Calculation and Simulation of Commercial Electrical Detonators

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Abstract: The transient pulse testing is used in a commercial electric detonator to measure the electrothermal performance. The conventional inspection has the disadvantage of destruction with a number of detonators tested, while the transient pulse testing can give a dynamic electrothermal curve at a user's command. In addition, the transient pulse testing can be used to measure a passel of commercial matches one by one rather than by a statistical spot check. Unfortunately, a statistic spot check cannot provide the firing reliability of products efficiently. The other way round, the transient pulse testing may put an end to the possibility of loss for users absolutely. The reason that the transient pulse testing is not devastating for products is that these mixtures of a match have a required thermal stability, and then are simultaneously able to be responded reliably by a very small pulse current. We have determined that these bridge wires in air and under water electrothermal responsibility curves. Eletrothermal responsibility, calculation and simulation of electrothermal parameters are presented in this paper.

Keywords: commercial electrical detonator; electrothermal parameter; Rosenthal calculation; FlexPDE simulation.

1 Introduction

A commercial electrical detonator is used only by one time. Rosenthal put forward integral parameters to predigest electrothermal equations [1] and calculation methods [2] of eletrothermal parameters. Literature [2]-[9] introduced types, peak values and pulse breadth of the input signals. USA promulgated the military acceptance criterion MIL-STD-1512 in 1972. The 605B thermal transient test without a computer was manufactured in 1979, and it had nine kinds of proof-testing functions [10]. This instrument was used in the product line [11]. In 1980s, it was popularized in the EED and thin films [12,13]. The method is developing, of the firing controlling and performance forecasting, yet it is not well rounded [14,15]. Rosenthal equations are trying to improve [16]. In 1994 and in 1997, this field articles were respectively called for in the sheet of meeting motive and call for papers by the International Symposium on Explosives and Pyrotechnics (E&P) [17]. Literature [18-21] reported the firing reliabilities and performance forecasting by using thermal parameters and modeling EEDs with the Monte—Carlo Code. The match head, consisting of an electrically insulting substrate with bridgewire is investigated. A study is concerned on the calculation and simulation of electrothermal responsibilities of a commercial electrical detonator.

2 Electrothermal Responsibility Equations

Electrothermal equations brought forward by Rosenthal define the net heat flow for the systems governed by convective- and conductive- heat flow.

$$P(t)\mathrm{d}t-\gamma(T-T_0)=C_p\mathrm{d}T \tag{1}$$

$$C_p\frac{\mathrm{d}\theta}{\mathrm{d}t}+\gamma\theta=P(t) \tag{2}$$

$$P(t)=I^2R=I^2R_0(1+\alpha\theta) \tag{3}$$

The temperature of the bridge-charge systems T ($\theta=T-T_0$) to (2) is given by (4).

$$\theta = \frac{I^2 R_0}{\gamma - \alpha I^2 R_0}[1-\exp(-\frac{\gamma - \alpha I^2 R_0}{C_p}t)] \quad (4)$$

In these equations, C_p is heat capacity, γ the thermal conductivity, R_0 the initial resistance of bridge wire, I the current value, α the resistance-temperature coefficient of bridge wire, and t the time.

The (4) formula assumes the same temperature on a bridge wire. The temperature increment curves may be expressed with the voltage increment as follows.

$$V(t) = \frac{\alpha I^3 R_0^2}{\gamma - \alpha I^2 R_0}[1-\exp(-\frac{\gamma - \alpha I^2 R_0}{C_p}t)] \quad (5)$$

Where V_m is the maximum $V(t)$.

$$V_m = \frac{\alpha I^3 R_0^2}{\gamma - \alpha I^2 R_0} \quad (6)$$

$$\Delta R = V_m / I \quad (7)$$

$$\theta = V_m / \alpha I R_0 \quad (8)$$

$$\gamma = \frac{\alpha I^3 R_0^2}{V_m} + \alpha I^2 R_0 \quad (9)$$

The electrothermal curve is an exponential function one. τ is the time constant of temperature increment.

$$\tau = \frac{C_p}{\gamma - \alpha I^2 R_0} \quad (10)$$

In condition of $V = 0.5V_m$, time is expressed with $t_{1/2}$. The solution to (5), (6) and (10) is given by (11).

$$\tau = \frac{t_{1/2}}{\ln 2} \quad (11)$$

C_p may be calculated by (10).

