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The Hot-Wire Ignition of Secondary Explosives in Squibs

by

Robert J. Reithel

ABSTRACT

Electrically heated platinum bridgewires have been used to ignite secondary explosives in pressure cartridges. These cartridges, containing only RDX or HMX, have been ignited at currents ranging from a fraction of 1 A to over 50 A in times ranging from less than 1 msec to more than 1 sec. HMX-loaded cartridges have functioned after being subjected to a temperature of 190°C for many hours. When subjected to rapid heating, these pressure cartridges did not undergo autoignition until reaching 240°C. The safe current, i.e., that current to which the bridgewire may be subjected for 1 min without igniting the explosive, of these pressure cartridges may be adjusted to values as large as 10 A by an appropriate choice of the bridgewire diameter. The pressure cartridges may be converted to detonators by using the evolved gases to drive a flying plate against a second charge of secondary explosive.

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INTRODUCTION

Squibs, i.e., small pyrotechnic or explosive devices, usually contain a quantity of some primary explosive. This report describes the development of a pressure cartridge containing only a secondary explosive (RDX: Cyclotrimethylenetrinitramine[1] or HMX: Cyclotetramethylenetetranitramine, see Ref. 1, pp. 129-134) which is ignited by an electrically heated bridgewire. Experiments showed that the necessary conditions for the operation of this pressure cartridge were: (1) sufficient confinement to support that threshold pressure required for a self-propagating deflagration in the pressed pellet of granular explosive and (2) a source of heat of sufficient temperature and persistence to decompose enough of the explosive to attain that threshold pressure within the heated volume of the explosive. Pressing the explosive to a high density (1.65 g/cm^3 or $\sim$0.9 crystal density) decreases the amount of decomposition required by reducing the interstitial volume. Furthermore, it seems reasonable that the reduced permeability of the explosive resulting from increasing the density contributes to an increase of interstitial decomposition gas pressure in the immediate vicinity of the heat source.

The effect of pressure in accelerating the deflagration of explosives has been discussed in a review article by Kistiakowsky.[2] While pertinent data are not presently available for RDX and HMX, appropriate experiments were performed during the development of a pressure cartridge with a different secondary explosive. This study showed that a threshold pressure exists for the self-propagating deflagration of a pressed pellet of granular PETN (Pentaerythritol

Tetranitrate, see Ref. 1, pp. 192-197) ignited by an electrical arc formed upon the vaporization of a 0.0015-in.-diam gold bridgewire. This experiment[3] demonstrated the existence of the threshold pressure. The explosive pellet was enclosed in a container of many times the volume of the explosive pellet, and a nitrogen gas tank was attached to the container. Attempts were made to secure the deflagration of successive pellets as a function of the initial pressure of the gas in the container. Attempts made at pressures below 525 psig resulted in most of the PETN being scattered as an unburned powder; attempts made at pressures above this value resulted in the deflagration of the entire pressing.

A second experiment on arc ignition, also described in Ref. 3, showed that increasing the density of PETN from 0.7 to 1.6 g/cm^3 decreased from 130 to 8 V the minimum voltage of a charged capacitor required to establish an arc capable of effecting a self-propagating deflagration in a sealed container filled with the explosive. For this experiment the interstitial gas in the sealed container was initially at ambient pressure. Various experiments on hot-wire ignition of pressed pellets of PETN, RDX, and HMX lead to the belief that all exhibit similar behavior in ignition to a self-propagating deflagration by a heat source. Therefore, it appears reasonable to predict that the factors governing the arc ignition of PETN also govern the hot-wire ignition of RDX and HMX, although the numerical values may differ.

This report is the result of a research and development project intended to show the feasibility of using only secondary explosives in pressure cartridges. Problems of the reliability of the device and the reproducibility of such parameters as the operating time as a function of bridgewire current and the pressure developed by the cartridge were not studied. During the course of the project, bridgewires of several materials, shapes, and sizes were studied. Several explosives were tested, and several cartridge configurations were used. This report is concerned with two of the explosives (RDX and HMX), two similar cartridge configurations, bridgewires of only one material (platinum), one length (0.100 in.), one shape (straight), and of several diameters. The errors associated with the data of this report are those normal to the instrumentation. Since each datum point on the graphs is the result of the firing of only one pressure cartridge per point, a statistical error analysis is not included.

