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Technical Report 32-1534

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Preface

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Abstract

An apparatus based on the use of a half-sine wave current pulse for electroexplosive device firing is presented. Energy for adiabatic firing can be readily measured. Theory and equations of energy transfer are developed. The application to measurements on certain insensitive electroexplosive devices is presented as an example of capabilities.

Half-Sine Wave Pulse Firing of Electroexplosive Devices

I. Introduction

The energy necessary to adiabatically fire an electroexplosive device (EED) is an important characterization parameter. This mode of firing corresponds to delivering the energy in a time that is short compared to the thermal time constant in order that heat diffusion and loss to the explosive environment surrounding the hot bridgewire are at a minimum. Practical firing systems, in most cases, operate in an adiabatic manner by using the discharge of the energy stored in a capacitor. An accurate measurement of this energy provides a useful sensitivity parameter which can be used in the design of any impulsive firing system.

Many fast energy waveforms are capable of meeting the test requirements. Consider capacitor-discharge waveforms which actually simulate the practical firing system. The energy stored in a capacitor C is $CV^2/2$ where V is in volts and the energy is in joules (i.e., watt-seconds). To deliver this energy with high efficiency, the switch employed for discharge must close in zero time, the capacitor must offer only a small surge resistance, and lead losses must be kept low. With insensitive electroexplosive devices, requiring the transfer of larger energies, all components must have appropriate impulsive ratings. For example, an insensitive item rated at 100 mJ and 1-Ω resistance would require a 10 μF capacitor charged to 141 V to deliver the energy. The surge current would be 141 A, and the discharge time constant would be 10 μs. There are obvious problems in preserving the initial rise time of the current waveform, which would be over 10^8 A/s. Circuit loop inductance would inhibit the rapid delivery of energy. If the capacitor size is increased by a factor of 10 to 100 μF, currents are reduced by only $1/\sqrt{10}$. Larger capacitors reduce the current but generally have higher internal resistances and tend to draw out the exponential discharge region. It is desirable to terminate the energy flow abruptly and avoid extending into the cooling region.

In spite of the problems indicated, the use of high-quality capacitors, mercury discharge switches, and good engineering design and layout have made this capacitor discharge testing method very satisfactory and acceptable. In extending this method to the higher energy levels, increased problems are to be anticipated and, hence, other techniques are to be considered.

As an alternative, consider the use of solid-state switches capable of generating rectangular pulse waveforms. Switching losses will still exist, and the fast rise times will generally be deteriorated in the transfer to the EED. In testing any live explosive component, the item must be in an appropriate explosive enclosure (i.e., firing chamber) and energy is delivered by wire leads through safety interlock switches. Transistor switching will, in general, require a certain amount of auxiliary pulse forming equipment, and this entire procedure for impulsive energy delivery is not attractive.

This report is concerned with the use of a half-sine wave pulse form to fire an EED (Refs. 1, 2). This waveform is easily generated and not distorted by series inductance and resistance. There is a finite rise and fall time which will not be easily degraded, and the energy content can be continuously varied and readily calculated. The apparatus employed to generate the energy burst will be described, followed by a theoretical discussion of transferred energy. A final section will deal with certain experimental observations.

II. Pulse Generation

A complete circuit diagram for the half-sine wave pulse generator is shown in Fig. 1a, and Fig. 1b shows the discharge loop and associated waveform. The power supply is conventional and provides 350 Vdc to charge the capacitor. This voltage limits the energy capability of the set and, based on the thyristor ratings (i.e., blocking voltage), could be increased. The actual capacitor voltage is established by the set level potentiometer and monitored by the meter M, which is converted to a 0 to 500 V voltmeter. Resistor R_1 in the charge circuit limits the charging current rate at the maximum set point and isolates the discharge circuit from the dc charging source.

With thyristor (or silicon-controlled rectifier) T_1 in a blocked condition, the capacitor C will charge to the predetermined level. The discharge loop consists of the capacitor C, the inductor L, the thyristor T_1, and the EED (R_0) under test. A suitable capacitor for surge or rapid discharge is the "commutating" variety; the common filter-type is to be avoided. A low dissipation factor is a good criterion of performance, and typical voltage ratings are

