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AN IMPROVED METHOD FOR THE MEASUREMENT OF SOLID-PROPELLANT STRAND-BURNING RATES IN CLOSED BOMBS

by

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ABSTRACT. A new method for determining propellant strand-burning rates without the use of timing wires has been developed. It was found that when the cross-sectional area of the strand is sharply varied at known intervals, the burning rate can be obtained from assessment of the resulting pressure-time trace. Results of the new method are within 1% of the standard wire technique. The method is applicable to "difficult" propellant systems and offers advantages of lower cost, higher reliability, and safety.

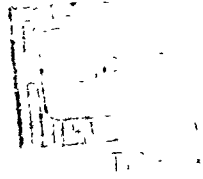
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U. S. NAVAL ORDNANCE TEST STATION

China Lake, California

May 1963



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FOREWORD

During the applied research studies of Nitrasol and other high-performance propellants, it became apparent that the normal system of measuring burning rates of these propellants was not adequate. Therefore, work was initiated on developing an improved method which would not require the use of timing wires. This report describes the method which was developed and compares it with the normal timing-wire procedure.

The development of the new strand-burning-rate method described herein was conducted under Bureau of Naval Weapons Task Assignment RMMP-21-001/216-1/F009-01-16.

This report has been reviewed for technical accuracy by
Dr. R. T. Merrow.

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INTRODUCTION

The usual method of measuring strand-burning rates employs a system of fuse wires and electric interval timers. An inhibitor (restrictor) is applied to the surface of solid-propellant strands with constant cross-sectional area so that burning is confined to a plane approximately normal to the axis or length of the strand. The strand is burned in a closed bomb to which a surge tank or some other device is attached to limit the pressure rise resulting from combustion of the strand. The system is pressurized with an inert gas to the pressure at which it is desired to make the measurement, and the strand conditioned in the bomb to the desired temperature. If a suitable pressure transducer is incorporated into the system, it may be observed that the pressure rise in the closed system is continuous and approximately linear with time. Most commonly, the strand-burning rate is obtained from the time elapsed of burning from one point to another along the length of the strand. The points are located by drilling small holes normal to the length of the strand at accurately known distances apart. Fuse wires pass through these holes forming an electrical circuit to activate and deactivate the magnetic clutches of electric interval timers as the flame front melts them.¹ This method is sufficiently accurate (approximately 1%), but there are several disadvantages which will be discussed later.

A new method has been devised which utilizes the fact that the instantaneous rate of production of gaseous combustion products depends on the burning surface area as well as on the instantaneous burning rate.

In the new method using pressure-time trace, no fuse wires are used, and no internal electrical circuits are needed except for ignition. Notches of suitable configuration are made along the strand at known intervals, and with a pressure transducer and recorder, a permanent record of the pressure-time curve generated by the burning strand is obtained. The notches produce disturbances in the normally smooth pressure-time curve. The average strand-burning rate at the average bomb pressure and conditioning temperature may be quickly and easily calculated from the chart speed of the recorder, the chart length between the disturbances, and the known distances between the notches.

¹U. S. Naval Ordnance Test Station. Strand-Burning Techniques for Evaluation of Propellants, by C. H. Carlton. China Lake, Calif., NOTS, 6 May 1955. (NAVORD Report 3478, NOTS TP 1090).

EXPERIMENTAL WORK

A Crawford-type bomb with internal dimensions of 10-1/2-inch length and 2-1/2-inch ID was used in this work. The bomb was mounted in a vertical position with the inlet-exhaust port located one inch below the bottom of the head closure assembly. The volume of the bomb was approximately 52 cubic inches. The bomb was connected, through approximately 5 feet of 5/16-inch port tubing and valves, to a surge tank approximately 83 cubic inches in volume (Fig. 1).