The pressure cartridge assemblies and the instrumentation used to study their behavior are also described. The effect of the bridgewire diameter on the operating time as a function of the applied current is discussed. The manner in which the cartridges are affected by temperature extremes is shown. The gas output of the pressure cartridge is considered both as to the shape of the pressure pulse and the maximum pressure developed as a function of the weight of the explosive charge. Finally, a method is described for conversion of the pressure cartridge to a detonator by using the gas to drive a flying plate in the manner of the Savitt, Stresau, and Weber detonator.[4]

EXPERIMENTAL ARRANGEMENTS

Pressure Cartridge Assemblies

Two experimental pressure cartridge assemblies were used. The component parts of the Type 1 pressure cartridge shown in Fig. 1 were retained by glue in a Type 303 stainless steel cylinder. The platinum bridgewire was soldered to the 24 gage soft copper wire electrodes against the surface of the plastic (D.A.P., short glass fiber-filled) head. After threading the electrodes through the holes in the steel case, the head was pressed into place so that the potting compound (Epon 828-Versamid glue, 2-1, plus Monsanto Mod-Epox accelerator) flowed up around the side of the head and thus sealed the channel between the case and the head. When this assembly was dry, the explosive charge was pressed into the 0.278-in.-diam well to a depth of

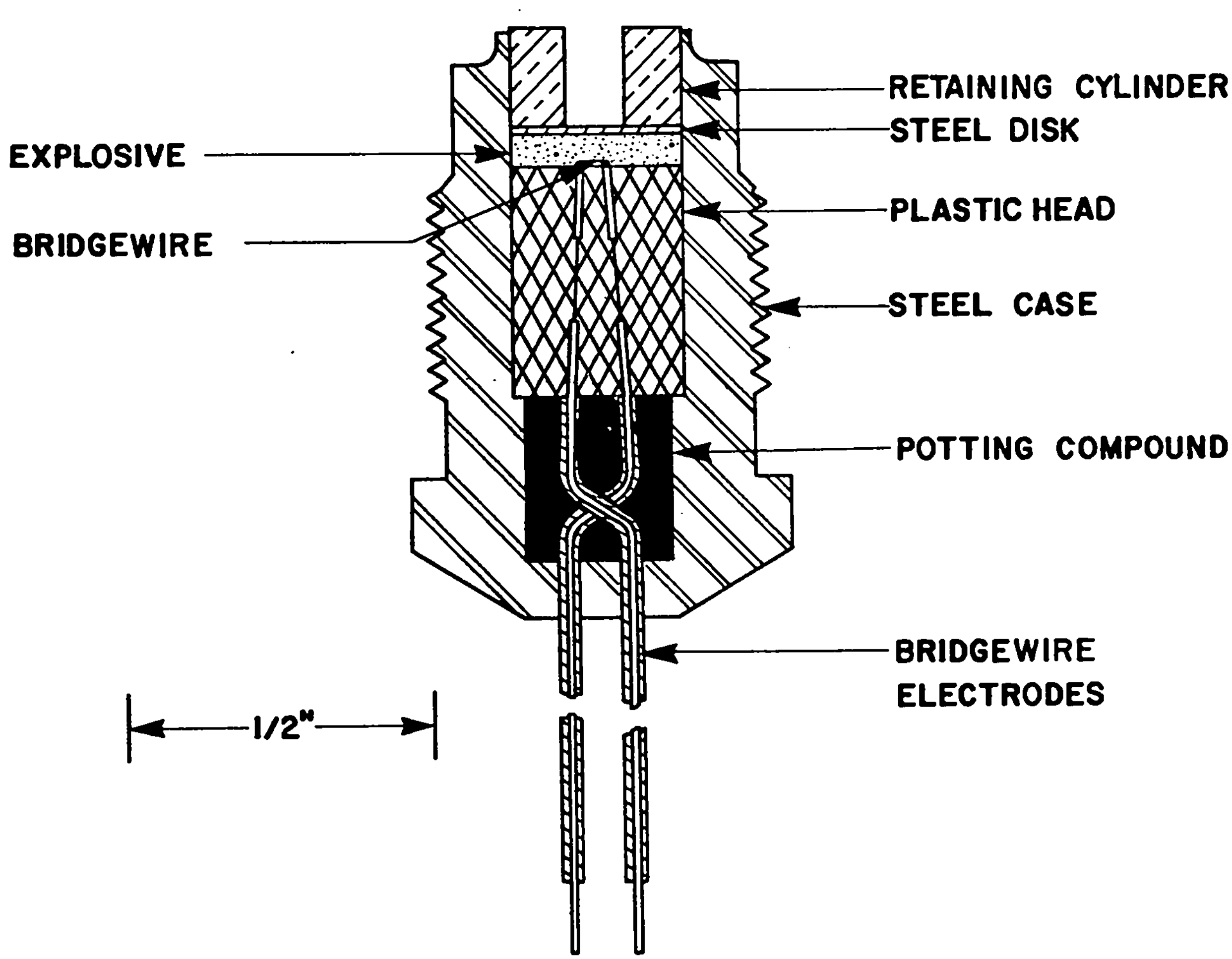

Fig. 1. Type 1 experimental pressure cartridge.

