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PREFACE

The work described in this report was performed by the Propulsion Division of the Jet Propulsion Laboratory.

CONTENTS

ABSTRACT

A test program was carried out to demonstrate an igniter motor initiation system utilizing the bimetallic material Pyrofuze*for a solid propellant rocket with controlled low rate of thrust build-up. The program consisted of a series of vacuum ignition tests using a slab burning window motor that simulated the principal initial ballistic parameters of the full scale igniter motor. A Pyrofuze/pyrotechnic igniter system was demonstrated that uses a relatively low electrical current level for initiation and that eliminates the necessity of a pyrotechnic squib, with its accompanying accidental firing hazards and the typical basket of pyrotechnic pellets. The Pyrofuze ignition system does require an initial constraining of the igniter motor nozzle flow, and at the low initiating electrical current level the ignition delay time of this system was found to be quite sensitive to factors affecting the local heat generation or loss rates.

* Trademark of Pyrofuze Corporation

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A. Introduction

A torus igniter, called g-Dot, for producing controlled thrust buildup in a solid propellant rocket was described in Ref. 1. This article describes a series of tests carried out with the objective of demonstrating a system for igniting the torus igniter motor under vacuum conditions utilizing the bimetallic material Pyrofuze. Pyrofuze is a coaxial wire with an aluminum core surrounded by palladium. When heated electrically to the melting point of aluminum (933°K), an alloying reaction occurs, generating a large exotherm. In this manner, it was hoped that the need for a pyrotechnic squib, with its accompanying accidental firing hazards, could be eliminated. The Lockheed Propulsion Company and the Air Force Rocket Propulsion Laboratory have used Pyrofuze successfully for igniting "wafer" stop-restart solid propellant motors, but their work appears to have been limited to firings at atmospheric pressure.

B. Test System

The program consisted of vacuum ignition tests using the slab burning window motor originally developed for a water injection thrust termination program (Ref. 3). The motor nozzle was threaded so that the motor could be screwed directly onto the Bldg. 117 vacuum tank leg (Fig. 1). The standard propellant slab configuration for the motor was used, except that a 0.318 cm wide by 0.635 cm deep by 34.8 cm long slot was cast into the top surface (Fig. 2). JPL 540-Mod C propellant was used. It has a polyether-polyurethane binder, ammonium perchlorate oxidizer, and contains 2% by weight aluminum. The window motor free volume was reduced by cementing wooden blocks to its top and bottom surfaces. The important initial parameters for the g-Dot torus and window motors are given in Table I. As can be seen the window motor simulated the torus initial L* (free volume/nozzle throat area) and K_n (propellant burning area/nozzle throat area).

The ignition system consisted of a length of eight strand braided Pyrofuze wire placed along the bottom of the slot with an electrical lead fastened to each end (Fig. 2). The wire was then covered with a thin layer of igniter paste, and a number of igniter pellets were pressed into the slot over the paste (Fig. 3). In theory the Pyrofuze exotherm would ignite the rapid burning paste. The paste would in turn ignite the pellets, giving the desired chamber pressurization and heating duration.

Several design constraints dictated the direction the test program would take. They included: (1) ignition system should be as simple, reliable, and reproducible as possible, (2) igniter current not to exceed 4-5 amperes (so that conventional squib firing hardware could be utilized), and (3) ignition delay time not to be unreasonably long (less than 1 sec.).

Constraints (2) and (3) meant 0.05 mm strand was the largest diameter Pyrofuze wire that could be used, and that the wire would have to be coated with a pyrotechnic paste material. Earlier tests measuring the ignition delay as a function of igniter current for 0.08 mm and 0.13 mm 8 strand wire showed that the delay times would be excessive (approximately 1 minute or more) at the desired current levels (Fig. 4). Also, earlier small specimen tests indicated that the ignition of boron igniter pellets directly using Pyrofuze became increasingly difficult as the wire size was reduced.

Boron pellets, type 2D, were used, as tests showed them to be much more readily ignitable than ALCLO (aluminum-potassium perchlorate) or Mg-Teflon pellets. The paste consisted of binder, boron fuel, and potassium nitrate oxidizer in approximately the same weight ratio as that of boron pellets.