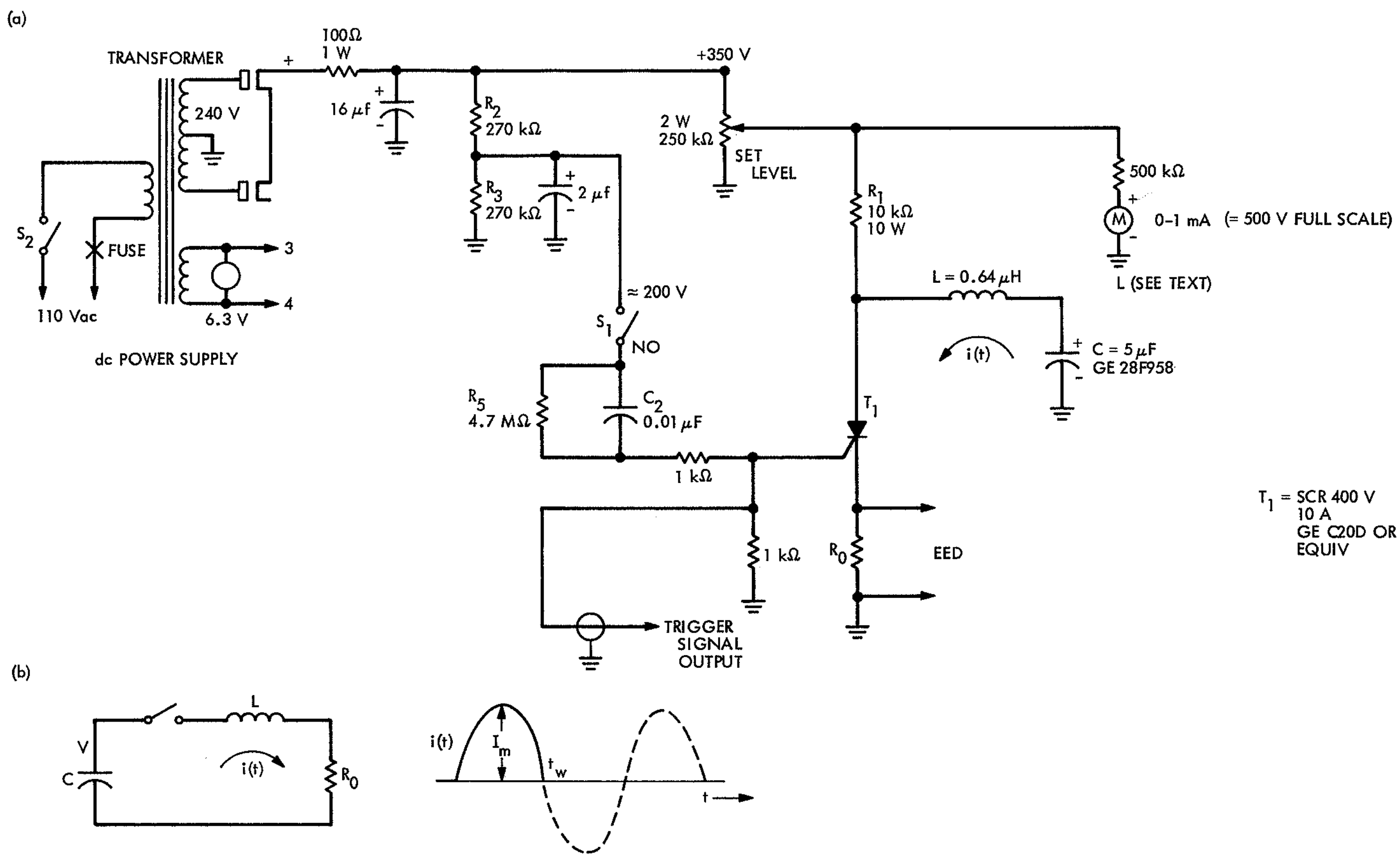


Fig. 1. Complete pulse generator: (a) circuit diagram, (b) discharge loop and waveform

600 Vdc. The inductor is specially wound for reasonable Q and low resistance. For example, the largest coil used consisted of 60 turns of No. 10 wire, 15.24 cm (6 in.) in diameter, with 5 layers of 12 turns each. At 1 kHz the Q was 23, the inductance 0.64 mH, and the resistance 0.175 Ω (ac equivalent). Note that the inductor experiences the peak capacitor voltage upon discharge.

The discharge is initiated by firing T_1. By means of the divider network R_2–R_3, a current limited trigger pulse can be applied to the gate circuit upon closing the microswitch S_1. The charging of C_2 generates a gate pulse at T_1. Since C_2 can only discharge or recover through R_5, misfiring due to contact bounce is avoided. The gate trigger pulse is made available for an oscilloscope trigger signal and, therefore, the complete discharge into R_0 can be displayed.

The discharge current waveform is shown in Fig. 1b and is the classical underdamped sinusoid. However, since the thyristor cannot conduct in the reverse direction, it is commutated *off* after the first half cycle. Recharging of the capacitor back up to the initial level commences, and the circuit is ready for the next firing. The energy lost in the capacitor is delivered to the circuit resistive components of which a major portion is the EED (R_0).

By monitoring the voltage waveform across the EED load, it is a simple calculation to determine the energy delivered. These calculations will be considered in the next section.

III. Energy Calculations

The discharge of a charged capacitor into an R–L circuit has the classical solution (Ref. 3):

$$i = \frac{V}{LN} e^{-mt} \sin Nt \tag{1}$$

where V is the initial capacitor voltage, L the circuit inductance and

$$N = \left(\frac{1}{LC} - \frac{R^2}{4L^2}\right)^{1/2} \tag{1a}$$

$$m = \frac{R}{2L} \tag{1b}$$

A sketch of the waveshape is shown in Fig. 2 for a realistic condition of damping. The presence of damping reduces the observed maximum current, shifts the maximum to the left of $\pi/2$, i.e., 1.57 rad (90 deg), and destroys the quarter-wave symmetry. These alterations in waveform must be accounted for in any energy determination. If damping is ignored or $R \rightarrow 0$, then Eq. (1) becomes