0.050 in. and to the desired density. A stainless steel disk of 0.005-in. thickness was placed upon the charge, and a brass retaining cylinder of 0.094-in. i.d. was glued to the disk and to the wall of the steel case with the same Versamid mixture as that used to seal the head.

The Type 1 assembly proved to be satisfactory at both ambient and dry-ice temperatures; however, the adhesive used to fix the retaining cylinder in place failed during experiments at high temperature. It was impossible to heat the cartridge to the point of auto-ignition, because the threshold pressure required for self-propagating deflagration of the explosive could not be attained.

The Type 2 pressure cartridge shown in Fig. 2 was designed with a threaded construction that provided a sufficiently strong mechanical seal of the explosive chamber at elevated temperature to allow heating to the point of auto-ignition. This design change resulted in a new explosive well diameter of 0.200 in., and the length was increased to 0.092 in. in order to provide the same well volume as that of the Type 1 cartridge.

Explosive Charges

RDX

Class A RDX of 99.3% purity was precipitated by the addition of a solution of RDX-dimethylsulfoxide to water. The permeametric specific surface, S_o^P, of the explosive obtained was 3520 cm^2/g. The crystal density of RDX is 1.82 g/cm^3. A quantity of RDX weighing 78 mg was pressed into the explosive well described above. This resulted in an RDX density of 1.65 g/cm^3 for both the Type 1 and the Type 2 pressure cartridges.

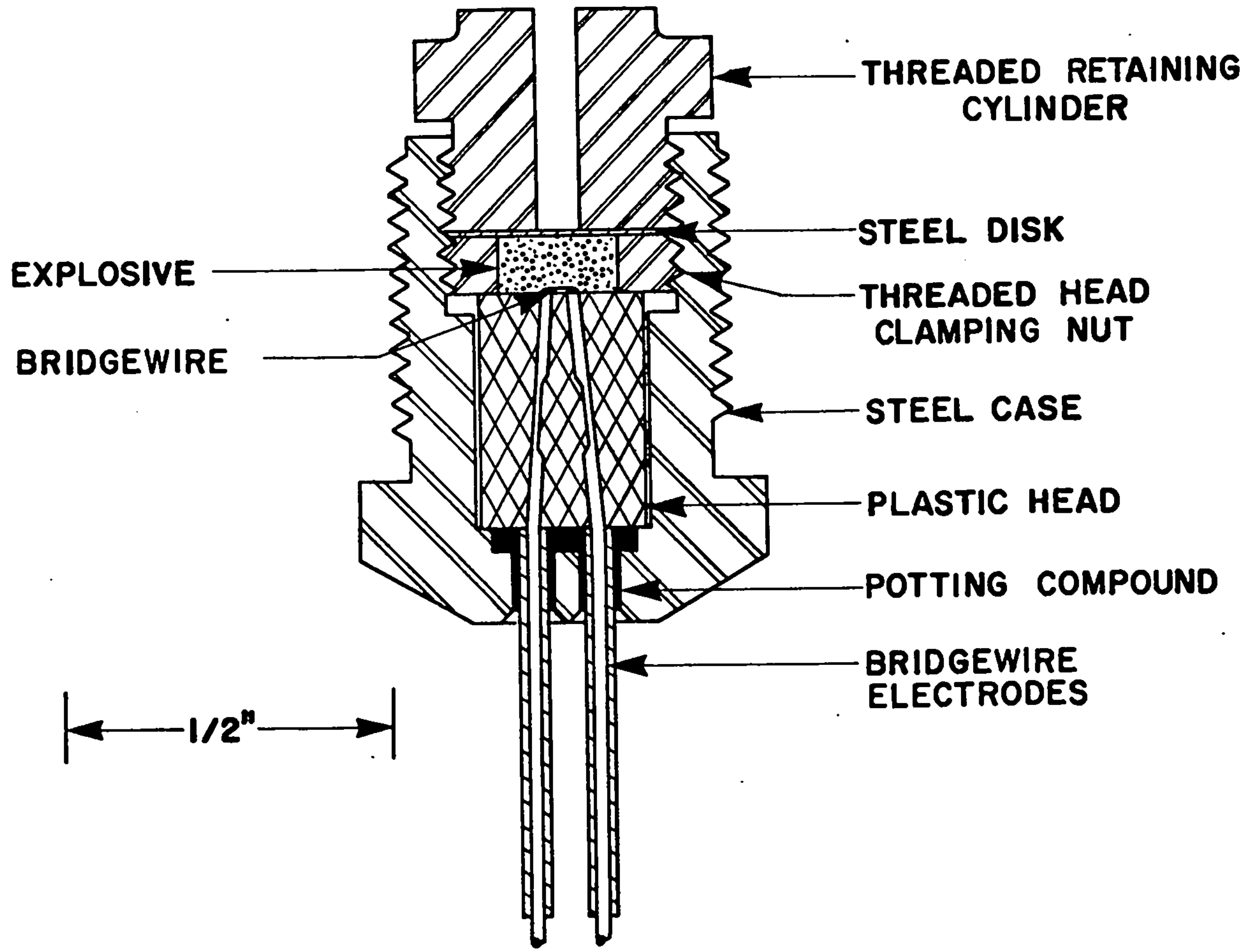

Fig. 2. Type 2 experimental pressure cartridge.