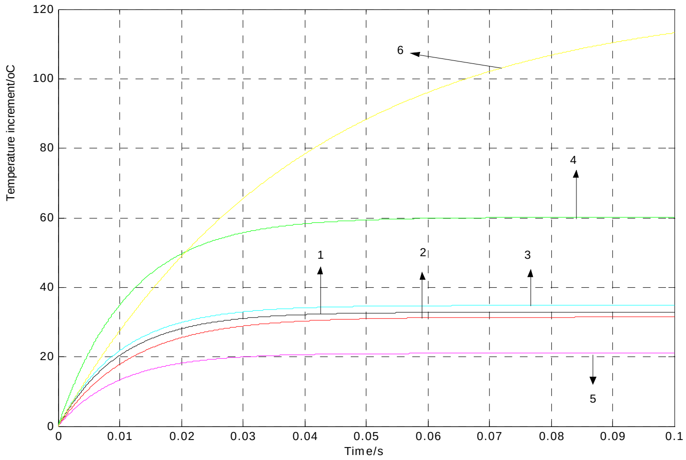
$$C_p = \tau(\gamma - \alpha I^2 R_0) \quad (12)$$

Table 1 The nondestructive inspection results under 0.08A

		Black matches	Red matches	Unqualified black matches	Both bridges in black matches	Under water	In air
Temperature increment /℃	Minimum	23.3	24.6	25.5	21.9	17.2	50.7
	Average	30.78	30.07	36.81	27.41	22.07	68.27
	Maximum	42.1	39.3	71.6	51.1	28.5	84.6
Temperature constant /×10^{-3}·s^{-1}	Minimum	5.57	8.08	6.49	3.15	4.88	23.3
	Average	10.42	12.00	10.38	10.96	9.74	41.97
	Maximum	14.0	15.5	12.8	17.1	15.9	60.7
Heat loss coefficient /×10^{-4}W·$℃^{-1}$	Minimum	3.83	3.99	1.49	1.25	6.47	0.816
	Average	5.58	5.83	5.27	3.06	8.71	1.51
	Maximum	8.05	8.15	10.4	4.37	11.4	3.18
Heat capacity /×10^{-6}J·$℃^{-1}$	Minimum	2.97	4.53	1.34	1.56	3.21	3.20
	Average	5.78	6.99	5.38	3.50	8.71	5.87
	Maximum	9.47	10.5	10.6	6.90	17.9	11.1

In Table 1, it is concluded that the interface status of the bridgewire-charge system impacts significantly the experimental results. For example, some small air bubbles will make the temperature of a bridge wire to increase, and the temperature of charges to decrease. At the same time, the containing water or moisture in charges also affects the testing results.

3 Rosenthal Calculation



1 - Black matches, 2 - Red matches, 3 - Unqualified black matches,

4 - Both bridges in black matches, 5 - Under water, 6 - In air

Fig. 1 Calculation results by the Rosenthal modeling

The bridgewire type is 6J20, its resistance coeffivient α 0.00015Ω /℃, and the bridgewire resistance 2.85Ω . The heat loss coefficients and heat capacities are given in the column of the average values in Table 1. These parameters are used in the equation (4). Electrothermal curves are given in Fig. 1 by using the Matlab software. Electrothermal curves calculated by varied parameters are shown in Fig. 2 to Fig. 5. In any of them, Fig. A is from black matches and Fig. B from red matches.

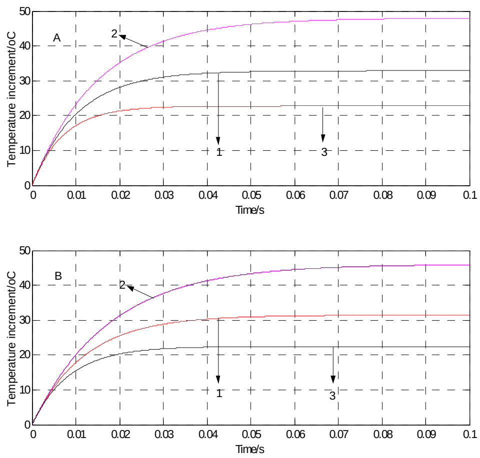


Fig. 2 Curves of varied heat loss coefficients

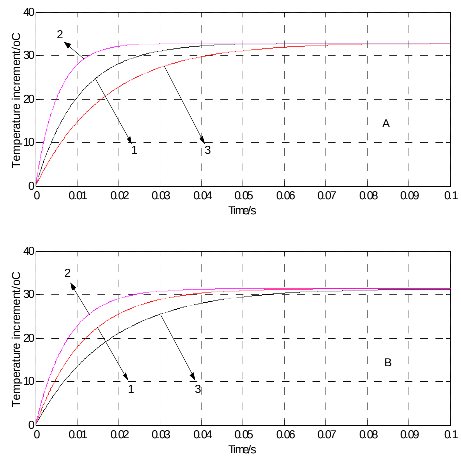


Fig.3 Curves of varied heat capacities

In Fig. 2 and Fig. 3, curve 1 comes from the average values, curve 2 from the minimum and curve 3 from the maximum.

