JPL Quarterly Technical Review Volume 2, Number 4 January 1973

Index: electronic components and circuits, pyrotechnics

Generation of Narrow High Current Pulses

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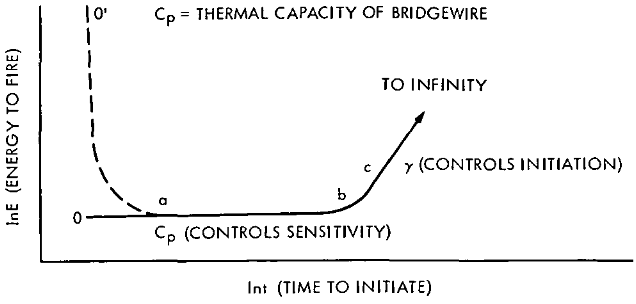
Many of the fundamental factors affecting the initiation of electroexplosive devices have not been satisfactorily explained. A description of a narrow, high current pulse generator capable of pulses 4 microseconds wide and 94 amperes is given which will be useful in the study of the initiation mechanism.

Introduction

The most critical area of an electroexplosive device (EED) is the bridgewire/header/explosive interface. The bridgewire acts as an electrothermal transducer accepting electrical energy and converting it to heat, consequently causing ignition of the explosive. The behavior of the bridgewire with various forms of electrical input energies and its coupling to the explosive material are of basic interest because many fundamental factors affecting the initiation of EEDs have not yet been satisfactorily explained. Increased reliability in EEDs can be realized from a thorough understanding of the initiation process.

Initiation of EEDs is presently categorized in at least three ignition regimes. These regimes are best illustrated in the conventional sensitive EEDs (military type) requiring less than 5 A to initiate; the less sensitive 1-W, 1-A, no-fire EEDs requiring 3 to 20 A to initiate (used primarily in aerospace); and the 20- to 100-A input where the EED no longer obeys the simple current vs time-to-fire relationship but may be entering the regime of exploding bridgewires. Considerable data has been accumulated from conventional firings but little is known about the initiation process. It is felt that above 50-A input for 1-W, 1-A, no-fire EEDs, the bridgewire burns out electrically and subsequent electrical arcing is responsible for initiation. Arcing may also occur in the more sensitive military type EEDs at lower current inputs. Little is known about this mechanism and latest data indicate that another current vs time-to-fire relationship may exist.



A plot of energy required as a function of initiation time (time from application of energy to first sign of light output) is given below. The plot indicates a region where anomalous behaviour is possible.

The region b to c is controlled by the heat loss of the EED (γ) and for constant current firing or long times the energy can increase to infinity or no fire. The region a to b corresponds to adiabatic firing or constant energy input. For extremely narrow pulses, it has been observed that the energy increases and a possible explanation is the inability to deliver energy rapidly in a typical electrical firing system. The region a to 0, theoretically predicted, may follow a to 0'. There is some speculation that for very fast energy delivery, degradation of heat transfer to the explosive at the bridgewire interface may be responsible. A method for delivering large current pulses for times less than 10 μs would be required to study this firing region.

Pulse Generator

The half-sine wave pulser has the capability of these rapid deliveries. A large amount of energy in a short time corresponds to a high "power" pulse. For the sine wave pulse,

$$\text{energy/time} = I^2 R t_w / 2t_w = I^2 R/2$$

$$\text{power} = \frac{V^2 C}{L} \times R/2$$

Since $Q = \sqrt{\frac{L/C}{R}}$ and must be 5 or greater for good half-sine waveform, the power follows as:

$$\text{power} = \frac{V^2}{Q^2 2R}$$

where R is the EED + circuit losses. As a conclusion, the only independent way to generate high power pulses is to go to higher operating voltages.

A system operating at voltages of nominally 1000 V with a Krytron as a discharge switch proved to be the most efficient mode of generation. A Krytron is a cold cathode gaseous discharge device of proven reliability from exploding bridgewire systems. It can operate at currents of 30 to 1200 A at voltage levels up to 5000 V. Early experiments proved that it would turn-off or commutate with a reverse oscillation, characteristic of the half-sine wave ring.