To aid the initial buildup in pressure in the motor a thin (0.318-cm thick) Lucite orifice plate was mounted over the nozzle inlet in all but two tests. The 0.833-cm diameter orifice produced an initial L* of 5 m; the 0.318-cm orifice, 36 m.

Electrical power was supplied by a Perkin Electronics constant current power supply. Instrumentation consisted of a Tabor pressure gage and, in a majority of the tests, an event marker showing initiation of current to and burn-out of the Pyrofuze (the time difference being the Pyrofuze initiation delay time).

C. Initial Test Program

Approximately a dozen test firings were conducted. A summary of the details and results for each test is given in Table II. The igniter current was 4 amps for the first nine tests and 5 amps for all tests thereafter. For a majority of the tests the vacuum back pressure was 0.07-0.08 N/cm^2 or less.

Test variables included igniter paste binder, binder concentration, oxidizer coarseness, Pyrofuze configuration, and boron pellet placement design. The paste binder for the first six tests was hydroxy-terminated polybutadiene (R-45 M polymer ARCO Chemical Corp). In the remaining tests a vinyl cement was used (Okun's Original Liquid Plastic Vinyl), which gave a more rapid burning paste. Earlier tests had verified that both types of paste would ignite and burn in a hard vacuum with the Pyrofuze initiator. After hand mixing a 5 gm batch, sufficient for one or two propellant slabs, the paste was diluted with solvent (hexane or Okun's

Liquator) to the desired consistency, applied over the Pyrofuze lying in the slot, and cured overnight in a 340 K oven. The paste had a more gritty appearance than ordinary propellant, but bonded to the propellant satisfactorily. The oxidizer/boron weight ratio was kept fixed at 3/1. The binder concentration was varied between 8 and 16 % for the first few tests. A value of 10% was eventually settled on as a compromise between better physical properties and the avoidance of excessive smokiness.

In hopes of igniting the entire propellant surface rapidly and uniformly, the Pyrofuze and paste extended the full length of the slot in the first six tests. The boron pellets were evenly spaced along the slot. Motor ignition occurred in only two of the tests. Each of the others had the same results; following closure of the circuit some weak flashes were observed in the motor, but no rise in pressure occurred. Upon examining the motor, all of the Pyrofuze, paste, and pellets were found to be consumed. The sixth test revealed what was going on. The Pyrofuze ignited at the aft end of the motor. Because of the heat sink effect of either the propellant or paste or both, it did not rapidly propagate along its length, as it does in air, but quenched. The ignited paste then propagated along the slot, igniting pellets individually as it passed under them. It became apparent that, at least at these low current levels, the heated 0.05 mm Pyrofuze does not alloy at the same instant along its length, and there was evidence that the heated wire was sensitive to the thermal nature of its surrounding paste. In a couple of tests the alloying appeared to initiate at the point where the paste looked most gritty and porous.

It was concluded that the pellets should be concentrated over a shortened length of Pyrofuze to insure uniform ignition. This was done in all subsequent tests, Figure 3, with excellent results. Fig. 5 is a reproduction of a typical test record. Two ignition delay times were identified:

(1) Pyrofuze initiation time, the time between closure and burnout of the Pyrofuze electrical circuit and (2) pyrotechnic ignition delay, time between burnout of the Pyrofuze and onset of motor pressure rise. They are both primarily transient heating times: the heating of (1) the Pyrofuze to its alloying temperature and (2) the igniter paste and pellets to their ignition temperature. The test delay times are listed in Table II and will be discussed in more detail later.

In a test (No. 11) to determine the effect of eliminating the Lucite orifice plate, the paste and pellets ignited and burned, but no pressure build-up occurred, and consequently, the propellant did not ignite. It was concluded that a temporary constriction to the nozzle flow is necessary to obtain the initial pressure build-up required for rapid ignition of the igniter pellets. The results of tests 12 and 13 verified that the slab motor could be ignited with the paste and boron pellet weights reduced by one-half using the reduced diameter orifice plate. The torus motor initiator would most likely be a dual system, either one having the ability to ignite the motor alone.