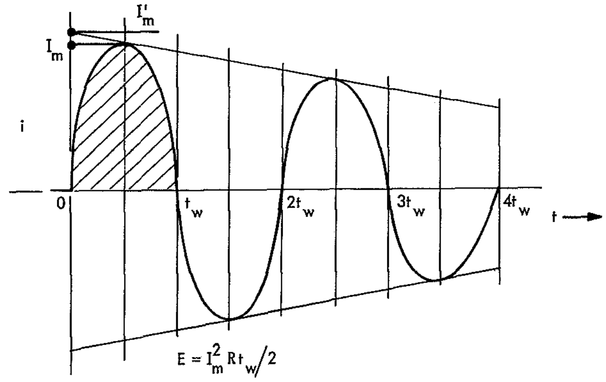


Fig. 2. Idealized discharge waveform

$$i = \left(\frac{V}{\sqrt{L/C}}\right) \sin \frac{t}{\sqrt{LC}} \tag{2}$$

The ultimate peak current I'_m is given as

$$I'_m = \frac{V}{\sqrt{L/C}} \tag{2a}$$

and an idealized natural frequency ω_0 is

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{2b}$$

From Eq. (1a), the true frequency N can be related to ω_0 according to

$$N = \omega_0 \sqrt{1 - \frac{1}{4Q^2}} \tag{2c}$$

where Q (the circuit Q) is defined as $Q = \omega_0 L/R$. If discussions are limited to Q values of five or more it can be seen that there is little difference between the ideal lossless frequency and the actual frequency (i.e., if $Q = 5$; $N = \omega_0 (0.995)$.

In a similar manner, for a reasonable Q, the nominal peak current is for all practical purposes I'_m. However, with damping the peak is *never seen* until the first maximum occurs in the vicinity of $\pi/2$. For example, Eq. (1b) can be written as $m = \omega_0/2Q$. The exponential time term has a value in this region of

$$\exp\left(-\frac{\omega_0}{2Q}\frac{t_w}{2}\right) = e^{-\pi/4Q} \tag{3}$$

Thus with a $Q = 5$, the ideal current amplitude (I'_m) is down by 15% corresponding to the energy being down by 30% based on the use of the theoretical current oscillation amplitude.

It can be shown that the true maximum current corresponds to a time (t_m)

$$t_m = \frac{1}{N}\tan^{-1}\left(\frac{N}{m}\right) \tag{4}$$

By a substitution it can be shown that

$$t_m = \frac{1}{\omega_0\sqrt{1-\frac{1}{4}Q^2}}\tan^{-1}\sqrt{4Q^2-1} \tag{4a}$$

For reasonable Q values and using the expansion

$$\tan^{-1}X = \frac{\pi}{2} - \frac{1}{X} + \frac{1}{3X^3}\cdots$$

where X is large ($X \cong 2Q$) the location of the maximum is

$$\begin{aligned} t_m &= \frac{1}{\omega_0}\left\{\frac{\pi}{2} - \frac{1}{2Q}\cdots\right\} \\ &= \frac{\pi}{2\omega_0}\left\{1 - \frac{1}{\pi Q}\right\} \end{aligned} \tag{4b}$$

Since $\pi/2\omega_0$ is the quarter-cycle point, the maximum is earlier by $(100/\pi Q)$%. For example, a Q of 5 would result in a maximum shift of 6.5% earlier in time. Thus the quarter-wave symmetry is upset.

Returning to the actual energy calculations for the energy delivery to a resistor R_0, assume an ideal sine wave with quarter-wave symmetry. The energy E is given as

$$E_1 = \frac{I_m^2 R_0 t_w}{2} \tag{5}$$

where t_w is the pulse width and I_m is the *observed* maximum.

If the pulse amplitude is reduced according to

$$\exp\left(\frac{-mt_w}{2}\right)$$

retaining the symmetrical shape and starting with Eq. (1) with moderate Q conditions, the result is

$$E_2 = \left(\frac{V}{\sqrt{L/C}}\right)^2 e^{-\pi/2Q}\frac{R_0 t_w}{2} \tag{6}$$

$$= \frac{1}{2}CV^2 e^{-\pi/2Q}\left(\frac{\pi}{Q}\right) \tag{6a}$$

In this expression the observed current is considered the ideal current $I'_m = V/\sqrt{L/C}$ reduced by the exponential term $e^{-\pi/4Q}$. Thus Eq. (6) is the energy transferred based on the observed current maximum assuming that the maximum follows:

$$I_m = \frac{V}{\sqrt{L/C}}e^{-\pi/4Q} \tag{6b}$$

This will be compared to the true energy transferred based on

$$E = \int_0^{t_w=\pi/\omega_0}\left[\frac{V}{LN}e^{-mt}\sin\omega t\right]^2 R\,dt$$

The result of integration with the limits indicated is

$$E_3 = \frac{1}{2}CV^2\left[1 - e^{-\pi/Q}\right] \tag{7}$$

where $Q = \omega_0 L/R$, and all the resistance is contained in the load. This expression clearly shows the fraction of the energy stored in the capacitor ($1/2\,CV^2$) which ends up in the load. Equation (7) must be compared to 5 and 6. By extracting factor $e^{-\pi/2Q}$

$$E_3 = CV^2 e^{-\pi/2Q}\sinh\frac{\pi}{2Q} \tag{7a}$$

Expanding the $\sinh^{-1}$, the result is

$$E_3 = CV^2 e^{-\pi/2Q}\left[\frac{\pi}{2Q} + \left(\frac{\pi}{2Q}\right)^3\frac{1}{3!} + \left(\frac{\pi}{2Q}\right)^5\frac{1}{5!}\cdots\right] \tag{7b}$$

using only the first two terms

$$E_3 = \frac{CV^2 e^{-\pi/2Q} \pi}{2Q} \left[1 + \left(\frac{\pi}{2Q} \right)^2 \frac{1}{6} \cdots \right] \tag{7c}$$