HMX

Regular production β-phase HMX, recrystallized from acetone, was subjected to two hot-water extractions by the Holston Defense Corporation of Kingsport, Tenn. The resulting material had a purity of 99.86% and an S_o^P of 786 cm^2/g. Two samples of this HMX were ball-milled to obtain S_o^P values of 1316 and 3338 cm^2/g. The crystal density of β-phase HMX is 1.91 g/cm^3. A pressing density of 1.60 g/cm^3 was chosen for both the Type 1 and the Type 2 pressure cartridges for reasons discussed below in the section describing high temperature experiments.

EXPERIMENTS

The Effect of the Bridgewire Diameter

Type 2 pressure cartridges were constructed using platinum bridgewires of 0.100-in. length and of various diameters ranging from 0.0005 to 0.008 in. The cartridges were loaded with either RDX or HMX as described above. These assemblies were fired by a lead storage battery source through an external circuit of 1-μH inductance. The resistance of the circuit and the voltage of the source were adjusted in order to provide a desired current through a dummy load of approximately the same resistance as the bridgewire being tested. The pressure cartridge was then substituted for the dummy load and fired by closing a mercury switch, which was held closed until the explosive ignited (breaking the bridgewire and terminating the pulse) or until one minute had elapsed. The current through the bridgewire was measured with a T&M Research Products Model L-31-.03 current-viewing resistor and a Type 555, Tektronix oscilloscope. The voltage across the bridgewire was also recorded on the oscilloscope. Thus the current, the voltage, the resistance of the wire, and the electrical energy supplied to the wire could be determined for each bridgewire for any time during the current pulse. The response of the firing circuit was sufficiently rapid that the current was applied to the wire essentially as a step function on the time scale required for a successful ignition. The current, thereafter, decreased and the voltage across the wire increased as the heating of the wire produced an increase in resistance. The change in resistance varied from an increase by a factor of more than two (for 0.0005-in.-diam wires subjected to the larger of the currents used with this wire) to a barely perceptible increase (for wires of 0.008-in. diam carrying the smaller of the currents used with this larger wire). It seems sufficient for developmental purposes to characterize the behavior of the pressure cartridge by the duration of the current pulse through the bridgewire, by the amplitude of the current measured at the midpoint of the pulse duration, and by the success or failure of the bridgewire to ignite the explosive. Ignition was considered to be successful if the disk retaining the explosive was ruptured and if no unburned explosive could be detected after the event.

RDX

Figure 3 shows the duration of the current pulse as a function of current amplitude for various diameter platinum bridgewires in RDX. Each point represents the behavior of only one pressure cartridge. All points represent successful operation, or firing of the cartridges. Failures were not plotted since the current continued until terminated by the switch.

HMX

Figures 4a and 4b contain data obtained for HMX in the manner described above for RDX. These data show that it is possible to cause a pressure cartridge to fail to operate by passing too much current through the bridgewire. Such failures occur when the current is sufficient to melt the bridgewire and, thus, to interrupt itself before a sufficient quantity of HMX is decomposed to propagate a deflagration. Similar results have been described by Griffiths, Rowson, and Quarry.[5] This limiting current for the functioning of a bridgewire of a given