D. Igniter Verification Tests

As can be seen from Table II, the ignition delay times varied quite markedly in tests 8-13. The large variation in the Pyrofuze delay was concluded to be due to the sensitivity of the heating Pyrofuze wire to the thermal nature of its surrounding paste, as the wire initiated quite reproducibly in air or a vacuum. In the igniter paste batch for tests 11 and 12 the KNO_3 oxidizer was ground with a mortar and pestle to reduce the particle size, and hopefully, to obtain a less gritty paste. This resulted in a significantly smoother, less porous paste, and probably explains the longer Pyrofuze delay times. Test 13 used unground oxidizer in the paste, and the delay time was considerably shorter again. Two additional three-motor series of tests were carried out to determine if this variation in the motor ignition could be reduced by closer control of the igniter system preparation.

In the first series (tests 14-16) the igniter systems were prepared from one 8-gm batch of igniter paste. The paste was diluted with solvent, divided into three roughly equal portions, and approximately 2 gms were applied to each propellant slab. By the time the third slab was prepared, its portion of paste had thickened sufficiently to necessitate the addition of more solvent to the paste.

The motors were fired in the order of preparation. Jubilation at the relatively close Pyrofuze delay times for the first two tests was short lived, as the delay for the third test was roughly five times as great. As indicated in Table II, the pyrotechnic delay times for the three tests were relatively constant.

For the second three-motor test series a much larger 100-gm batch of igniter paste, diluted with 100 cm^3 of solvent was prepared in a 470 cm^3 Baker-Perkins mixer, so that the solvent dilution of the paste was approximately the same for each motor tested. The igniter paste weights for the three motors, 2.7, 2.7, and 3.7 gms respectively, came out slightly larger than those of the previous series.

The three motors were again fired in the order of preparation. An attempt was made to control the time the propellant and igniter system was exposed to vacuum prior to ignition. In each test the vacuum tank was evacuated to a pressure of approximately 0.1 N/cm^2. The propellant slab was then removed from the ambient oven, the window motor assembled, and the test leg and motor evacuated to 0.07-0.08 N/cm^2. The resulting evacuation times were approximately 1 hour for the first two motors and 1-1/2 hours for the third.

The ignition delay time results are listed in Table II. They were somewhat encouraging in that the scatter in the Pyrofuze delay times was reduced considerably. The maximum deviation was less than 30 ms. In four of the final six firings the maximum deviation from the mean Pyrofuze delay time was 8 ms. Unfortunately, whereas in the previous three tests, the pyrotechnic ignition delay times varied by less than 30 ms, they progressively doubled in these tests. The test with the longest delay had a greater amount of paste, but there was no correlation of pyrotechnic ignition delay time with paste weight in any of the earlier tests. In a "soft" ignition system such as this, small variations in heat generation and loss rates apparently can produce significant variation in the ignition delay time.

E. Summary

A Pyrofuze/pyrotechnic igniter system for the g-Dot torus igniter motor has been shown to be feasible. It eliminates the necessity of a squib and a basket-type igniter, but does require an initial constraining of the igniter motor nozzle flow. The ability of the system to ignite under vacuum conditions a motor with the initial K_n and L* values of the g-Dot torus igniter was demonstrated, in that six slab motors at essentially the same initial conditions were all successfully ignited. Reproducibility of the quarter-to-half second ignition delay time can, it is felt, be improved by standardization and mechanization of the igniter paste mixing and application procedures, however, it seems safe to conclude that better than hundreds-of-milliseconds reproducibility is not possible under the required low electrical current firing condition. The application of this Pyrofuze ignition system for the g-Dot torus igniter motor therefore depends on what tolerance is required on the initiator delay time.