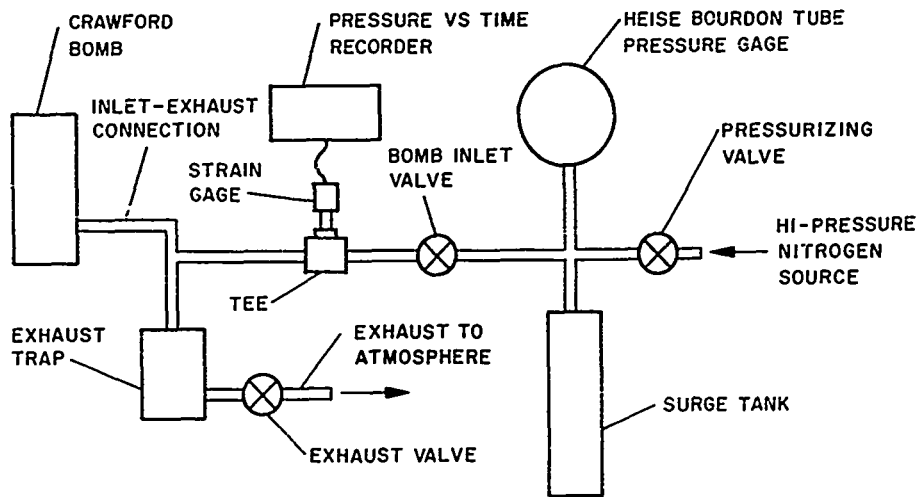


FIG. 1. Schematic Propellant Strand-Burning Equipment.

To measure the bomb pressure, a 1,500-psia full-range unbonded strain gage, Consolidated Electrodynamics Corporation Pressure Transducer Type 4-313-0001, was mounted diaphragm down and 18 inches from the bomb in a "tee" in the high-pressure line leading to the surge tank. The gage was energized by 6 volts DC, and the signal was led to a Heiland galvanometer Type No. v-40-1000, mounted in a Minneapolis Honeywell Model 906 Visicorder Oscillograph. The permanent pressure-time history of the burning strands was recorded on direct writing visicorder paper, 6 inches wide, at a chart speed of 12 inches per minute.

Initial tests were made with strands prepared in the conventional manner (Fig. 2); i. e., drilled, with wires inserted and with a 3,000-psia full range transducer. Conventional timing results were compared to the timing of the pressure pips in the interval $t_1 - t_3$ (Fig. 2). Although results obtained were very comparable (Table 1) it was not

always possible to observe pips with the equipment used, and larger holes had to be drilled to increase the amplitude of the pips to make them more clearly definable. It was found that increasing the hole size also increased the apparent strand-burning rate.

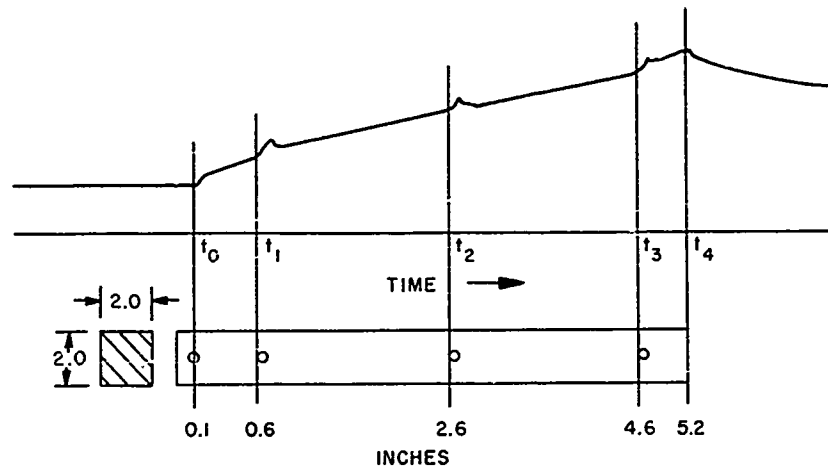


FIG. 2. Strand-Burning Pressure-Time Trace for Standard Type Strand, Drilled for Fuse Wires.