Compare this result with that of Eq. (6a). For a Q of 5, the correction term is 1.017 or the true energy is 1.7% higher. The energy term can be altered substituting $Q = \omega_0 L/R$ and $t_w = \pi/\omega_0$

$$E_3 = \frac{CV^2 \pi R}{2\omega_0 L} e^{-\pi/2Q}$$

$$= \frac{V^2}{L/C} e^{-\pi/2Q} \frac{R t_w}{2} \tag{7d}$$

Equation (7d) should be compared to Eq. (6), and as a conclusion, the *observed* maximum of the current can be used with the simple form of Eq. (5) with small error. Some practical considerations in the apparatus performance and design will be considered.

IV. Practical Considerations

Only a part of the energy stored in the capacitor can be delivered to the load resistor according to

$$E_3 = \frac{1}{2} CV^2 [1 - e^{-\pi/Q}] \tag{7e}$$

A Q of 5 would result in 47% of the energy being delivered. In keeping with high Q approximations it is desirable to start with a large energy and deliver a small fraction. Equation (7) includes the total energy lost, and there is a split based on the ratio of load resistance (EED) to the total circuit resistance. An "ultimate" energy based on the assumption that the *ideal* current discharge is available at the load resistance is

$$E = \left(\frac{V}{\sqrt{L/C}} \right)^2 \cdot \frac{t_w R_0}{2} \tag{8}$$

This energy can be used in scaling the apparatus. For the case of insensitive electroexplosive devices (i.e., 1 W–1 A no-fire) the impulsive firing energy generally falls between 20 and 100 mJ. Figure 3 shows this energy for four cases of inductance and capacitance selection based on a circuit resistance of 1 Ω. Once a suitable L–C combination is selected, the independent variable is the initial voltage. Energy will vary as the voltage squared and a 50 to 350 V gives a range to 49 to 1. The selection of L–C has several constraints. Pulse widths follow

$$t_w = \pi \sqrt{LC}$$

and this time must be short compared to the thermal time constant of the device. If high Q approximations are to be valid then for a Q of 5 or greater

$$Q = \frac{\sqrt{L/C}}{R} \geq 5$$

Based on the energy equation, for a fixed voltage energy varies as $C^{3/2}$ or $L^{-1/2}$.

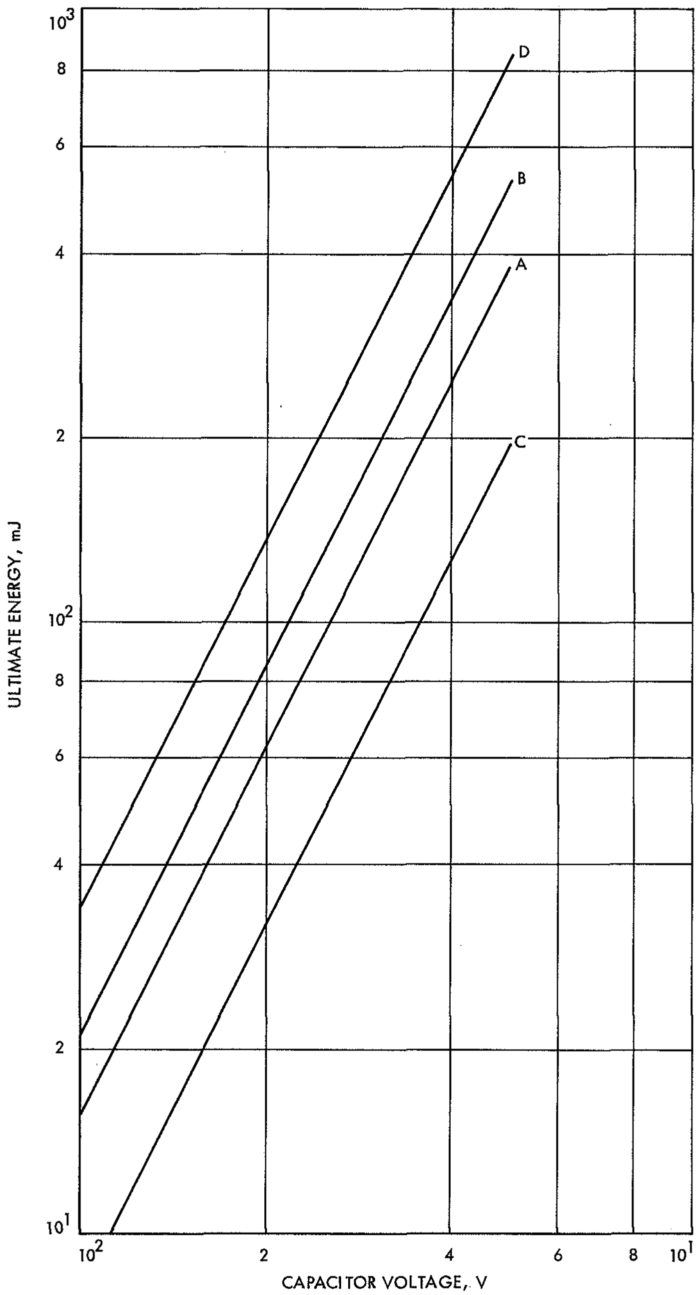
As shown in Fig. 3, it is quite simple to cover a large energy range at narrow pulse widths. Peak currents are also tabulated in Fig. 3 and in case D for 100 V, the ideal maximum current is 22.3 A. For 300 V this would be 66.9 A.

