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ELECTRICAL IGNITION OF LGP 1846
IN A TWO-STAGE IGNITER

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APRIL 1989

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<p>An electrically initiated, liquid propellant (LP)-based igniter was designed and tested. The igniter consisted of two stages, a 0.5 cm³ precombustion chamber and a 12 cm³ antechamber. A solution of potassium chloride was used in the initial tests as a LP simulant. LGP 1846 was used in all propellant tests. Preliminary results indicated that voltage breakdown (arc) may occur when the voltage across the electrode gap is greater than 500 volts. Ignition without voltage breakdown was not attained. Tests with 15 milliHenrys of inductance in the discharge circuit did not result in reliable ignition. The inductance was reduced to 2.5 mH, increasing the electrical power and absorbed energy, and reliable ignition was achieved. The amount of energy absorbed by the igniter was between 13 and 24 J in tests that resulted in ignition of the LP. This was 23 to 43 percent of the initial energy stored in the system. There was large variability in the maximum pressures attained in the igniter chambers. This was, at least in part, due to the failure of a teflon seal at the base of the precombustion chamber. (signature) ←</p>				
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TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES.....	v
LIST OF TABLES.....	vii
I. INTRODUCTION.....	1
II. EXPERIMENTAL.....	2
III. RESULTS AND DISCUSSION.....	4
IV. SUMMARY.....	13
REFERENCES.....	15
DISTRIBUTION LIST.....	17



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LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Two-Stage Electrical LP Igniter.....	2
2	Internal Components of Two-Stage Igniter.....	3
3	Comparison of gap voltages for Test No. KCL-01 (Solid) and Test No. 1846-01 (Dotted).....	7
4(a)	Precombustion Chamber Pressure, Test No. 1846-13.....	11
4(b)	Antechamber Pressure, Test No. 1846-13.....	11
5(a)	Gap Current, Test No. 1846-13.....	12
5(b)	Gap Voltage, Test No. 1846-13.....	12

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Results of Tests with KCl Solution, Long Electrode.....	5
2	Results of Tests with KCl Solution, Short Electrode.....	5
3	Electrical Characteristics of Tests with LGP 1846, 15 mH Inductance.....	6
4	Electrical Characteristics of Tests with LGP 1846, 2.5 mH Inductance.....	8
5	Maximum Pressures in Precombustion Chamber and Antechamber.....	9

I. INTRODUCTION

The development of a liquid propellant (LP)-based ignition system for medium and large caliber regenerative liquid propellant guns (RLPGs) is a goal of the US Army's present LP program. Liquid propellant igniter test programs are being conducted at General Electric Ordnance Systems (GEOS), the Ballistic Research Laboratory (BRL), and the Ernst-Mach-Institut (EMI), West Germany. The liquid propellants being tested are the HAN-based LGP 1845 and LGP 1846.

The results of tests at the BRL on the electrical ignition of LGP 1846 have been presented at the 23rd and 24th JANNAF Combustion meetings.^{1 2} The igniter discussed in those papers was a single stage igniter containing approximately 2 cm³ of liquid propellant initiated by discharging a current pulse between two electrodes. The results from this igniter showed that ignition of the LP resulted from the electrochemical reaction and resistive heating produced by the current flow through the liquid rather than from the energy produced by an arc. The former process is labeled Event 1 and the latter process is labeled Event 2. The Event 1 process has also been called the formative phase. The igniter geometry and discharge circuit used at the BRL (smooth electrodes with large surface areas, relatively long gap between electrodes, and high inductance) usually limited the process to the Event 1 type. In some tests an Event 2 did occur but the current was limited to values much lower than those seen in igniters designed for an Event 2 type of ignition.

Although the results from this igniter showed that acceptable performance could be achieved, the output of the igniter venting into a 100 cm³ closed chamber was not reproducible. The Ernst-Mach-Institut has achieved reproducible performance from an igniter of this design by venting the igniter into a smaller test chamber. This increases the probability of sustaining combustion of the LP that was injected, unburned, into the test chamber. The larger chamber, however, is more practical when considering application of the igniter for RLPG fixtures.

A second igniter was designed at the BRL in an attempt to achieve more reproducible performance with an Event 1 type of ignition. This igniter is called the two-stage electrical igniter. The main difference from the original igniter is that the cavity where ignition takes place is much smaller. The electrodes have smaller surface areas and less LP is involved in the ignition process. The result is that less energy will be required to ignite the propellant.