In Fig. 4, the resistances are 2.85Ω , heat loss coefficients and heat capacities the average values individually. In Fig. 5, the current values are 0.08A, heat loss coefficients and heat capacities the average values individually.

Results calculated by the Rosenthal modelling show that varied parameters present varied electrothermal curves. The temperature increments decrease and the time will shorten to come into the equivalent state with the increment of heat loss coefficients. Heat capacities have a little effect on temperature increment values. Yet, the time for the temperature increment to come into the equilibrium changes a little with the undulation of the resistance values.

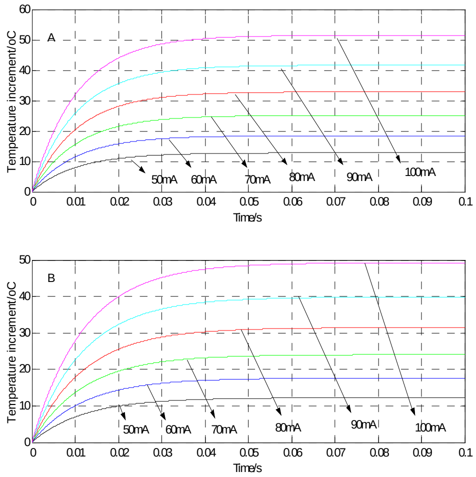


Fig. 4 Curves of varied currents

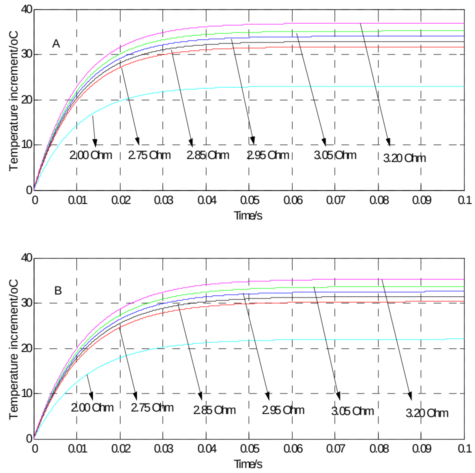


Fig. 5 Curves of varied resistances

4 FlexPDE Simulation

Rosenthal assumes that there is the coherent temperature distributing in both axial and radial directions. Yet, others' researches show that there is a different axial temperature distribution. So, based on the thermal conduct law, the vector expression is as follows:

$$\vec{q} = -K \ gradT = -K\nabla T = -K\frac{\partial T}{\partial n}\cdot\vec{n} \quad (13)$$

In the above equation, K is the heat loss coefficient, $\vec{q}$ the heat flow vector, i.e. the heat flow density, $\vec{n}$ the unit normal vector and $\partial T/\partial n$ the derivative of T in the n direction.

The three-dimension thermal conduct equation can be expressed by formulation (14).

$$\rho C_p\frac{\partial T}{\partial t} = K\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right) + P(t) \quad (14)$$

In this equation, ρ is the density, C_p the heat capacity, T the temperature, x, y, z the interspace coordinate, and $P(t)$ the power.

Initial and boundary conditions are individually given. In case of $T|_{t=0} = 0$ and $T|_{x=0} = T|_{x=l} = 0$, the boundary condition is $K\left.\frac{\partial T}{\partial n}\right|_{r=r_0} + H(T|_{r=r_0} - T_0)$ =0.

With the implement of the FlexPDE, short for A Flexible Solution System for Partial Differential Equations, we simulate the temperature increment processes of bridge wires individually under varied heat loss coefficients, heat capacities and electrical currents. The simulation results are shown in Fig. 7 to Fig. 11. In each Figure, A is the axial distribution of bridgewire temperatures and B the central temperature variety vs. time. Fig. 6 is the object properties of the radial distributing of central temperatures of a bridge wire, from the average values in Table 1. X and Y are the radial coordinates, Z the axial coordinate, T_P the bridge temperature (℃), T the time(s). X, Y and Z are dimensionless parameters. The unitage of resistance is 800Ω /m and the bridge wire diameter 4.0×10^{-5}m. When the resistance is 2.85Ω , the ratio of the length to the diameter is 89/1.

The above simulation results show that the bridgewire temperatures in radial direction change a little with the location. So, we can consider that in any section, the temperatures are the same. Compared with the results by the Rosenthal calculation, the FlexPDE simulation results indicate that there is an axial temperature distribution, and the time to reach the equilibrium is smaller than that from the Rosenthal calculation. The three-dimension simulation results are true of the experimental results.