Although the inductor Q can be measured or calculated, a simple experiment can establish the *in situ* value. A 1-Ω resistor is substituted for the EED, and a mercury switch is placed across the thyristor T_1 in Fig. 1. Closing the mercury switch will result in a complete oscillation decay which can be compared to the single discharge pulse. Figure 4 shows two significant oscilloscope traces. In Fig. 4a the single shot and oscillatory discharge are superimposed. No difference between the mercury switch and thyristor is discernible. The solid-state switch operating with a constant voltage drop of less than 1 V when conducting, is extremely efficient in this high-voltage circuit. A measurement of pulse width compared excellently with $t_w = \pi \sqrt{LC} = 178\ \mu s$. The peak current ($I_m$) was 24 A for this discharge.

An oscillatory discharge is shown in Fig. 4(b) with the time scale compressed. From two successive peak current values the Q can be derived as

$$Q = \frac{\pi}{\ln \left(\frac{I_n}{I_{n+1}} \right)} \tag{9}$$

and a value of $Q = 5.7$ is calculated. Theoretically assuming no circuit losses but the load of 1 Ω, the Q would be $\sqrt{L/C}/1 = 11.3$. It is obvious that an additional resistance of 1 Ω exists in the circuit loop. The natural frequency of the circuit was 2.8 kHz or $\omega_0 = 17.5 \times 10^3$ rad/s.



ULTIMATE ENERGY INTO 1-Ω LOAD VERSUS VOLTAGE

CASE	L, μH	C, μF	$z_0 = \sqrt{L/C}$	t_w, μs	E (AT 100 V), mJ	$I'_m = V/z_0$ AT 100 V, A
A	1000	10	10	314	15.7	10
B	500	10	7.07	212	21.2	14.14
C	500	5	10.0	157	7.85	10
D	100	5	4.5	70	34.5	22.3

$t_w = \pi\sqrt{LC}$ $\qquad E = \left(I'_m\right)^2 R\, t_w/2$

$Q = \sqrt{(L/C)}/R = z_0/R$ $\qquad R = 1\,\Omega$

Fig. 3. Ultimate energy versus capacitor voltage for four different conditions

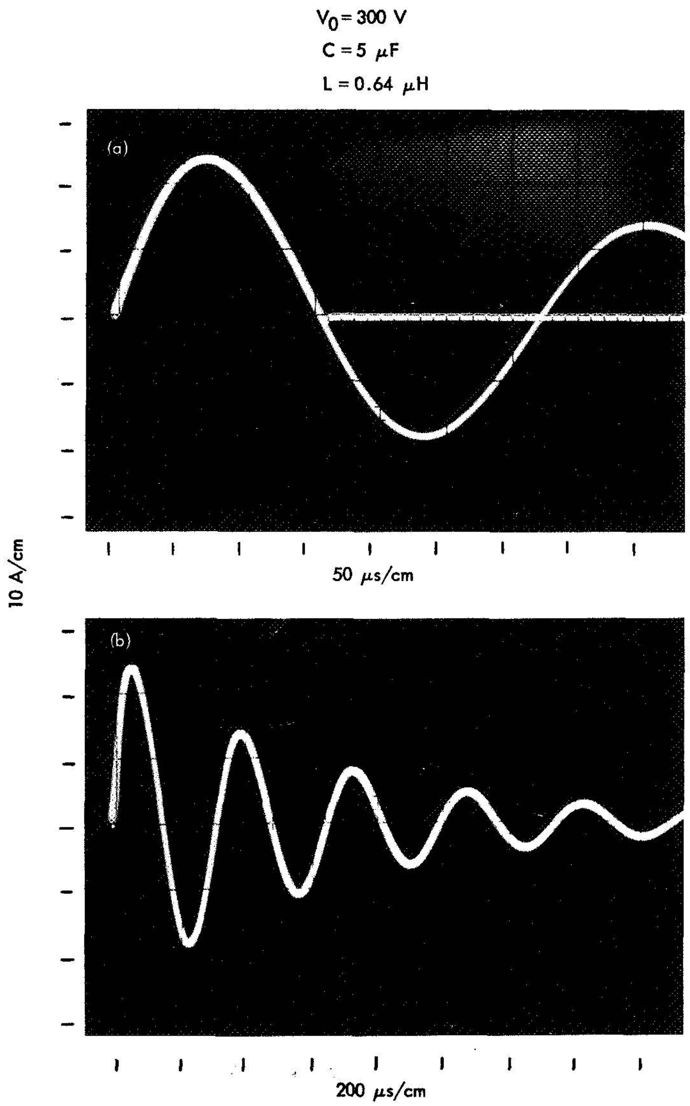


Fig. 4. Discharge waveforms: (a) comparison between a thyristor and a mercury switch, (b) measurement of *in situ* Q from peak value

To calculate the observed current maximum Eq. (6b) can be employed using the measured value of Q as 5.7. The values are

$$I_m = (300/11.3)\, e^{-\pi/4(5.7)} = 23.0\ \mathrm{A}$$

as compared to an observed value of 24.0 A. Examining the entire decay by this procedure completely evaluates the L–C circuit performance.