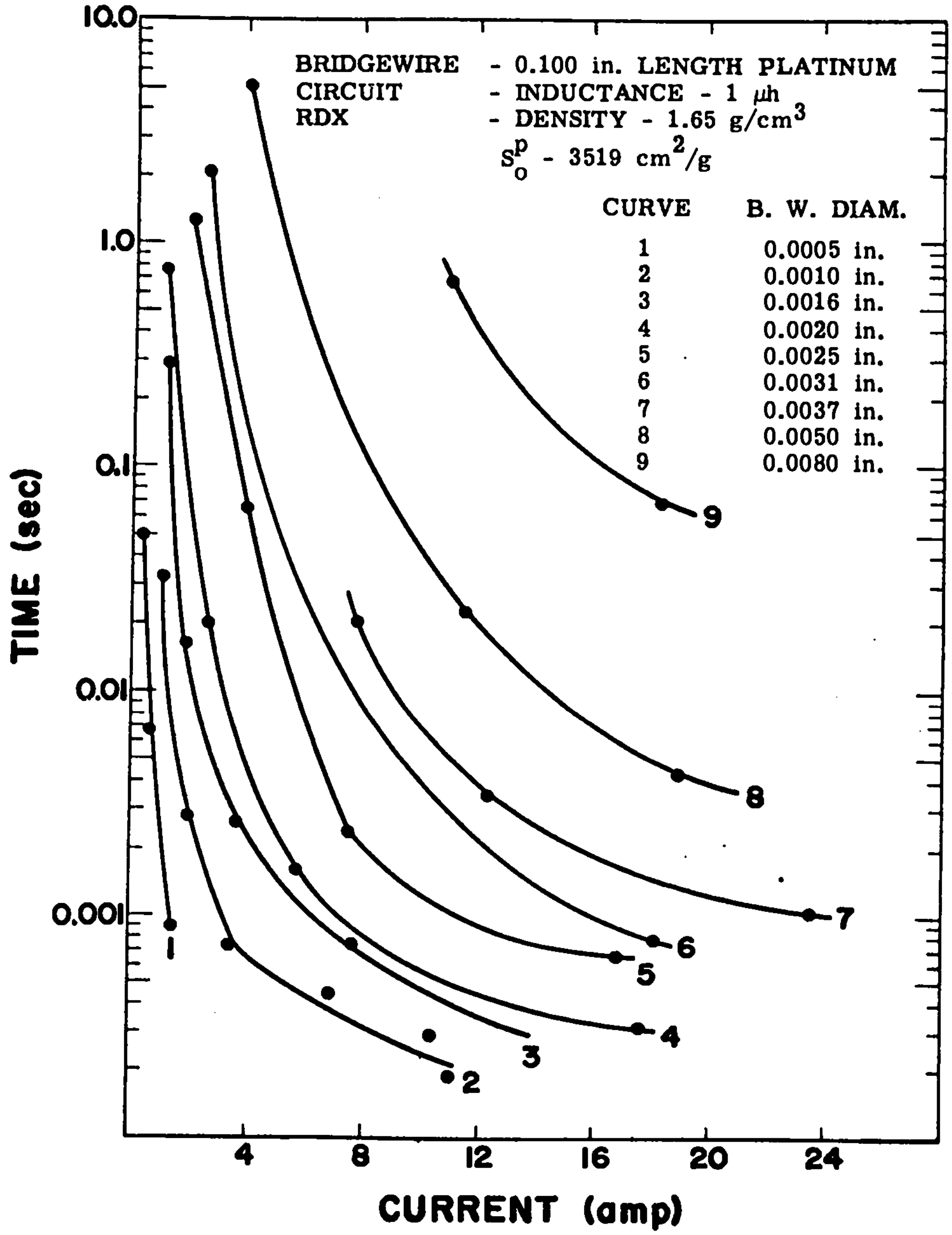

Fig. 3. Current versus current duration for hot-wire ignition of RDX in a Type 2 pressure cartridge.