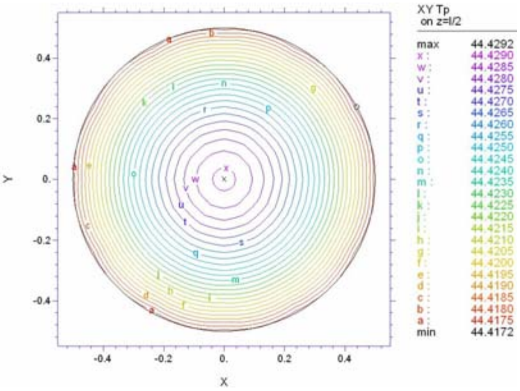
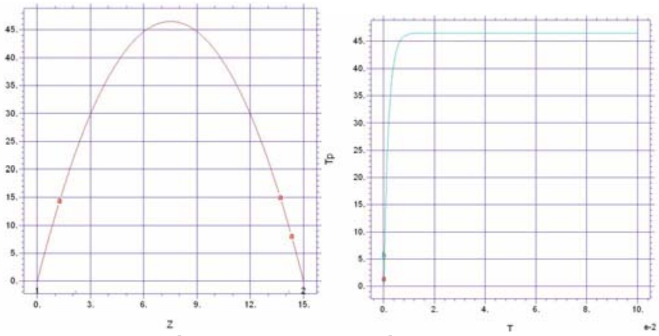


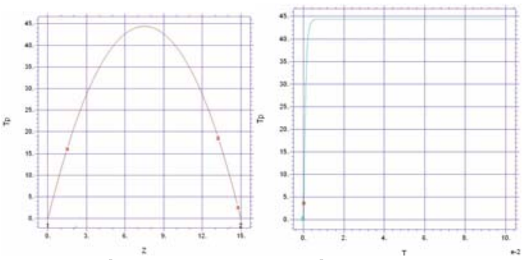
Fig. 6 Radial distribution



A. Axial temperature   B. Central temperature vs. time

Fig. 7 *T* distribution, I = 80mA ,

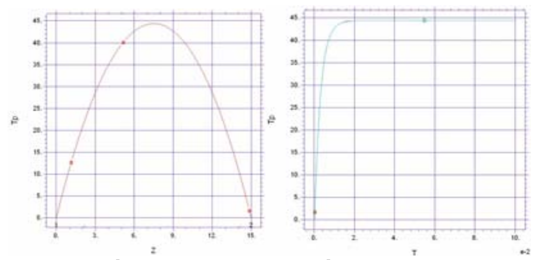
$C_p = 5.78\times10^{-6}$J·℃$^{-1}$, H = 8×10^{-4}W·℃$^{-1}$



A. Axial temperature   B. Central temperature vs. time

Fig. 8 *T* distribution, I = 80mA ,

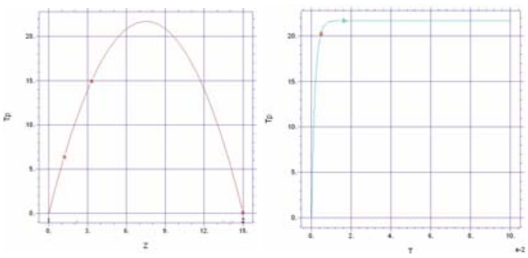
$C_p = 3\times10^{-6}$J·℃$^{-1}$, H = 6×10^{-4}W·℃$^{-1}$



A. Axial temperature   B. Central temperature vs. time

Fig. 9 *T* distribution, I = 80mA ,

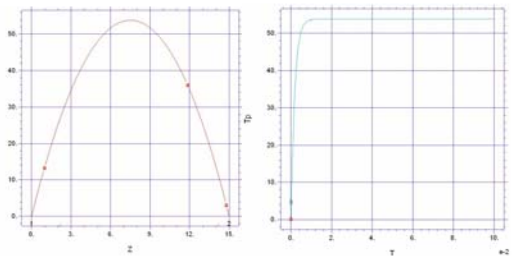
$C_p = 10\times10^{-6}$J·℃$^{-1}$, H = 6×10^{-4}W·℃$^{-1}$



A. Axial temperature   B. Central temperature vs. time

Fig. 10 *T* distribution, I = 50mA ,

$C_p = 5.78\times10^{-6}$J·℃$^{-1}$, H = 6×10^{-4}W·℃$^{-1}$



A. Axial temperature   B. Central temperature vs. time

Fig. 11 *T* distribution, I = 100mA ,

$C_p = 5.78\times10^{-6}$J·℃$^{-1}$, H = 6×10^{-4}W·℃$^{-1}$

5 Conclusions

The investigation concerns the transient pulse testing for commercial electric detonators. The electrothermal responsibilities and the testing system are discussed. It is concluded that the transient pulse technique can be used in the nondestructive inspection. The transient pulse testing can display the dynamic process of the temperature increments of the bridgewire-charge system.

Rosenthal calculation and the FlexPDE simulation are effective to give the electrothermal parameters.

Acknowledgements

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