This report presents preliminary data obtained from this second igniter. Tests were performed using a salt solution (0.73 M KCl) and LGP 1846. The purpose of using the KCl solution was to become familiar with both the operation of the igniter and the electrical characteristics of the current discharge. Except for Test No. 1846-16, the LP tests were performed with the antechamber unvented and without an LP booster charge in the antechamber. Test No. 1846-16 was performed with a booster charge 1.0 cm³ of LP in the antechamber and vented into a test chamber, which would be the normal igniter configuration.

II. EXPERIMENTAL

The two-stage igniter is shown in Figure 1. The design is similar to the 30-mm Basic LP Igniter developed at GEOS.³ It 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. Figure 2 shows a close-up view of the internal section of the igniter. The precombustion chamber contains 0.5 cm³ of LP that is initiated by discharging a high current pulse between a pair of coaxial electrodes. The reaction in the precombustion chamber is confined by a small orifice. The combustion of the propellant in the precombustion chamber forces some unburned propellant and combustion gases into the 12 cm³ antechamber containing an additional LP "booster" charge. This additional propellant then burns in the antechamber and vents into a 100 cm³ test chamber simulating the combustion chamber of a 30-mm RLPG.

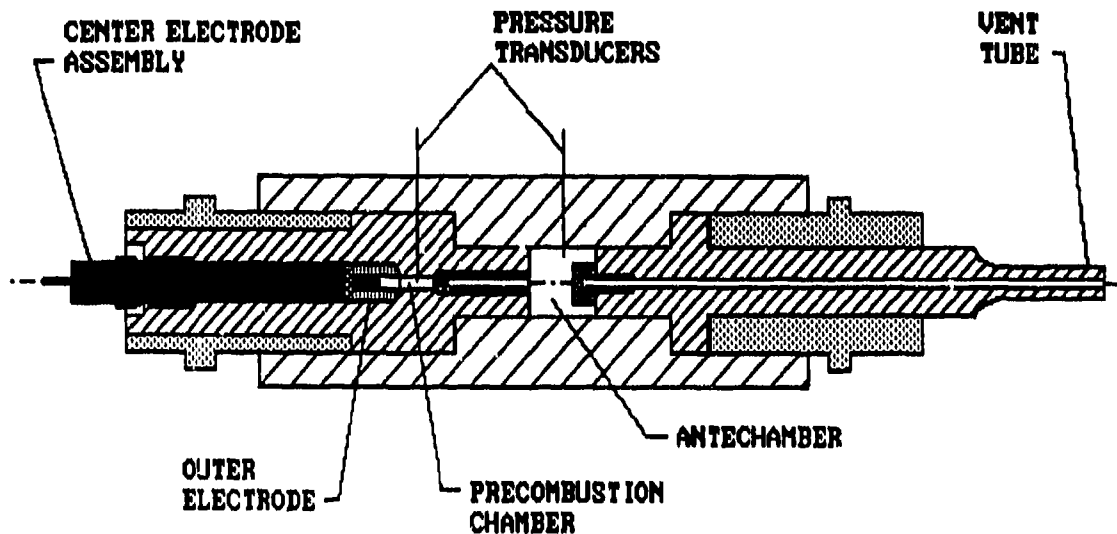


Figure 1. Two-Stage Electrical LP Igniter

The igniter components are fabricated of PH 13-8 Mo stainless steel (a precipitation hardenable 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 ceramic insulator is designed to hold the stresses produced by the pressure in the precombustion chamber. An expendable teflon spacer makes up the base of the precombustion chamber and acts as a seal. The center electrode is 1.5 mm in diameter and the length of protrusion into the precombustion chamber can be varied from 3.2 mm to 7.9 mm by using additional teflon spacers. All tests were performed

with a center electrode with a hemispherical tip although square and pointed tip electrodes were available. The diameter of the precombustion chamber is 4.8 mm, making the distance between the electrodes 1.7 mm. Two precombustion chamber vent orifice diameters are available, 1.5 and 2.3 mm. A vent orifice bolt, shown in Figure 2, 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. This should also enhance the mixing of the combustion gases with the LP that is initially contained in the antechamber.