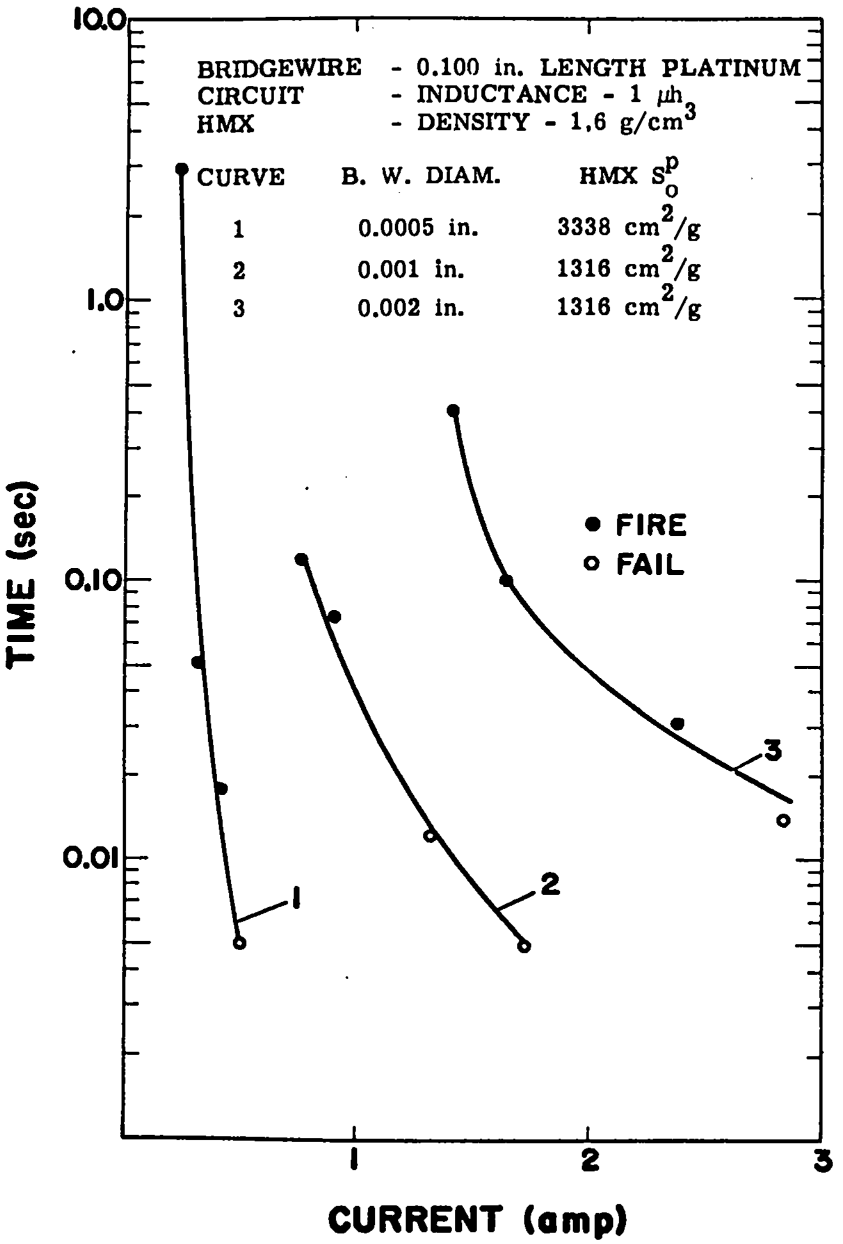

Fig. 4a. Current versus current duration for hot-wire ignition of HMX in a Type 2 pressure cartridge.