TABLE 1. Comparison of Results of Strand-Burning Rate Tests From Interval Timers and From Pressure-Time Traces

Test no.	Fuse wire hole dia., in.	R_B , std. timer, in/sec	R_B , pressure-time trace, in/sec	Av. test pressure, psig
1	0.032	0.284	0.286	646
2	0.076	0.287	0.289	643
3	0.076	0.415	0.419	1,065
4	0.076	0.416	0.419	1,065

NOTE: The strands had square cross sections, 0.2- x 0.2-in. and consisted of two 2-inch test intervals with an additional 0.6 inch on each end.

After considering that drilling an uninhibited hole of any size in a burning-rate strand must increase the measured burning rate, the desirability of completely eliminating such holes was realized. The

pressure-time method was then tested on strands which had been notched at accurately known intervals. These notches were inhibited as part of the periphery of the strands. They presented a sudden decrease in burning surface area and hence a disturbance in pressure-rise rate which was easily detectable (Fig. 3). Once more, strand-burning rates measured by this method were essentially the same as when measured in the conventional method (Table 2).

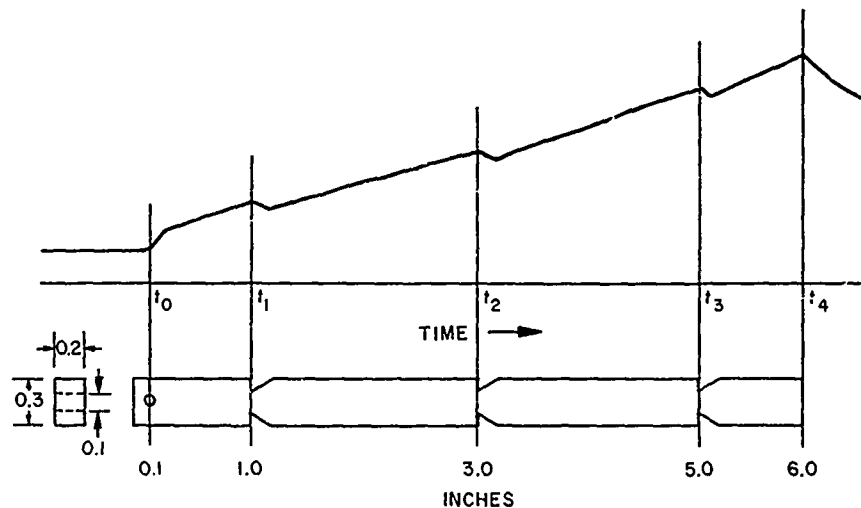


FIG. 3. Strand-Burning Pressure-Time Trace for Notched Strand.

Two other methods of obtaining strand-burning rates from pressure-time traces were tried with some degree of success. Standard strands were "timed" from ignition to burnout on the pressure-time trace (Table 2, Col. 3) with their length being taken from the ignition wire hole to the end of propellant (Fig. 2). This method, in fact, has been commonly used by the Station for obtaining burning rates when propellant types are encountered that yield conductive residue which consistently fouls the interval-timer circuits. The time interval between ignition and burnout can be measured with a stop watch by observing the pressure rise on the Bourdon tube-type pressure gage. The results so obtained are consistent (usually within 0.005 in/sec) and compare to results calculated from clock readings (within 0.010 in/sec) in those instances when the interval timers function properly. Here, of course, it must be assumed that equilibrium burning is obtained from nearly the moment of ignition. From the comparison of results obtained so far, this assumption appears to be valid when 5.2-inch strands or longer are burned.

TABLE 2. Comparison of Different Methods of Measuring Strand-Burning Rates

	Column 1 ^a	Column 2 ^b	Column 3 ^c	
Test no.	R _B , std. timer, in/sec	R _B , pressure-time trace, in/sec	R _B , pressure-time trace, in/sec	Av. test pressure, psig
A. 600 psig initial bomb pressure				
1	0.192	--	0.194	800
2	--	0.187	0.186	775
3	0.188 ^d	--	0.194	790
4	--	0.194	0.195	802
B. 1200 psig initial bomb pressure				
5	0.224	--	0.220	1,430
6	--	0.225	0.224	1,400
7	0.231 ^e	--	0.236	1,415
8	--	0.225	0.225	1,440

^aColumn 1 gives results obtained with the std. fuse-wire technique over two 2-inch intervals.