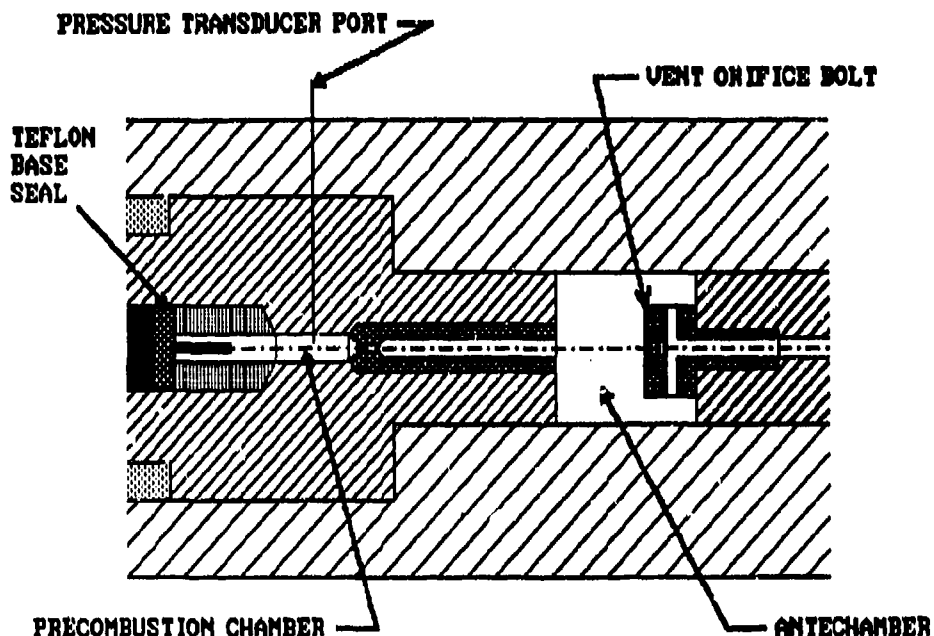


Figure 2. Internal Components of Two-Stage Igniter

The parameters that were measured in each test are 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 discharge current was measured with a Pearson Model 411 Current Monitor. The voltage was determined by measuring the current through a 1000 ohm equivalent resistor in parallel with the electrode gap. The voltage was then obtained by multiplying the measured current by the known shunt resistance. This current was measured with a Pearson Model 110 Current Monitor. The current across the gap was then obtained by subtracting the current in the shunt resistance from the measured discharge current. This current is usually within one percent of the discharge current. The pressures were measured with Kistler 607C4 pressure transducers. All data was recorded on a Nicolet 4094 Digital oscilloscope. The electrical power and energy dissipated were calculated using programs available on the oscilloscope.

An Impulse Engineering Model LD-16 High Current/High Voltage Pulse Former⁴ was used to transfer the electrical energy to the igniter. The inductance, resistance, and capacitance of the pulse forming network (PFN) of this device can be varied in order to change the pulse characteristics. For the tests described in this report, the capacitance was set to 7 microFarads, the maximum available. The circuit resistance was assumed to be about 2 ohms. The initial tests were performed with an inductance of 15 milliHenries. This was reduced to 2.5 mH for the last series of tests.

There was a problem with interference from the current pulse on the pressure transducer signals during the initial tests. The interference was of the same shape as the current pulse, however it was inverted. The interference was large enough to inhibit the determination of the actual pressure in the precombustion chamber in the first several tests. The level of this interference was reduced to only a couple of percent of full scale by reducing ground loops and electromagnetic interference. Further reduction and elimination of this interference will be a goal of future testing.

III. RESULTS AND DISCUSSION

The first series of tests were performed with a 0.73 Molar solution of potassium chloride. The purpose of these tests was to become familiar with the operation of the igniter and check the electrical characteristics of the current discharge using a LP electrical conductivity simulator. The electrical conductance of the KCl solution and LGP 1846 are nearly the same at room temperature, approximately $0.08 \text{ ohm}^{-1}\text{-cm}^{-1}$. The tests were performed with the precombustion chamber venting into atmospheric pressure. The results of tests with a 7.9 mm center electrode length are shown in Table 1. In the following tables, V_s and E_s are the voltage and energy stored on capacitors; I_{max} and V_{max} are the maximum current and voltage across electrode gap; t_{bd} is the time at which voltage breakdown occurs; E_{bd} is the energy absorbed by the system at the point of breakdown; and E_{ve} is the energy absorbed by the system at time voltage returns to zero.

Table 2 shows the results of tests with KCl solution using a 3.2 mm long center electrode. The shorter electrode increases the resistance between the electrodes, increasing the maximum gap voltage relative to that attained with the longer electrode under the same initial circuit conditions. The higher gap voltage leads to voltage breakdown occurring with lower initial stored energy (Test No. KCl-14) and at an earlier time, t_{bd} (Test Nos. KCl-15 and KCl-16).

The results indicated that the voltage across the electrode gap would have to be kept below about 500 volts in order for voltage breakdown (Event 2) not to occur. The initial stored energy would have to be kept below 126 Joules for this discharge circuit configuration.