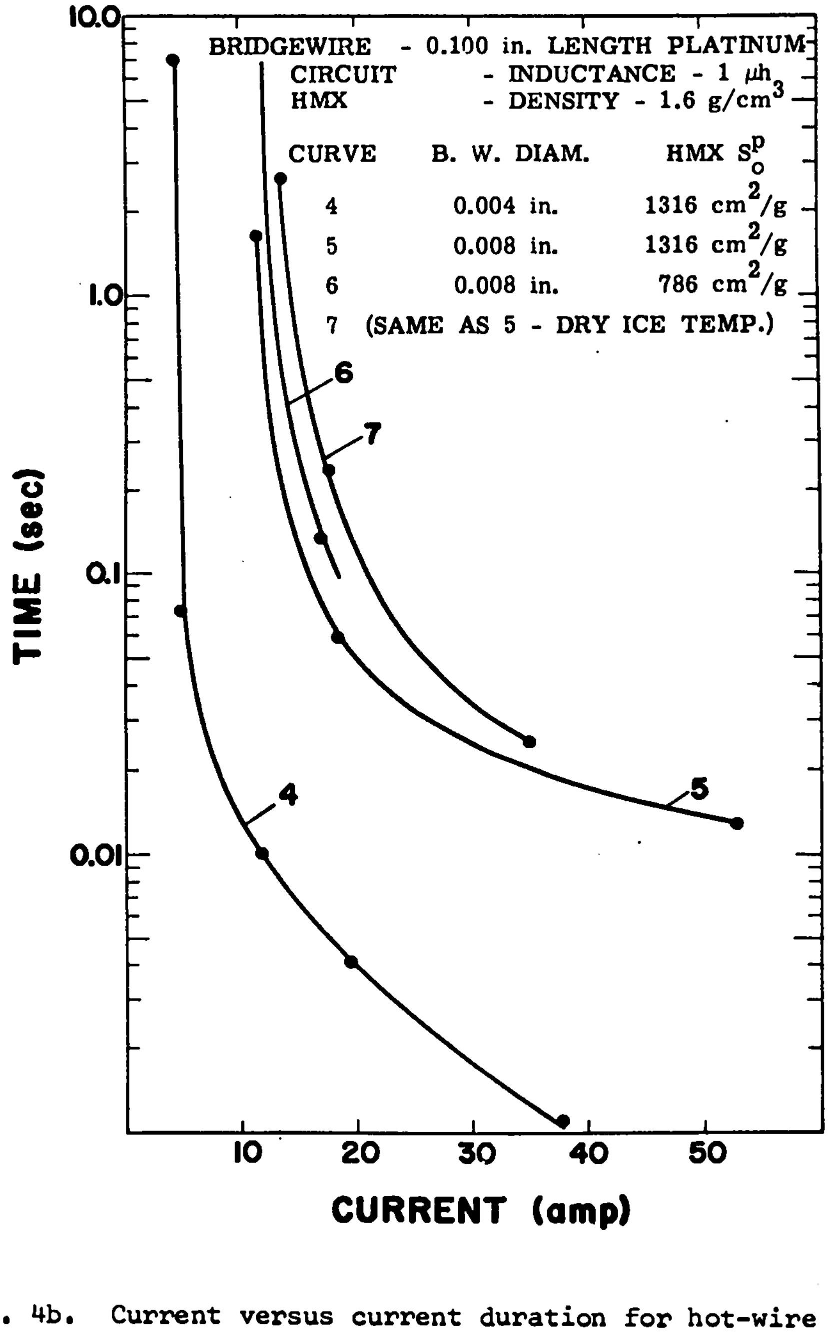

Fig. 4b. Current versus current duration for hot-wire ignition of HMX in a Type 2 pressure cartridge.

diameter will be termed the maximum firing current for that diameter wire; the tests of RDX were not sufficiently extensive to enter limiting current phenomena.

Ignition Energy

Since both the currents through and the voltages across the bridgewires were recorded as functions of time for each pressure cartridge firing, the electrical energy required for ignition of the explosive could be calculated in each case. A few values for extremes of bridgewire diameters and firing currents used to ignite HMX are listed in Table I.

Table I. Electrical Energy Required by Selected Platinum Bridgewires in Order to Ignite HMX in Representative Times

Bridgewire Diameter (in.)	Current (A)	Pulse Duration (sec)	Power (W)	Energy (J)
0.0005	0.42	0.018	1.05	0.019
0.0005	0.23	3.000	0.18	0.540
0.008	53.0	0.013	189.0	2.46
0.008	10.6	1.600	17.05	27.3

The Effect of Temperature

Low Temperature

The results of firing HMX in pressure cartridges at the temperature of dry ice is shown in Fig. 4b. The time required for any particular current to successfully ignite the explosive is increased by reducing the temperature. This places a lower limit on the choice of bridgewire diameter if reliable firing at reduced temperature is to be achieved, since operation at low temperature requires a higher current to obtain ignition in a given time than does operation at ambient temperature.

High Temperature

A Type 2 HMX-loaded pressure cartridge has been fired successfully at ambient temperature after having been maintained at 190°C for 24 hr. RDX-loaded cartridges will function after being maintained at 175°C for the same period. Neither will operate after being held at 200°C for only 30 min. The β to δ phase transition which occurs in HMX at approximately 175°C makes it necessary to limit the charge density for explosive assemblies that may be subjected to increased temperatures. The expansion accompanying this phase transition (crystal density changes from 1.91 to 1.80 g/cm^3) was sufficient to rupture the steel explosive retaining disk when the HMX was pressed to an initial density of 1.7 g/cm^3 (89% crystal density). For this reason subsequent tests of HMX were performed at a density of 1.6 g/cm^3. At this density the phase transition did not rupture the retaining disk.

Temperature for Auto-ignition

Pressure cartridges of Types 1 and 2 loaded with RDX and HMX were tested to determine the temperature necessary to cause auto-ignition. Squibs loaded with lead styphnate and ball powder* were included for comparison. The items were heated in an oven at a rate of approximately 2.5°C/min. All squibs containing lead styphnate suffered auto-ignition in a temperature range of 159° to 172°C. Two RDX- and two HMX-loaded Type 1 pressure cartridges failed to ignite when subjected to temperatures between 216° and 278°C, because the adhesive fixing the retaining cylinder in place failed to maintain a gas-tight seal. Two RDX-loaded Type 2 pressure cartridges fired by auto-ignition at temperatures of 208° and 214°C. Two HMX-loaded Type 2 assemblies fired at 240° and 243°C. It may be seen that the necessity for tight

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*These squibs were of similar external configuration to the pressure cartridges. Each squib contained 25 mg of lead styphnate and 175 mg of ball powder.

confinement might be used in order to design a pressure cartridge with inherent safety to auto-ignition by providing an explosive enclosure that would vent itself before attaining the necessary temperature for auto-ignition.

The Pressure Pulse Generated by RDX and HMX

The pressure pulse generated by an RDX charge in a pressure cartridge, Type 1, is graphically compared to that produced by a squib containing lead styphnate and ball powder in Fig. 5. The devices were fired into a standard test chamber of 0.035-in.^{3} volume. A Model PZ-14, Kistler SLM Pressure Pickup equipped with a force adaptor to achieve a range of 0 to 30,000 psig was used to measure the pressure in the test chamber. The principal difference in the two graphs lies in the very rapid increase of pressure developed by the RDX as compared to the rate of pressure increase generated by the lead styphnate-ball powder charge.

Table II lists the pressure maxima measured by the transducer for various quantities of RDX and HMX in Type 1 pressure cartridges. These values by no means exhaust the available pressure range, which may be extended by further adjustment of the quantity of explosive.