^bColumn 2 gives results over two similar 2-inch intervals bounded by the shoulders of notches t₁ - t₃ (Fig. 3).

^cColumn 3 gives results over the full 6-inch length of the strand less 0.1-inch ignition wire advance t₀ - t₄ (Fig. 3).

^dClocks stopped momentarily after starting.

^ePressure-time trace revealed abnormally fast burning, beginning approximately 1/3 way through the second time interval.

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	Column 1 ^a	Column 2 ^b	Column 3 ^c	
Test no.	R _B , std. timer, in /sec	R _B , pressure-time trace, in/sec	R _B , pressure-time trace, in/sec	Av. test pressure, psig
C. 500 psig (approx.) initial bomb pressure				
1	0.286	0.290 ^f	0.291 ^g	565
2	0.258	0.264	0.262	542
3	0.258	0.262	0.262	534
4	0.257	0.256	0.262	535
5	0.268	0.269	0.271	545
6	0.272	0.271	0.273	551
7	0.260	0.262	0.263	552
8	0.268	0.271	0.270	554
9	--	0.266	0.267	548
10	0.273	0.275	0.277	548
11	0.280	0.278	0.281	558
12	0.284	0.285	0.285	555
13	0.260	0.262	0.262	549
14	0.266	0.268	0.268	548
Av.	0.268	0.269	0.271	
		$\frac{-0.001^h}{0.268}$		

^fThe strands in this group differed from Fig. 3 as follows: 0.2-x0.2-inch square by 5.2 inches long; 0.1 inch ignition wire advance; clock wire holes at 0.6, 2.6, 4.6 inches; notches of configuration similar to Fig. 3 at 0.8, 2.8 and 4.8 inches.

^gResults over full 5.2 inches of strand less 0.1 inch ignition wire advance to - t₄ (Fig. 3).

^hCorrection due to calculated average pressure of 4 psi higher due to 0.2 inch advance of shoulder over clock wire.

Finally, a "polliwog" configuration was tested (Fig. 4). It was hoped in this case to obtain accurate burning rates when rather short strands were burned (because of limited amounts of material being available). The tests were successful, but the accuracy was limited to 6% of the value, principally due to uncertainty in the length of the test section from $t_1 - t_2$ and chart assessment.

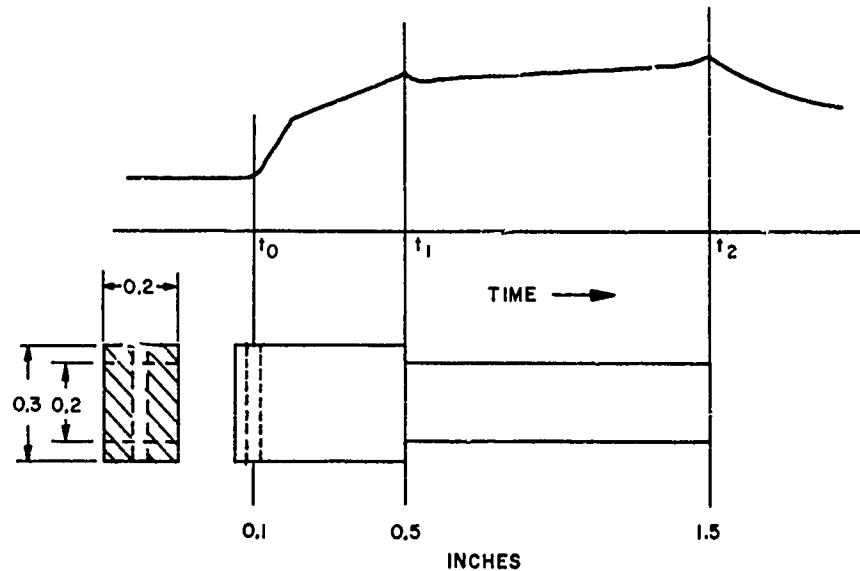


FIG. 4. Strand-Burning Pressure-Time Trace for "Polliwog" Strand.