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TABLE I

COMPARISON OF INITIAL PARAMETERS FOR G-DOT TORUS IGNITER MOTOR

AND WINDOW MOTOR

PARAMETER	TORUS	WINDOW MOTOR
D_t, cm	12 Nozzles, @ 0.586	1 Nozzle, 1.422
A_t, cm^2	3.24	1.59
Initial free Vol., cm^3	574	280
L*, cm	175	175
A_b, cm^2	639	310
$K_{n_{in}}$	198	194
P_{in}(est m'd), N/cm^2	240	240

TABLE II

PYROFUZE IGNITER TEST DETAILS AND RESULTS

Run No.	Pyrofuze Length, cm	Paste Wt., gm	Pellet Wt., gm	Total Wt., gm	Lucite Orifice Dia., cm	Test Results*	Pyrofuze Delay, ms	Pyrotechnic Delay, ms	Total Delay, ms
1	34.3	3.5	3.8	7.3	0.833	I		No Data	
2	34.3	1.0	1.5	2.5	----	NI		No Data	
3	34.3	3.0	1.5	4.5	0.833	I		No Data	
4	34.3	2.2	1.5	3.7	0.833	NI	270	----	-----
5	34.3	2.4	1.8	4.2	0.833	NI		No Data	
6	34.3	3.0	1.8	4.8	0.833	NI		No Data	
7	10.2	2.0	2.3	4.3	0.318	I		No Data	
8	10.2	1.5	2.3	3.8	-----	NI	3200	----	-----
9	10.2	1.5	2.3	3.8	0.833	I	187	223	410
10	10.2	1.6	2.4	4.0	0.820	I	400	260	660
11	10.2	2.0	2.3	4.2	-----	NI	1200	----	-----
12	5.1	1.0	1.2	2.2	0.318	I	810	130	940
13	5.1	1.2	1.2	2.5	0.820	NI	130	----	-----
14	10.2	2.0	2.3	4.3	0.318	I	155	95	250
15	10.2	2.0	2.3	4.3	0.318	I	144	125	269
16	10.2	2.0	2.3	4.3	0.318	I	717	125	842
17	10.2	2.7	2.3	5	0.318	I	140	96	236
18	10.2	2.7	2.3	5	0.318	I	168	212	380
19	10.2	3.7	2.3	6	0.318	I	145	398	543