TABLE 1. RESULTS OF TESTS WITH KCl SOLUTION, LONG ELECTRODE*

Test No.	V _s	E _s	I _{max}	10-90% Rise Time	Duration of Current Pulse	V _{max}	t _{bd}	Max Power	E _{bd}	E _{ve}
	(kV)	(J)	(A)	(ms)	(ms)	(V)	(ms)	(kW)	(J)	(J)
KCl-01	3	31.5	47.8	0.395	1.240	212	N/A	9.69	N/A	5.74
KCl-02	5	87.5	82.8	0.390	1.235	392	N/A	27.6	N/A	17.1
KCl-03	6	126.	97.0	0.385	1.230	478	N/A	44.9	N/A	27.7
KCl-04	7	172.	116.	0.390	1.245	532	1.055	60.9	32.9	33.3
KCl-05	8	224.	131.	0.390	1.230	534	N/A	68.1	N/A	39.7
KCl-06	9	284.	146.	0.390	1.250	602	0.870	87.5	39.3	41.5
KCl-07	10	350.	162.	0.390	1.245	618	1.030	99.6	54.0	54.7
KCl-08	11	424.	176.	0.390	1.255	648	0.790	115.	46.4	49.7
KCl-09	12	504.	192.	0.390	1.255	674	0.660	129.	39.0	44.2
KCl-10	13	592.	207.	0.390	1.255	722	0.640	147.	41.3	47.2
KCl-11	14	686.	222.	0.395	1.255	692	0.675	149.	50.4	57.1
KCl-12	15	788.	241.	0.405	1.255	700	0.560	159.	39.3	47.6

*Note: Volume of KCl solution was 0.5 cm³.
Length of center electrode was 7.9 mm.
Diameter of vent orifice was 2.3 mm.
Inductance in PFN was 15 mH.
N/A = no voltage breakdown

TABLE 2. RESULTS OF TESTS WITH KCl SOLUTION, SHORT ELECTRODE*

Test No.	V _s	E _s	I _{max}	10-90% Rise Time	Duration of Current Pulse	V _{max}	t _{bd}	Max Power	E _{bd}	E _{ve}
	(kV)	(J)	(A)	(ms)	(ms)	(V)	(ms)	(kW)	(J)	(J)
KCl-13	3	31.5	46.2	0.365	1.235	478	N/A	22.1	N/A	11.7
KCl-14	5	87.5	80.2	0.390	1.270	602	0.685	46.7	16.4	17.7
KCl-15	7	172.	115.	0.420	1.265	696	0.505	71.3	15.4	19.8
KCl-16	9	284.	152.	0.445	1.260	688	0.475	86.4	20.0	24.8

*Note: Volume of KCl solution was 0.5 cm³.
Length of center electrode was 3.2 mm.
Diameter of vent orifice was 2.3 mm.
Inductance in PFN was 15 mH.
N/A = no voltage breakdown

A second series of tests were performed with LGP 1846 and the same discharge circuit. These tests were performed with the igniter in a "closed chamber" configuration, i.e., the vent orifice of the antechamber was sealed by using a vent orifice bolt without holes (see Figure 2). No LP was used in the antechamber in these tests. The goal of this series of tests was to determine the performance characteristics of the first stage of the igniter. It is desired to attain a pressure of at least 5 to 10 MPa in the antechamber in order to ignite a booster charge that will be present in the igniter configuration. Table 3 shows the electrical characteristics of these tests.

TABLE 3. ELECTRICAL CHARACTERISTICS OF TESTS WITH LGP 1846, 15 mH INDUCTANCE*

Test No.	V _s	Orif. Size	I _{max}	10-90% Rise Time	Duration of Current Pulse	V _{max}	t _{bd}	Max Power	E _{bd}	E _{ve}
	(kV)	(mm)	(A)	(ms)	(ms)	(V)	(ms)	(kW)	(J)	(J)
1846-01	3	2.3	47.2	0.385	1.265	694	0.655	30.3	6.11	7.01
1846-02	3	2.3	50.8	0.455	1.260	744	0.705	29.3	8.06	8.88
1846-03	4	2.3	66.2	0.390	1.230	792	0.920	36.0	13.2	14.0
1846-04	5	2.3	82.4	0.390	1.235	752	0.890	50.6	19.0	20.2
1846-05	5	1.5	79.6	0.365	1.230	926	0.640	70.7	14.4	22.3
1846-06	5	1.5	81.8	0.395	1.250	598	N/A	45.9	N/A	17.6
1846-07	5	2.3	82.6	0.390	1.260	918	0.530	71.0	10.9	14.7
1846-08	5	1.5	83.8	0.500	1.250	950	0.525	71.4	12.0	20.0

*Note: Volume of LP was 0.5 cm³.
 Test Nos. 1846-01 to 1846-06 performed with 7.5 mm center electrode.
 Test Nos. 1846-07 and 1846-08 performed with 6.4 mm center electrode.
 N/A - no voltage breakdown

The igniter did not perform well in this series of tests. There was unburned LP left in antechamber when the igniter was opened after the tests. A pressure was only recorded in two tests, Nos. 1846-05 and 1846-08, in which the smaller orifice was used. The highest pressure was recorded in Test No. 1846-08, which was about 30 MPa in the precombustion chamber and 3 MPa in the antechamber. The conditions produced in the antechamber would not have led to ignition of a booster charge if it were present.

