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Firing Reliability of Bridgewire-charges

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Abstract: The transient pulse testing is used in bridgewire-charges to measure the electrothermal performance non-destructively rather than by the conventional inspection. The conventional inspection has the disadvantage of destruction with a number of products 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 products 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 product 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 red matches based on Si/Pb_3O_4/DDNP mixtures electrothermal responsibility curves. Firing performance, measurements of the transient pulse testing, and electrothermal parameters are presented in this paper.
Keywords: transient pulse testing; electrothermal parameter; red match; nondestructive inspection; firing performance

1 Introduction

A mining 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 new red match head, consisting of an electrically insulting substrate with bridgewire is investigated.

2 Electrothermal Equations

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

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

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

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

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

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

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.

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

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

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

$$\Delta R = V_m / I \tag{7}$$

$$\theta = V_m / \alpha I R_0 \tag{8}$$

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

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

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

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

$$\tau = \frac{t_{1/2}}{\ln 2} \tag{11}$$

C_p may be calculated by (10).

$$C_p = \tau(\gamma - \alpha I^2 R_0) \tag{12}$$

3 Experiments

The apparatus consists of an IT-4 electric parameters instrument and a DR-3 system of transient process testing and nondestructive inspection with an IBM lap top computer, similar to that used for digital data processor. A schematic of the testing systems is illustrated in Fig. 1. The control circuitry of current may control the reference voltage of a power supply, i.e. zero current value. The power supply outputs a constant value of current. The analog circuit makes the initial voltage output zero. The program-controlled amplifier will magnify the voltage values between the two ends of a bridge wire. The A/D convertor may change analog data into digital data. The memorizer saves testing signals. The collection controller can control the start and end, the collection speed and scope of the A/D convertor and so on. The coupling provides a channel for data transfers between an instrument and a computer. The computer dominates the whole apparatus to adjust the setting of conditions of the nondestructive inspection or the transient firing process.

4 Nondestructive Inspection

When the constant current value is separately set to 0.08A and 0.1A, the red matches are tested repeatedly. The results calculated are listed in Table 1 and Table 2.
Under 0.08A, the electrothermal parameters don't vary markedly. And the errors are from the apparatus itself. Yet, when the testing current is 0.1A, compared with the data in Table 2, we can find that all of the electrothermal parameters other than the resistance values change obviously during testing repeatedly. It shows that after electrified with 0.1A, the electrothermal performance varies sharply.

The durative time electrified is lasting for 0.1s. The sampling interval setting is 2.0×10^{-5}s. The amplificatory multiple is selected as 16×50. The memory capability is 4k.

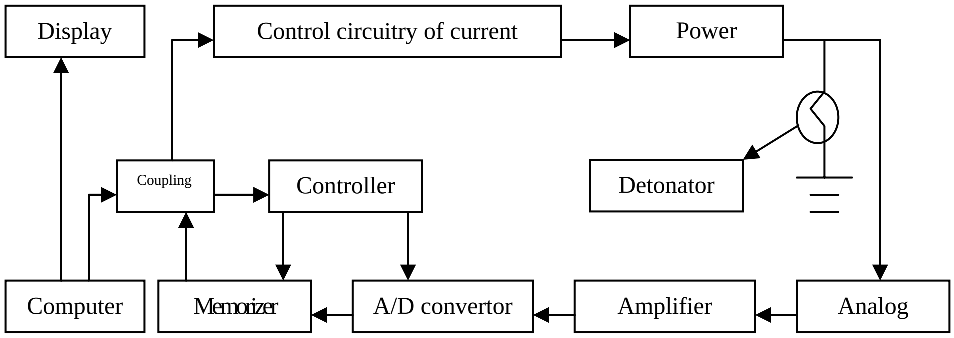

Fig. 1 Apparatus

Table 1 The nondestructive inspection results of red matches under 0.08A

Product sequence	Repeating order	Temperature increment /℃	Resistance /Ω	Temperature constant $/\times10^{-3}\cdot s^{-1}$	Heat loss coefficient $/\times10^{-4}$W·℃$^{-1}$	Heat capacity $/\times10^{-6}$J·℃$^{-1}$
	1	30.8	2.66	9.90	5.54	5.48
1	2	31.0	2.66	9.69	5.49	5.33
	3	30.3	2.66	11.60	5.62	6.53
	1	29.1	2.76	11.80	6.07	7.18
2	2	28.7	2.76	10.70	6.16	6.61
	3	28.2	2.76	12.70	6.27	7.96