*I - Ignition, NI - No Ignition

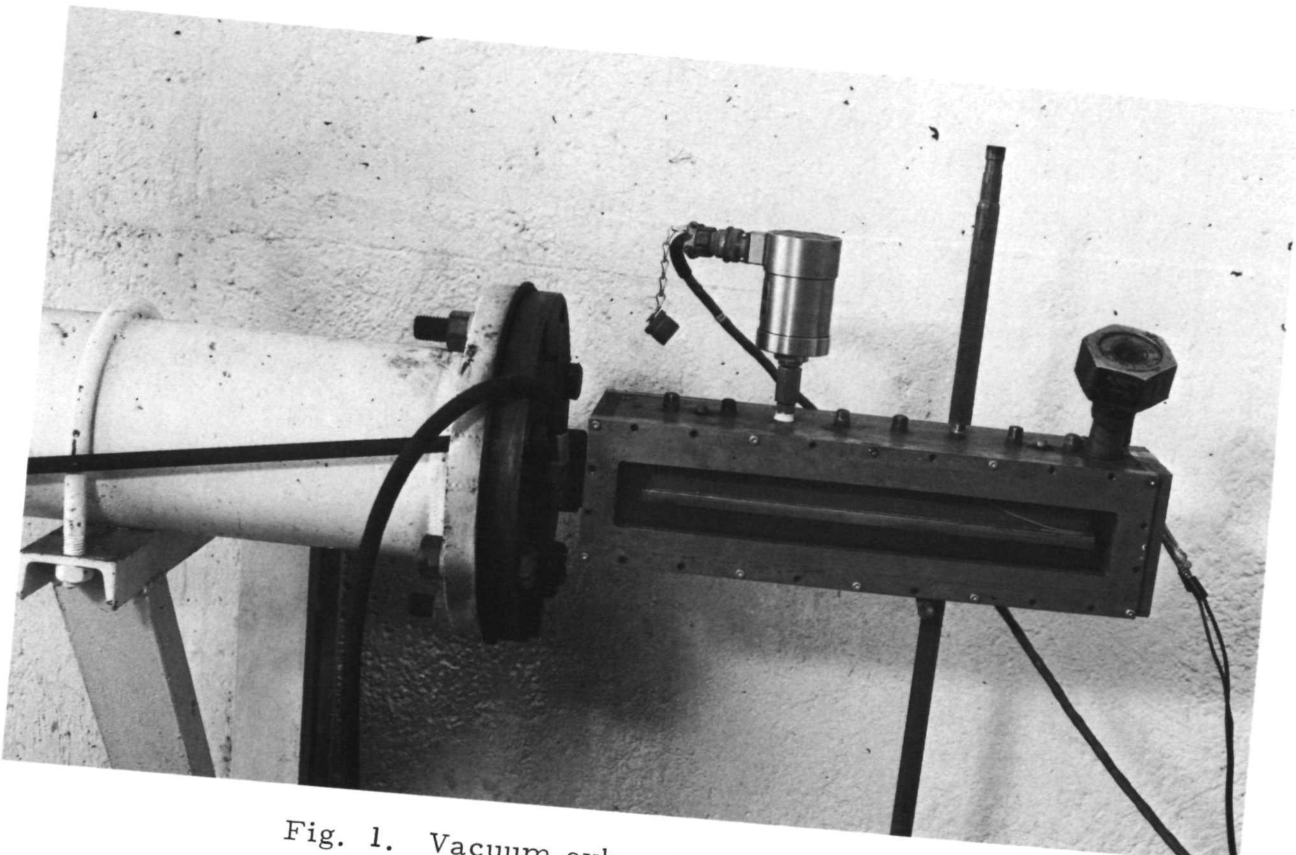

Fig. 1. Vacuum exhausted window motor

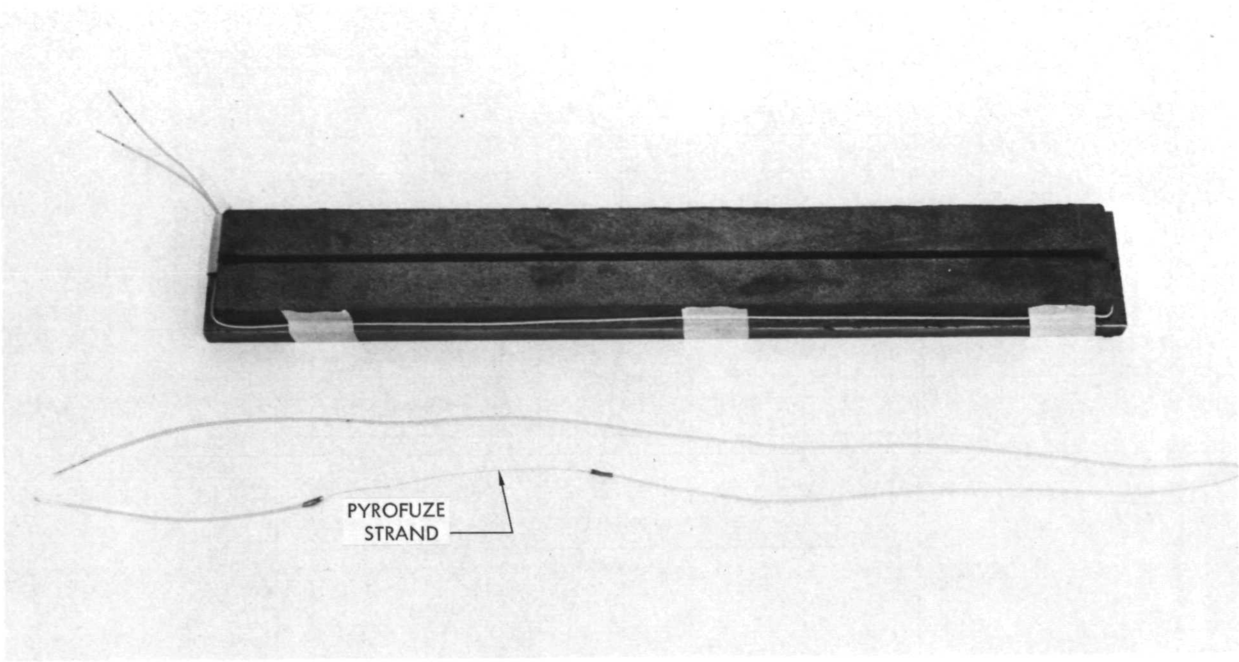

Fig. 2. 10.2-cm-long 0.05-mm Pyrofuze strand alone and mounted on window motor propellant slab