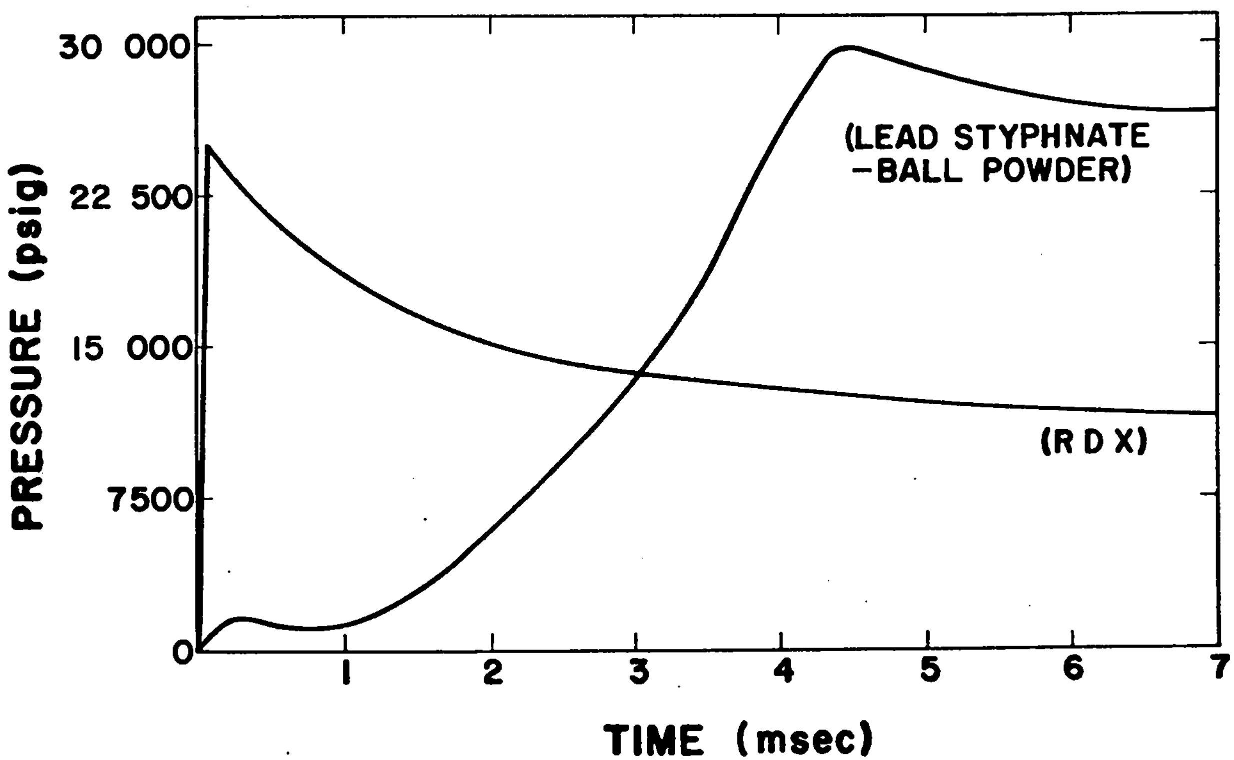

Fig. 5. Pressure behavior of a squib containing lead styphnate and ball powder and of the Type 1 pressure cartridge containing RDX. (Time was measured from the beginning of the pressure transducer pulse.)

Table II. Pressure Generated by Various Quantities of RDX and HMX in Type 1 Pressure Cartridges

Density (g/cm^3)	Weight (mg)	Pressure (psig)	
		RDX	HMX
1.2	59.6	12 400	13 600
1.4	69.5	17 000	13 200[a]
1.6	79.5	23 900	19 400

[a] A possible case of incomplete deflagration.

Conversion to a Detonator

Several of the Type 2 pressure cartridges were converted to detonators in the manner of the Savitt, Stresau, and Weber detonator by substituting a Mild Detonating Fuze (MDF) adaptor for the threaded retaining cylinder. This adaptor resembled the cylinder except that the inside diameter of the cylinder was changed to fit the outside diameter of a length of MDF containing 5 grains/ft of PETN. The end of the adaptor adjacent to the steel disk used to retain the explosive charge in the pressure cartridge was axially counterbored to a depth and diameter of 0.125 in. Any desired length of MDF was glued into the end of the adaptor opposite the steel disk, so that the end of the MDF protruded about 0.0005 in. into the counterbored space. Thus, when the pressure cartridge was fired, the steel disk ruptured along the circumference of the counterbored space in the adaptor, and the resulting flying plate was propelled across the space by the high-pressure gas. The impact of this flying plate detonated the MDF.

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