The circuit of Fig. 1 shows the essential components. Power supplies are not shown and most of the testing was performed on a +1000 V, +300 V supply. For energy control, the high voltage supply was made variable. Switch S1 is a mercury-wetted switch, normally closed. Upon opening, a +300 V trigger pulse is injected to the Krytron. This same pulse can be used for scope triggering and should not be excessively long compared to t_w or the Krytron will not commutate. The EED or load shown as R was a 1-Ω resistor in the tests to be described. An assortment of L-C combinations were evaluated.

Figure 2a shows the pulses generated by a 70-μH inductor for two capacitor sizes. The capacitors were mica RF varieties rated at 2000 V and the largest energy corresponded to 66 A peak at a t_w = 10 μs or 22 mJ. In

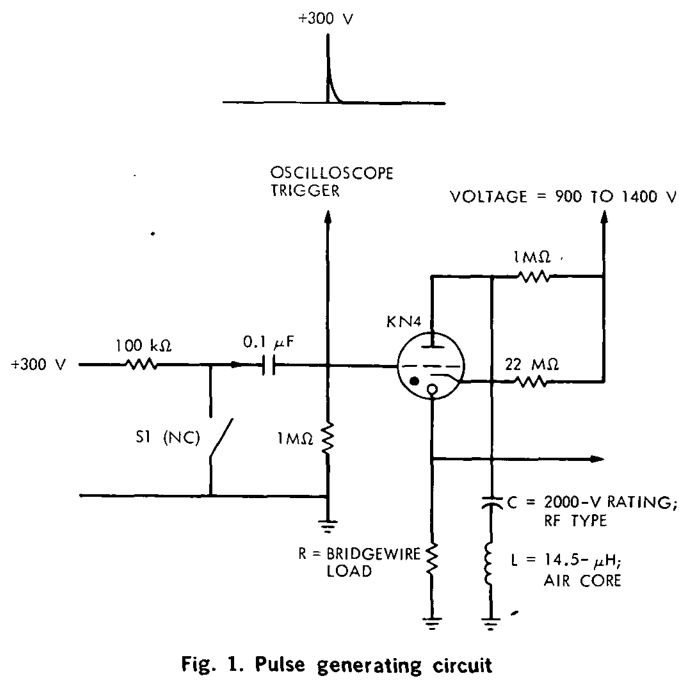
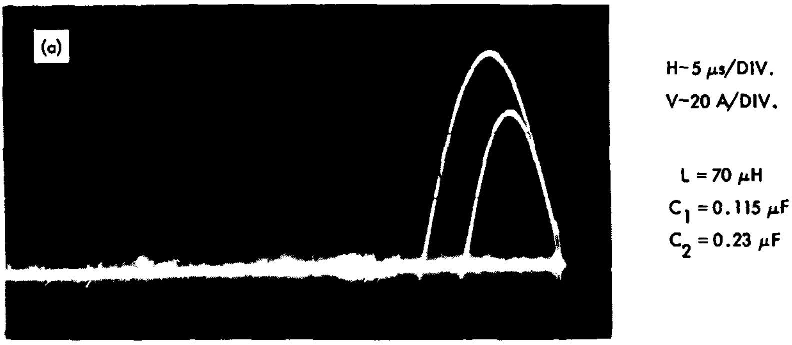