The maximum voltages attained in this series were higher than those achieved with the KCl solution at the same initial stored energy. Voltage breakdown occurred in almost every test. It is believed that the chemical reaction taking place due to the current flow occurred more rapidly in the propellant than in the KCl solution. This chemical reaction causes an insulating vapor sheath to form around the electrode, increasing the

electrical resistance of the electrode gap, resulting in a higher voltage. Figure 3 shows a comparison of the gap voltage for a test with KCl solution (Test No. KCL-01) and LGP 1846 (Test No. 1846-01) under the same conditions. The figure shows the voltage beginning to increase more rapidly at about 250 microsec for the LP and at about 650 microsec for the KCl solution. The voltage can be used as a qualitative measure of the resistance in these two tests since the gap currents were very similar. The current is not a strong function of resistance in this discharge circuit, which is indicated in Tables 1 and 2 by the small difference in maximum current between tests with the long and short center electrodes.

It was concluded that an insufficient amount of energy was being delivered to the LP in order to achieve reliable ignition with the amount of confinement that was being used. It was also obvious that an Event 1 only type of ignition would not be achieved with this configuration of the discharge circuit. It was decided that this discharge circuit would not be suitable for igniting the LP with an Event 1 alone because it is limited to 7-microFarad capacitance. Higher capacitance will be needed in order to keep the maximum voltage low and still have high enough stored energy. However, it was decided to continue testing in order to gain information and check-out the system.

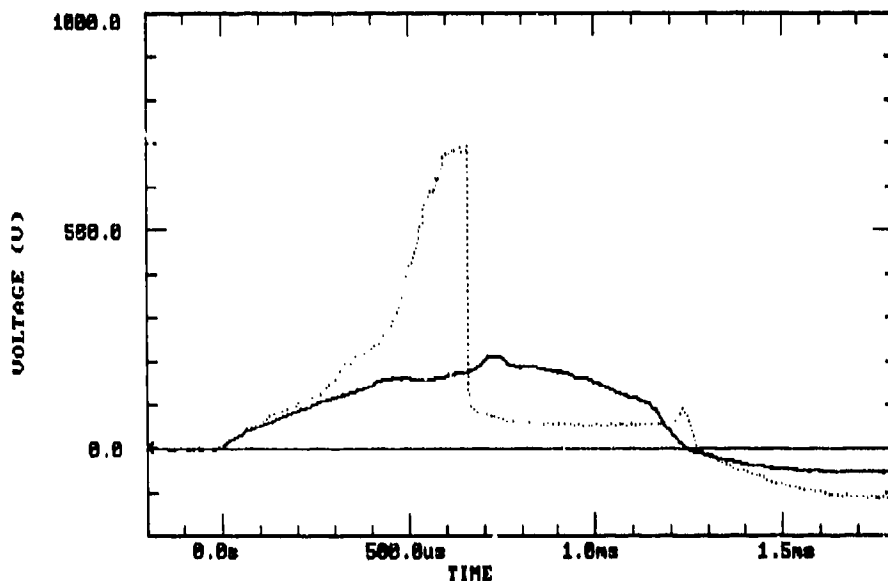


Figure 3. Comparison of gap voltages for Test No. KCL-01 (Solid) and Test No. 1846-01 (Dotted).

Therefore, another series of tests was performed with the inductance in the circuit reduced from 15 to 2.5 mH. This was done in order to get more energy to the LP during the current discharge. The inductance was reduced,

rather than increasing the initial voltage, because it was not desired to increase the total stored energy. Voltage breakdown would be even more likely in these tests due to the higher gap voltage. This modification increased the energy delivered to the LP, even though the duration of the current pulse was reduced from 1.25 ms to 0.43 ms, since the maximum current was increased by a factor of three. In addition, the power was increased by a factor of three to five. The inductance was still relatively high and prevented a high current from forming when voltage breakdown occurred. Tables 4 and 5 show the electrical characteristics and the pressures recorded, respectively, for this series of tests. The small orifice was used in all tests in this series.