DISCUSSION

The results of the experiments described in the previous section show that time measurement of pressure disturbances during the burning of a propellant strand, with cross-sectional area variation at known intervals along the strand, is a useful means of accurately obtaining strand-burning rates on a wide variety of propellants. Results obtained show the measurements are comparable to standard techniques. The applicability of the method appears to be quite broad. The new principle involved is that of utilizing pressure disturbances (made to occur at known distances along a strand restricted to burn in one direction) to obtain the elapsed time of burning along a known length, from which the burning rate may be calculated. With ordinary equipment and strands of approximately 5-inch lengths, an accuracy of 1% is readily obtainable. In addition to this accuracy, the method is

believed to have the following advantages over the standard method of timing with fuse wires: (a) reliability; (b) lower cost of maintenance and testing; and (c) safety.

The method is believed to be more reliable because it is more generally applicable and because inhibitor failure can be immediately detected. This is shown in Fig. 5-9 in which pressure-time traces were taken on strands timed with fuse wires in the standard manner.

Figure 5 is a typical curve generated by propellant strands which yielded high and scattered strand-burning rate results. The inhibitor used was a cured polyester which presented problems because of plasticizer migration from the plasticized rubber-composite propellant.

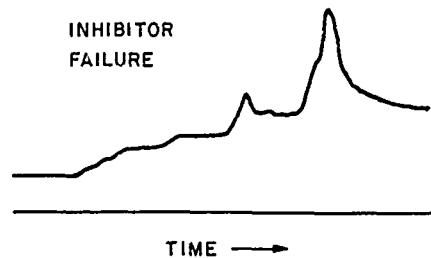


FIG. 5. Pressure-Time Trace of a High Value, Scattered Data Burning Rate Test.

Marginally successful inhibiting is indicated in the pressure-time curves of Fig. 6 which show slightly high and scattered results by the conventional method. These results were obtained when a cured epoxy coating was used to inhibit strands of a composite propellant. Strands from the same propellant batch inhibited with an oil-paraffin mixture burned well, with ranges of approximately 0.003 in/sec between duplicate test results.

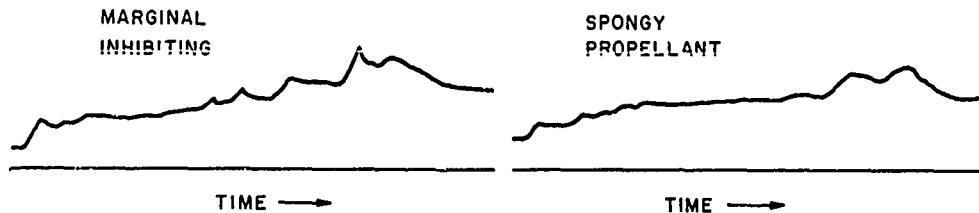


FIG. 6. Pressure-Time Traces of Slightly High, Slightly Scattered Data Burning Rate Tests.

The traces of Fig. 7 are typical of burning strands having identical configuration, the same propellant composition, traced on the same day and given the same initial pressure, but with different inhibitors.

The mineral oil-paraffin inhibitor used here works well on most polyurethane and polybutadiene-acrylic acid type binders of composite propellants of medium energy; i. e., ΔH reaction up to $\approx 1,400$ cal/gram. It often fails with higher energy or plasticized propellants, especially at pressures over 1,000 psig.