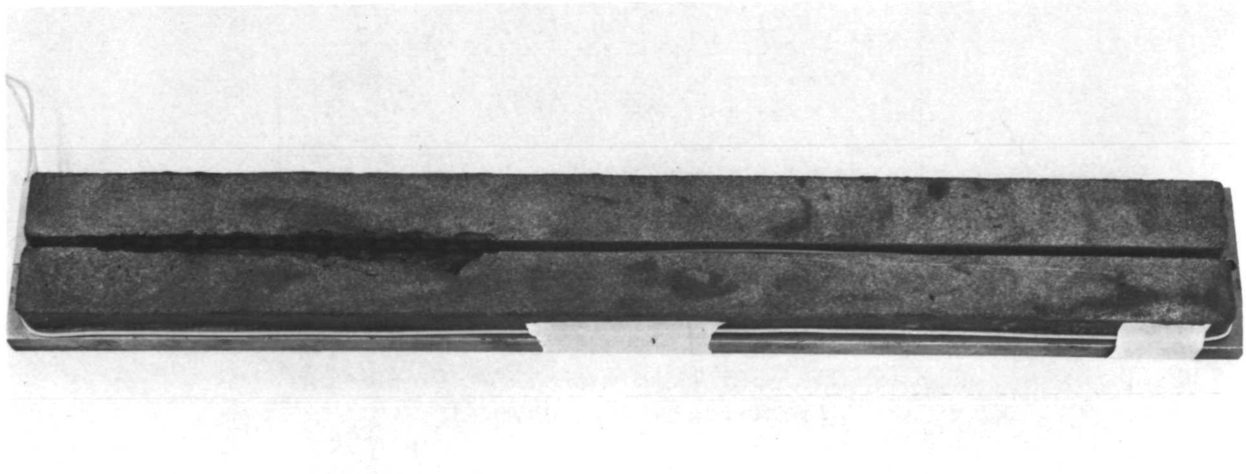

Fig. 3. Propellant slab with Pyrofuze/pyrotechnic igniter system prior to test

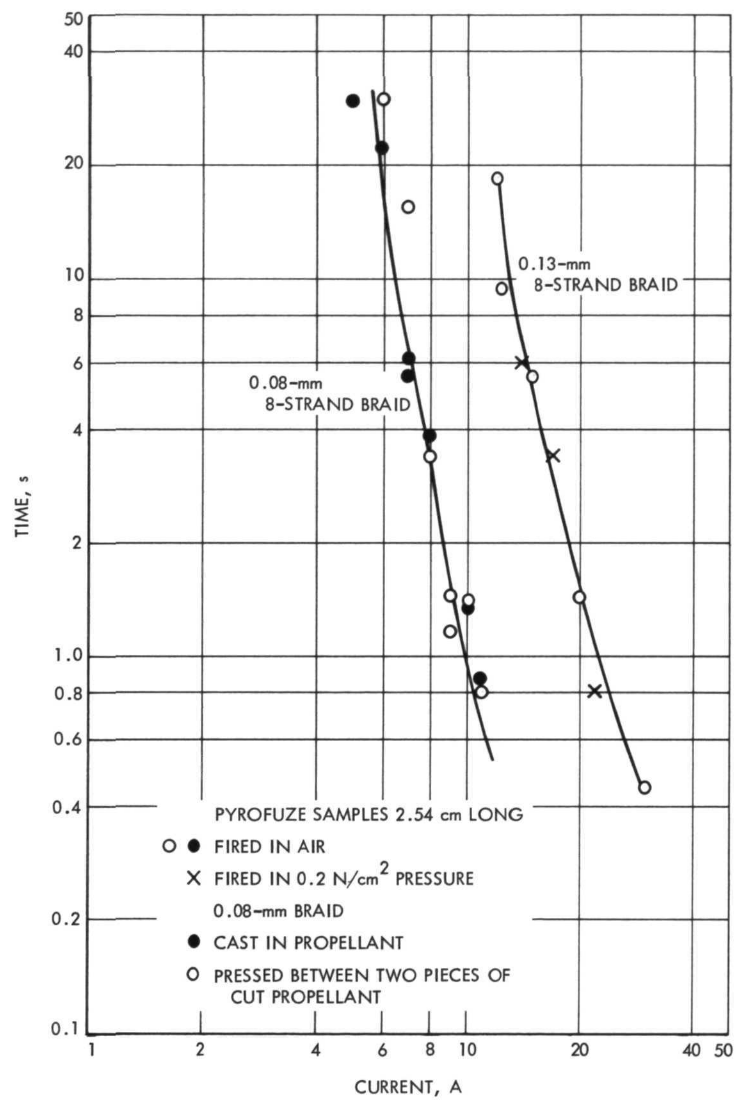