The results from this series of tests were much better. Ignition of the LP was achieved repeatably with 56 J of stored energy (4 kV) in the discharge circuit. The energy absorbed by the igniter, E_{bd} , was measured at the point at which voltage breakdown occurred and ranged from 13 to 24 J in tests where ignition occurred. The LP did not ignite in Test No. 1846-11 with only 8.8 J of absorbed energy (14 J of stored energy). Test No. 1846-12 was a marginal case with 13.6 J of absorbed energy (31.5 J of stored energy). The pressures recorded before Test No. 1846-12 were not accurate because of interference from the current pulse. This interference was reduced to about one percent of full scale for Test No. 1846-12. This is the reason for the uncertain maximum pressures listed in Table 5 for Test Nos. 1846-09 and 1846-10.

TABLE 4. ELECTRICAL CHARACTERISTICS OF TESTS WITH
LGP 1846, 2.5 mH INDUCTANCE*

Test No.	V_s	I_{max}	10-90% Rise Time	Duration of Current Pulse	V_{max}	t_{bd}	Max Power	E_{bd}	E_{ve}
	(kV)	(A)	(ms)	(ms)	(V)	(ms)	(kW)	(J)	(J)
1846-09	5	227.	0.150	0.270	1188	0.160	244.	14.2	31.6
1846-10	4	181.	0.145	0.230	1058	0.175	178.	12.9	19.4
1846-11	2	86.4	0.130	0.390	740	N/A	41.9	N/A	8.78
1846-12	3	136.	0.130	0.430	884	0.250	108.	13.6	16.3
1846-13	4	181.	0.135	0.395	1348	0.305	165.	23.9	26.7
1846-14	4	178.	0.130	0.420	1176	0.205	198.	17.0	26.9
1846-15	4	181.	0.125	0.350	1490	0.260	220.	22.9	30.5
1846-16	4	183.	0.125	0.395	1364	0.245	225.	21.5	28.3

*Note: Length of center electrode was 6.4 mm.
Volume of LP was 0.5 cm³.
Orifice size was 1.5 mm.
N/A = no voltage breakdown

TABLE 5. MAXIMUM PRESSURES IN PRECOMBUSTION CHAMBER AND ANTECHAMBER*

Test No.	V _g (kV)	Precombustion Chamber		Antechamber	
		Max Pressure (MPa)	Rise Time (ms)	Max Pressure (MPa)	Rise Time (ms)
1846-09	5	?158.	----	? 2.55	----
1846-10	4	?199.	----	?13.9	----
1846-11	2	none	----	none	----
1846-12	3	32.4	1.125	1.50	0.415
1846-13	4	257.	0.185	30.4	0.705
1846-14	4	90.8	0.365	2.06	0.860
1846-15	4	187.	0.150	3.48	0.535
1846-16	4	117.	0.190	1.73	0.300

*Note: Length of center electrode was 6.4 mm.
Volume of LP was 0.5 cm³.
Orifice size was 1.5 mm
Vertical igniter orientation in Test Nos. 1846-09 to 1846-13.
Horizontal igniter orientation in Test Nos. 1846-14
to 1846-16.
Test No. 1846-16 contained 1.0 cm³ of LP in antechamber.
Question mark denotes uncertainty in measurement (see text).

Voltage breakdown occurred in all tests except No. 1846-11, which was at a low initial voltage. There was a small amount of pitting on the inside surface of the outer electrode due to the arc. This indicates that the arc occurred at the anode even though the highest temperature would have been at the smaller diameter center electrode, the cathode. This adds support to the theory that the electrochemical reaction caused by the current discharge through the LP may play a larger role than ohmic (resistive) heating during the Event 1 phase. The arc discharge probably occurred between the outer electrode wall and the boundary between the liquid and the gas produced at the outer electrode during Event 1. This phenomenon has been observed by Carleton et al. using high speed photography.⁵ It is likely that a vapor sheath is forming around the center electrode also, since this is where the highest temperature will be before ignition.

There was a large amount of variability in the maximum pressures recorded in Test Nos. 1846-13 to 1846-16. However, the teflon seal at the base of the precombustion chamber failed in all tests in which there was high pressure in the precombustion chamber. Therefore, the repeatability of the system can not be determined from these few tests. In addition, Test No. 1846-16 was performed with 1 cm³ of LP in the antechamber and the igniter venting into a 100 cm³ test chamber. The LP in the antechamber did not ignite and no pressure was recorded in the test chamber. It is believed that the failure of

the teflon seal reduced the maximum pressure produced in the antechamber, failing to ignite the LP booster charge. The failure of the teflon seal will have to be eliminated before the performance of the igniter can be fully evaluated.

Tests through No. 1846-13 were performed with the igniter in the vertical position, with the vent orifice pointing upwards. Test Nos. 1846-14, 1846-15, and 1846-16 were performed with the igniter in the horizontal position. The effect on performance cannot be determined from these few tests.