V. Application and Experimental Observations

The apparatus described was applied to the testing of certain insensitive electroexplosive devices. As shown, the inductor of 640 μH resulted in a pulse width of 178 μs, and two other coils were wound to provide pulse widths of nominally 110 and 76 μs. In all cases the EED under test is mounted in an explosive firing chamber, and the voltage drop across the device is fed into a calibrated oscilloscope. Energy is calculated using Eq. (5) according to

$$E_1 = \frac{I_m^2 R_0 t_w}{2}$$

or in terms of voltage

$$E_1 = \frac{V_m^2 t_w}{2R_0}$$

The voltage V_m is directly observed on the scope trace together with the pulse width. It has been found that pulsing the electroexplosive device with subfiring energies will not alter the sensitivity a measurable amount. This may be unusual to these insensitive devices and should be checked for the particular item under test. Therefore, it is possible to progressively increase the pulse amplitude in modest steps until initiation takes place.

The effect of resistance change during the pulsing should be considered. All previous equations have ignored the possibility of thermal feedback with a positive TCR[1] bridgewire. It can be shown (Ref. 4) that for impulsive current firing assuming a constant TCR the actual energy delivered is increased according to

$$E' = E\left\{\frac{\Delta R}{R_0} \Big/ \ln\left(1 + \frac{\Delta R}{R_0}\right)\right\} \tag{10}$$

where $\Delta R/R_0$ is the final per unit change in resistance. For example, a 500 K temperature rise with a nominal TCR of $100 \times 10^{-6}\ \Omega$/K would result in a 5% increase in resistance. The correction term is 0.05/ln (1.05). By expanding the log term according to

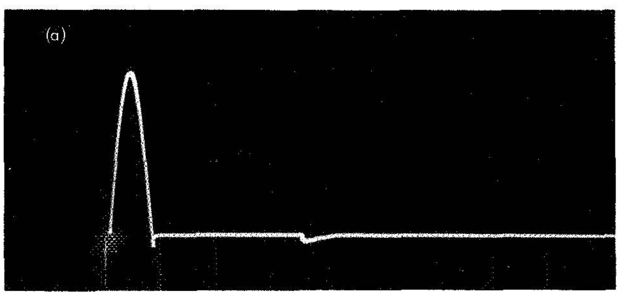
$$\ln(1 + x) = x - \frac{1}{2x^2} + \frac{1}{3x^3}$$

where $x = 0.05$, the correction to the energy becomes 2.5%. This correction is lost in the resolution of the oscilloscope detection system.

[1]Temperature coefficient of resistivity.

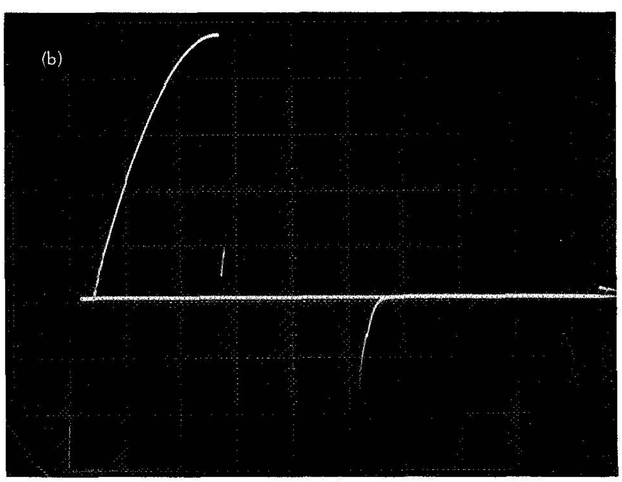
It was observed that the firing of certain (1 W–1 A no-fire) EEDs employing thermally conductive insensitive mixes never terminated the complete half-cycle discharge. This suggested that the time to bridgewire rupture was a poor criterion to calculate energy to fire. Opening the bridgewire would certainly result in terminating the current pulse. By passing a trickle current from a small battery through a large inductor (i.e., 100 to 500 mH) into the bridgewire, the breaking of the bridgewire would result in an inductive pulse (i.e., $L\,(di/dt)$. The battery polarity will determine the sense of the indicator pulse. This ancillary circuit is not shown in the circuit diagram of Fig. 1. The firing trace of Fig. 5(a) is a typical output signal obtained. In this case the pulse width is 76 μs ($= t_w$), the peak current was 27.8 A (resistance = 1.08 Ω) and the energy required for firing was 22 mJ. The bridgewire clearly opens 250 μs after the energy delivered has ceased. For better energy resolution, the time base should be expanded and a dual trace scope system is a preferred approach. The wire breaking is not always "clean," but the onset of wire rupture is discernible. An example of another explosive system behavior is shown in Fig. 5(b).