Fig. 4. Pyrofuze initiation delay time vs electrical current level

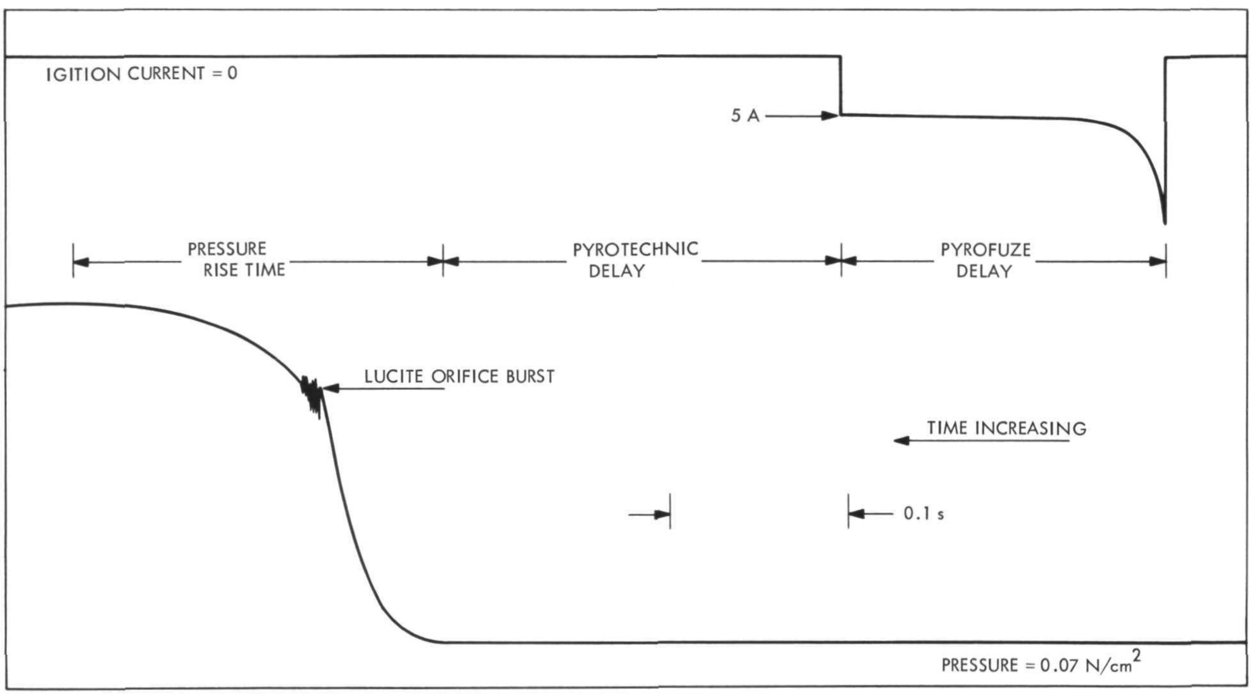

Fig. 5. Record for Pyrofuze igniter test No. 9