The maximum currents and rise times were repeatable. The repeatability of the voltage was not as good. The voltage signal is more dependent on the physical process taking place inside the precombustion chamber during Event 1. The formation of vapor around the electrode affects the resistance across the electrode gap which in turn affects the gap voltage. The current has already been shown not to be a strong function of resistance in this circuit.

Figures 4a and 4b show the pressures recorded in Test No. 1846-13. These were the highest pressures recorded. A pressure of 30 MPa was achieved in the antechamber in this test, Figure 4b. Tests at GE and the BRL indicate that puddles of LP can be ignited with as little as 5 to 10 MPa generated by an ignition source.³ Therefore, it is expected that a pressure on this order is only required to ignite a booster charge in the antechamber.

The current and voltage across the electrode gap are shown in Figures 5a and 5b, respectively. Voltage breakdown occurred at about 0.3 ms and it can be seen that the current does not increase substantially at this time. The second peak of the voltage signal is a result of the open circuit caused by the combustion of the LP.

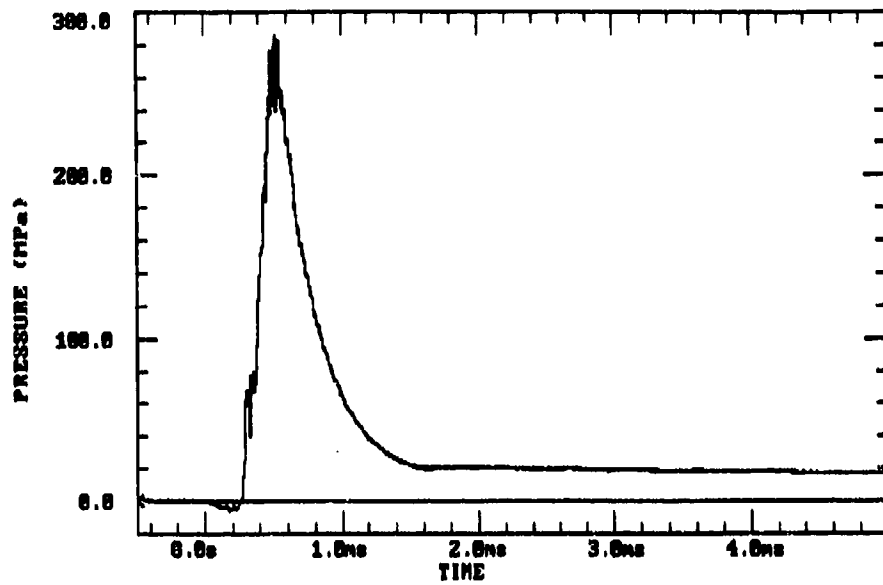


Figure 4(a). Precombustion Chamber Pressure, Test No. 1846-13

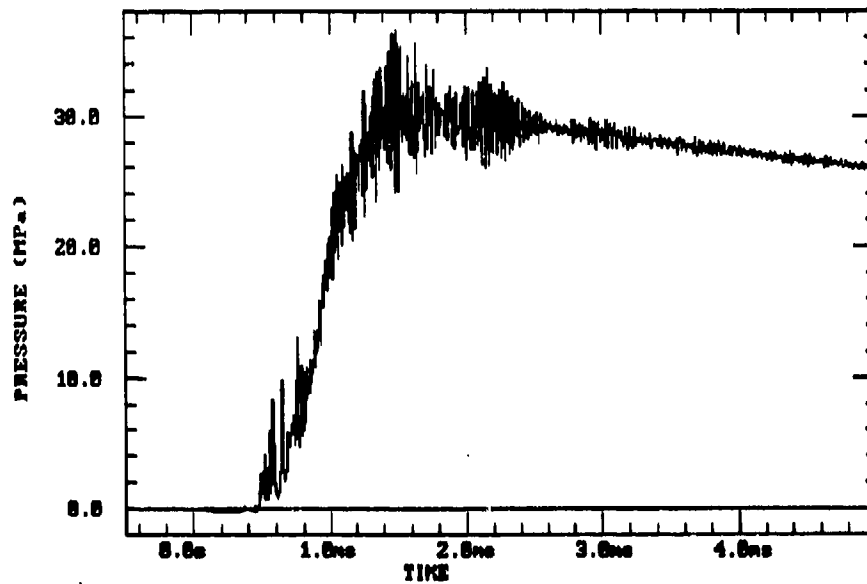


Figure 4(b). Antechamber Pressure, Test No. 1846-13

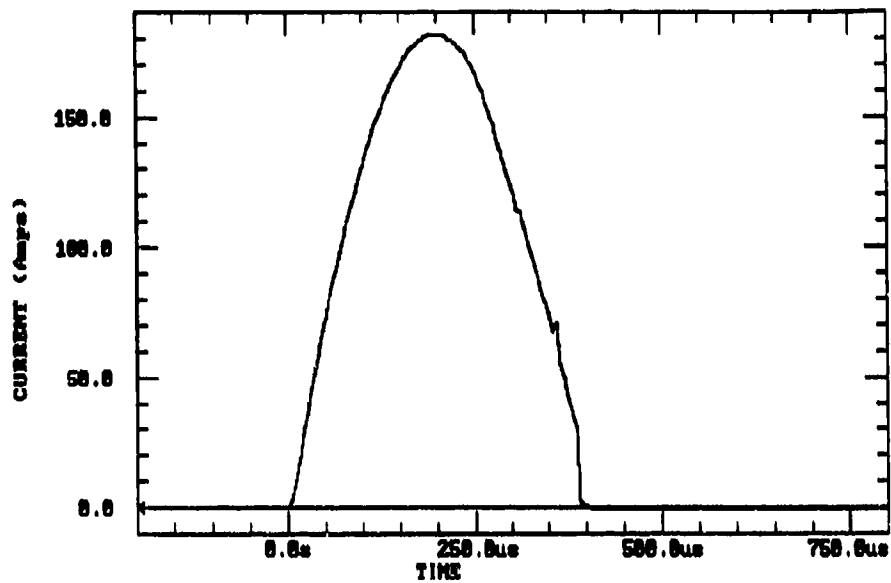


Figure 5(a). Gap Current, Test No. 1846-13

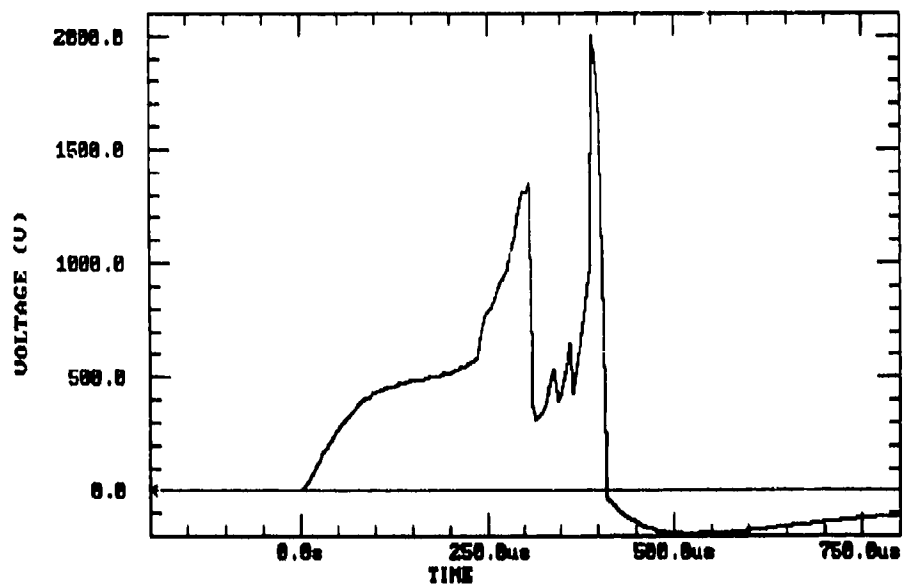


Figure 5(b). Gap Voltage, Test No. 1846-13

IV. SUMMARY