10 V/cm



0.1 ms/cm

10 V/cm



50 μs/cm

Fig. 5. Discharge waveforms: (a) for an insensitive explosive mixture, (b) for a primary explosive system

This item is again an insensitive device with a 1 W–1 A no-fire capability (Mark 101 or BBU-7B) rated for a nominal 100 mJ firing energy (Refs. 5,6). The primary high-explosive (lead azide) system employed results in rapid (order of microseconds) breaking of the wire. Functioning took place near the quarter cycle, and the calculated energy was 108.5 mJ. When attempting to use the energy creep-up technique to fire the EED, it was not possible to complete a full discharge without breaking the wire. The rapid build-up to detonation characteristic of lead azide is obviously responsible for immediate wire rupture in this explosive system design.

A variety of 1 W–1 A no-fire squibs were initiated from the half-sine wave pulse generator at liquid nitrogen (77 K), room temperature ($\cong$298 K), and elevated temperature (400 K). Figure 6 shows three typical responses at these temperatures. In Fig. 6(a) the peak current was 25.4 A (resistance = 1.16 Ω), the pulse width 70 μs, and the energy required to fire 26.3 mJ. The bridgewire rupture was not recorded and assumed to be greater than 925 μs from the end of the pulse. In Fig. 6(b) ignition occurred on the second pulse producing a slight perturbation slightly past the peak. Bridgewire rupture occurred slightly after the end of the pulse. The peak current was 35.0 A (resistance = 1.03 Ω), pulse width 70 μs and energy required to fire 44.0 mJ. Figure 6(c) shows ignition occuring on the second pulse from a peak current of 20.9 A. The pulse width was 70 μs and the energy to fire 16.8 mJ. Bridgewire rupture occurred 6.5 ms after the end of the pulse. Additional typical data is given in Table 1 below:

In the particular systems investigated, no apparent relationships developed. Excess energy input did in most

Table 1. Half-sine wave pulse firing test results

Squib No.	V_{peak}, V	t_w, μs	R_o, Ω	w, mJ	t_b, μs	Temperature, K
40858	29.5	70	1.09	27.9	5000	77
40916	30.0	70	1.11	28.4	3950	77
82065	27.0	70	1.04	24.5	160	77
82044	31.0	70	1.14	29.4	500	77
82055	25.0	70	1.03	21.2	158	298
82049	27.0	70	1.05	24.3	1000	298
40996	30.0	76	1.14	30.0	800	298
41290	30.0	76	1.08	31.7	360	298
41292	29.5	70	1.20	25.4	2156	400
40950	29.5	70	1.18	25.8	1750	400
82051	29.0	70	0.99	29.7	200	400

t_w = pulse width.
w = energy.
t_b = time to bridgewire rupture.

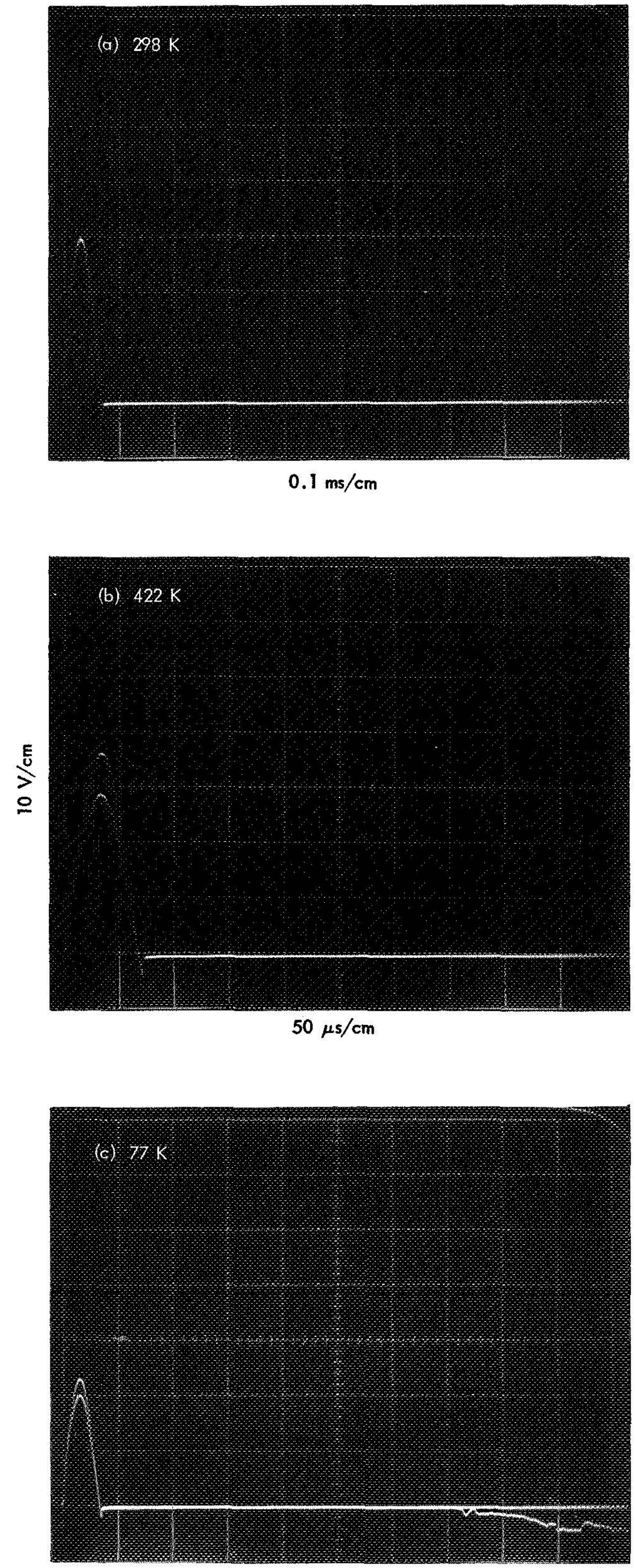


Fig. 6. Typical pulse discharge waveforms at different temperatures

cases reduce the time to bridgewire rupture, but a consistent pattern did not emerge. Firing at liquid nitrogen (77 K) compared to elevated temperatures (400 K) did not produce a clear trend. It would require further work to interpret the significance of the time to bridgewire rupture which for a given system varied from several to over 2000 μs.