Fig. 1. Pulse generating circuit



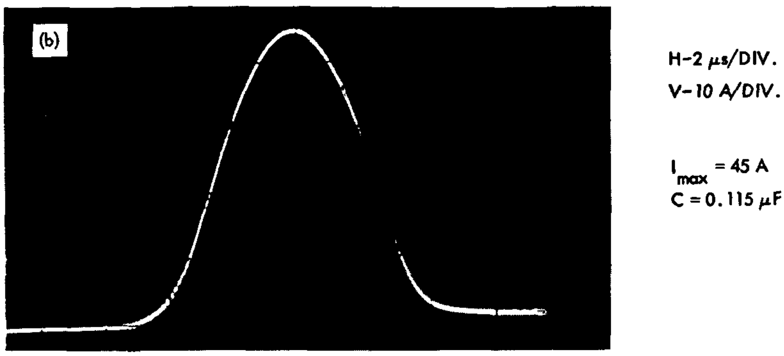


Fig. 2. Several half-sine pulse waveforms: (a) half-sine wave pulses generated in a 1-Ω resistor; (b) pulse generated employing a ferrite core

Fig. 2b, a "pulse" reactor employing a ferrite core produced a "sine-squared" type of pulse with I_{max} 45 A at t_w = 7 μs. The delay in the pulse rise is attributable to the nonlinear flux linkages (λ) characteristic.

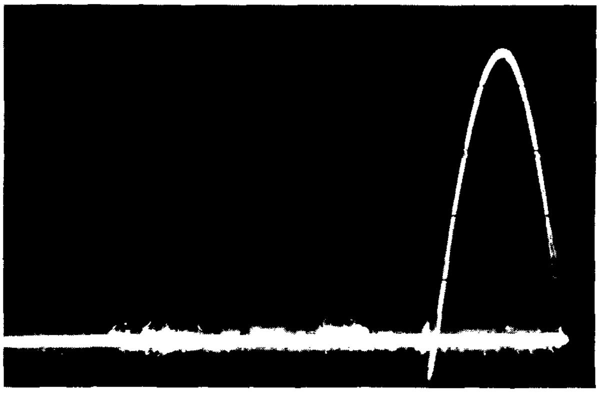
In Fig. 3, a transmission line was explored as a means of obtaining a more rectangular pulse waveform. A cable of approximately 300 m in length replaced the L-C circuit. Since the characteristic impedance (Z_0) of the cable limits the discharge current to V/Z_0 the maximum current was 20 A. Attenuation in the cable produced tilt in the waveform and at the rapid start and termination of the pulse, a large shock excitation oscillation was apparent. This confirms the concept that discontinuous (i.e., rectangular) pulses cannot be properly delivered to a load. A smooth sine wave pulse is generally superior. The pulse width was 2.8 μs corresponding to two delay times for the transmission line.

Figure 4 shows an acceptable pulse waveform generated with an inductor of 14.5 μH. At 1000 V the amplitude was 90 A at t_w = 4 μs, and 4 shots were superimposed to indicate the absence of jitter in the proposed circuit. The energy was 16.2 mJ, but by increasing the supply voltage to 2000 V, 64

H-2 μs/DIV.
V-10 A/DIV.

I_{max} = 20 A
PULSE WIDTH = 2.8 μs
VOLTAGE = 1000 V

Fig. 3. Pulse waveform generated from an approximately 300-m cable



H-2 μs/DIV.
V-20 A/DIV.

I_{max} = 90 A
PULSE WIDTH = 4 μs

Fig. 4. Acceptable pulse waveform generated with an inductor of 14.5 μH

mJ could be obtained. The upper limit of the circuit was not explored and but for the inability of the Krytron to self-commutate, there is no reason to expect any problem. The substitution of a higher power Thyratron (3C45) as an alternate solution is possible. The capacitor size could be doubled to increase the energy by $2^{3/2}$. With C = 0.23 μf, a pulse width of 6 μs and peak current of 120 A was obtained with good waveform symmetry.

A compact instrument for delivering the required energy pulses can be built. The power supply should be adjustable up to 5000 V and two or more capacitors with a tapped inductor would offer pulse width and energy (coarse) control.

Applications

The pulse generator will allow the study of explosive initiation in the three regimes indicated above and in particular the transition between regimes. Other areas of interest resulting from this study will be the behavior of I^2t or "action" that theoretically should be a constant. The data will give a greater scope in the design of firing circuits (through relief of present electrical restrictions), which can be lighter and more compact. Also, skin effects and efficiency of energy transfer can be studied.