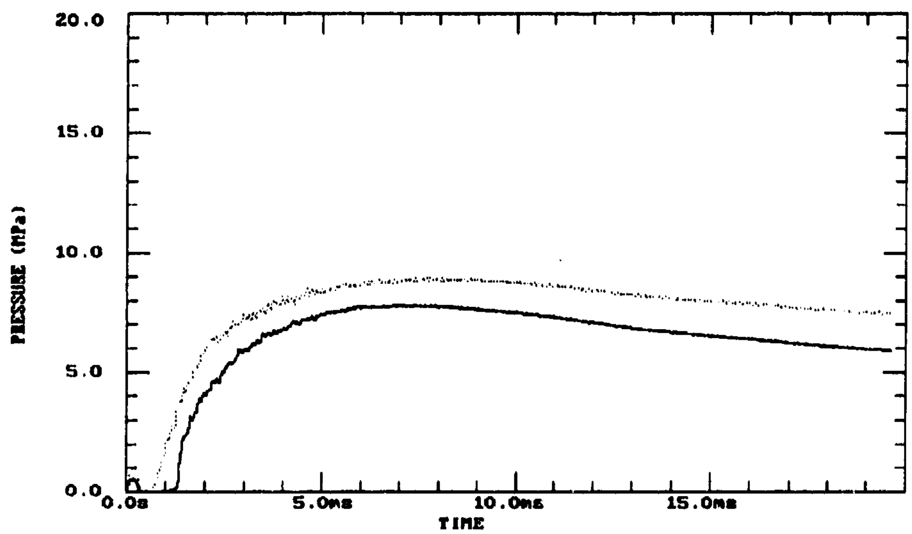

Figure 12. Test Chamber Pressure in "arcless" ignition test, Test No. 1846-57, (Solid Line) and test with arc breakdown, Test No. 1846-50 (Dotted Line).

Although the results of the arcless ignition test were very encouraging, a repeatability series using arcless ignition must be performed. In addition, guidelines for obtaining arcless ignition in this type of configuration should be established. The only change made to obtain arcless ignition in Test No. 1846-57 was an increase in the length of the center electrode from 5.36 mm to 7.14 mm. However, the discharge circuit pulse characteristics, i.e., capacitance and inductance, must also be in the proper regime in order to control the discharge energy and prevent the arc from occurring.

4. CONCLUSIONS

Test results from a two-stage, electrical LP igniter were described. Two critical areas were identified relating to the operation of the igniter. The first is the confinement of the LP in the ignition cavity, or precombustion chamber. The second is the interaction of the gases venting from the precombustion chamber with the LP booster charge in the antechamber. Both problems were overcome with small modifications to the design of the igniter.

Typical electrode gap voltage and current traces were presented. The maximum voltage ranged from approximately 1000 to 1500 V and the maximum current ranged from approximately 175 to 185 A. The energy that was dissipated into the igniter ranged from 21 to 30 J, with only 10 to 30 percent of this energy due to the arc phase of the discharge. Typical precombustion chamber, antechamber, and test chamber pressure traces were presented. The maximum pressures were 502 MPa in the precombustion chamber, 329 MPa in the antechamber, and 16 MPa in the test chamber. The results of five tests staging up to the maximum booster charge of 2.5 cm^3 were also presented. The average test chamber pressure rise time in these five tests was 3.55 ms, or about 5.4 MPa/ms in the test at maximum charge. This was within the desired range of 4 to 8 MPa/ms. The results of these five tests demonstrated very good overall operation of the Two-Stage Igniter. A test successfully demonstrating arcless ignition was also presented. The performance (i.e., the precombustion chamber, antechamber, and test chamber pressures) with arcless ignition was comparable to that achieved in arc-based ignition tests. The demonstration of the feasibility of arcless ignition in a practical igniter configuration warrants its further investigation as a potential method of ignition.

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