For cases where the energy delivered terminated during the half-sine wave pulse the energy equation can be derived as

$$E = \frac{V_m^2}{2R_0} t_f \left[1 - \frac{\sin X}{X}\right] \tag{11}$$

where

$$X = 2\pi \frac{t_f}{t_w}$$

and t_f is the termination time out of a full half-cycle time of t_w. The equation assumes firing takes place from $\pi/2$ to π rad of the cycle. If the peak is never reached a modified equation can be developed.

Studies of the firing energies at low temperature, room temperature, and elevated temperature for one particular system showed negligible differences. Since the number of samples tested was limited, it would be improper to hypothesize as to the reasons for this anomoly.

The major application of the apparatus to date has been for the basic characterization of firing energy requirements. For adiabatic firing, the energy input can be related to bridgewire temperature based on a lumped model (Ref. 7) analysis as

$$E = C_p \Delta\theta \tag{12}$$

where C_p is the equivalent system heat capacity and $\Delta\theta$ is the temperature rise. In terms of the particular firing system described

$$\frac{I_m^2 R_0 t_w}{2} = C_p \Delta\theta \tag{12a}$$

In a given explosive system design, the right side of Eq. (12a) is essentially constant but for manufacturing control. If the resistance could be controlled, then the system action ($I_m^2 t_w$) should be constant. A small set of data resulting from 10 samples is shown as a plot in Fig. 7. Averages of three groups, fired at three different pulse widths, are plotted: $\ln(I^2)$ versus $\ln(t_w R)$. The results should follow a line of slope -1 as shown, and the deviation may be a reflection of product quality control. The firing energy for this system based on an average of 10 samples was 28.39 mJ. Setting this as the right side of the equation, the current squared can be calculated for 1 Ω at 100 μs. The calculated point is correctly on the plot. As a point of interest, if current is plotted as the ordinate, rather than the square, the slope would be $-1/2$ instead of -1.

In testing small lots of devices all capable of meeting the 1 W–1 A no-fire criterion, the firing energies went from a low of 16 mJ to a high of 165 mJ. The pulse width in these cases were set to 70 μs which is a typically satisfactory energy delivery time. By adjusting the voltage or I_m level a wide range of energies can be provided.

VI. Conclusions

The half-sine wave pulser will provide a reliable and versatile energy source for adiabatic firing. In addition to characterizing the firing energies of devices, other behavior characteristics can be examined. Continued use in larger sample studies are necessary for a more thorough evaluation.

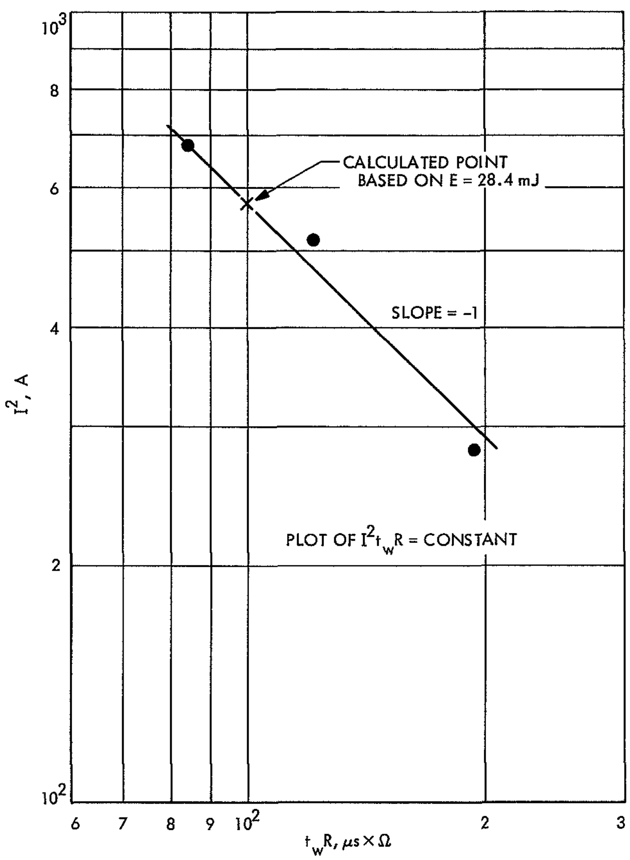


Fig. 7. Adiabatic firings for three different pulse widths

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16. Abstract

An apparatus based on the use of a half-sine wave current pulse for electro-explosive device firing is presented. Energy for adiabatic firing can be readily measured. Theory and equations of energy transfer are developed. The application to measurements on certain insensitive electroexplosive devices is presented as an example of capabilities.

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