It was determined from tests with both KCl solution and LGP 1846 that voltage breakdown occurs in the electrode configuration under study when the gap voltage is above about 500 to 600 volts. Ignition from the Event 1 process alone was not achieved because high enough energy cannot be attained with the present discharge circuit while keeping the gap voltage below 500 volts. A vapor sheath likely forms around the outer electrode (anode) before voltage breakdown, which occurs at that electrode. Ignition was achieved with 13 to 24 J of energy transferred to the igniter, which is 23 to 43 percent of the total stored energy. The actual amount of energy absorbed by the LP was not determined in these tests. Acceptable performance was achieved only after reducing the inductance in the discharge circuit, thereby increasing the power and energy delivered to the LP. There was a large amount of variability in maximum pressure, however, this may have been partly due to the failure of the seal at the base of the precombustion chamber.

In future tests, the seal at the base of the precombustion chamber will be modified and tests will be performed to evaluate the performance of the igniter. The effect of electrode pitting and igniter orientation will be determined. In addition, a new discharge circuit will have to be obtained in order to increase the capacitance of the system and attempt to ignite the LP without voltage breakdown occurring.

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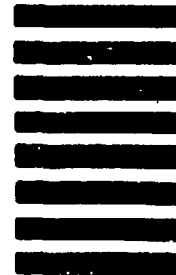


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