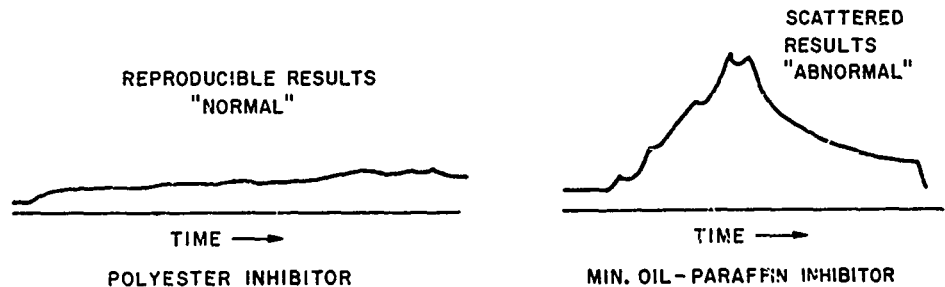


FIG. 7. Pressure-Time Traces Showing Normal and Abnormal Strand-Burning Tests.

The test results in Fig. 8 show marginal success obtained with a different aluminized rubber composite propellant inhibited with polyester. The oil-paraffin inhibitor worked well with this propellant.

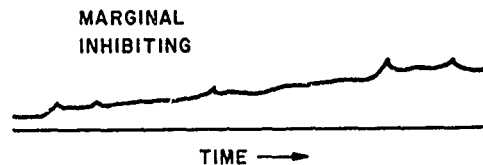


FIG. 8. Pressure-Time Trace From a Strand-Burning Test for a Marginally Inhibited Strand.

The test results in Fig. 9 are from a group of rubber composite propellant strands in which the oil-paraffin inhibitor had worked satisfactorily. The pressure-time method provides a basis for interpretation of unusual results which occur in the strand-burning test.

Propellants have been encountered which form conductive residues on burning which causes the loss of nearly 100% of the data when the fuse-wire method is used in conjunction with electric interval timers. These residues cause no problems with the pressure-time method because no electrical timing circuits are exposed to combustion products. That inhibitor failure can be quickly detected is illustrated in Fig. 7 where a normal burn is contrasted to an abnormal one.

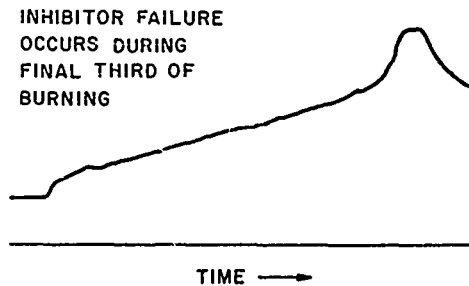


FIG. 9. Pressure-Time Trace
From a Strand-Burning Test
With Late Inhibitor Failure.

The lower cost of maintenance results from the fact that interior electrical circuits are eliminated, except for ignition which is relatively rugged and consists of one wire only. The maintenance of these circuits contributes a large portion to the total maintenance of the strand burner and its supporting equipment. The lower cost of testing results from the fact that only one wire needs to be passed through the strand and attached to the strand holder instead of a minimum of three and often five. The strand may be affixed to the holder by clipping or taping. Also, the time spent in preliminary electrical-continuity checks will be saved and the cleaning of strand holders will be less time consuming. Finally, an estimated 10 to 20% of the total data now lost due to faulty functioning of electrical circuitry will be recovered by the pressure-time technique.

The method is inherently safer because, at the most, only one hole needs to be drilled in the propellant strand. Strands have been successfully tested after being cast and cured in molds which pre-form suitable notches in the strand. Cutting and drilling strands of castable propellants which are particularly hazardous or toxic may be completely eliminated by attaching the ignition wire during casting.

ABSTRACT CARD

U. S. Naval Ordnance Test Station
An Improved Method for the Measurement of Solid-Propellant Strand-Burning Rates in Closed Bombs, by D. H. Stewart and E. L. Moon. China Lake, Calif., NOTS, May 1963. 10 pp. (NAVWEPS Report 8070, NOTS TP 3076), UNCLASSIFIED.

ABSTRACT. A new method for determining propellant strand-burning rates without the use of timing wires has been developed. It was found that when the cross-sectional area of the strand is sharply varied at known intervals, the burning rate

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