Table 2 The nondestructive inspection results of red matches under 0.1A

Product sequence	Repeating order	Temperature increment /℃	Resistance /Ω	Temperature constant $/\times10^{-3}\cdot s^{-1}$	Heat loss coefficient $/\times10^{-4}$W·℃$^{-}$	Heat capacity $/\times10^{-6}$J·℃$^{-}$
	1	71.5	1.75	9.00	2.45	2.20
1	2	66.9	1.74	10.20	2.60	2.64
	3	61.9	1.74	13.30	2.81	3.73
	4	58.0	1.74	14.50	3.00	4.35
	1	55.9	1.81	7.85	3.24	2.54
2	2	52.6	1.81	11.20	3.44	3.85
	3	52.2	1.80	14.00	3.45	4.83
	4	51.0	1.80	12.00	3.53	4.23
	1	62.2	1.93	8.28	3.10	2.57
	2	54.9	1.93	11.30	3.52	3.97
	3	64.9	1.93	8.69	2.97	2.58
3	4	55.4	1.93	16.10	3.48	5.60
	5	62.2	1.93	8.66	3.10	2.69
	6	60.2	1.93	9.26	3.21	2.97
	7	45.4	1.93	20.00	4.25	8.50
	8	55.9	1.93	13.30	3.45	4.60

These red matches based on Si/Pb_3O_4/DDNP mixtures are tested by the nondestructive inspection. Each of them weighs 0.03～0.04g approximately. These experimental results are listed in Table 3.

In Table 3, 120 red matches are tested. Thereinto, the temperature increments of four of them are less than 25.0℃, individually 24.6℃, 24.7℃, 24.9℃ and 24.9℃; five of them more than 38.0℃, individually 38.1℃, 38.1℃, 36.6℃, 36.7℃ and 39.9℃. The temperature constants, only two of them, are under $9.00\times10^{-3}\cdot s^{-1}$, and separately $8.08\times10^{-3}\cdot s^{-1}$ and $8.45\times10^{-3}\cdot s^{-1}$; and fourteen of them preponderate over$14.0\times10^{-3}\cdot s^{-1}$. The heat loss coefficients fasten between $4.0\times10^{-4}\cdot$ ℃$^{-1}$ and $7.0\times10^{-4}\cdot$ ℃$^{-1}$, one of them less than $4.0\times10^{-4}\cdot$ ℃$^{-1}$ and eleven of them more than $7.0\times10^{-3}\cdot$ ℃$^{-1}$, two of them more than $8.0\times10^{-3}\cdot$ ℃$^{-1}$, individually $8.0\times10^{-3}\cdot$ ℃$^{-1}$ and $8.2\times10^{-3}\cdot$ ℃$^{-1}$. Compared with those parameters, the heat capacities are more of dispersing, six of them less than $5.0\times10^{-6}J\cdot$ ℃$^{-1}$ and six of than more than $9.5\times10^{-6}J\cdot$ ℃$^{-1}$.

Table 3 The nondestructive inspection results of commercial red matches

Index	Variety range	The proportion /%	The maximum	The minimum
Temperature increment /℃	25 ~ 30	53.33	39.3	24.6
	30 ~ 35	32.50		
	35 ~ 38	6.67		
Temperature constant /$\times10^{-3}\cdot s^{-1}$	10 ~ 11	7.50	15.5	8.08
	11 ~ 13	43.33		
	13 ~ 14	19.17		
Heat loss coefficient /$\times10^{-4}W\cdot$℃$^{-1}$	4 ~ 5	18.33	8.15	3.99
	5 ~ 6	37.50		
	6 ~ 7	34.17		
Heat capacity /$\times10^{-6}J\cdot$℃$^{-1}$	5 ~ 6.5	32.50	10.5	4.53
	6.5 ~ 8	40.83		
	8 ~ 9.5	16.67		

5 Firing Reliability

In Fig. 2, from curve 1 to curve 6, the testing current separately is 0.48A, 0.51A, 0.54A, 0.45A, 0.43A and 0.46A. And the resistance of a red match head individually is 2.54Ω , 2.57Ω , 2.94Ω , 2.78 Ω , 2.51Ω and 2.72Ω . Curve 1 has a typical shape and a peak value of temperature increment. Just as curve 2, curve 3 and curve 6, because of unstable propagations of combustion waves, the temperature increments put up concussive phenomena. Curve 2 and curve 6 show us that the bridge wires are not broken after ignition. Curve 3 explains that the bridge wire is broken after ignition. When electrified with a smaller current, for example, curve 4 and curve 5 vary smoothly, yet we also may find an obvious inflexion individually. Notwithstanding the corresponding red match head of cure 5 doesn’t explode. Fig.3 shows us the ignition curves of rejects and double bridge wires.

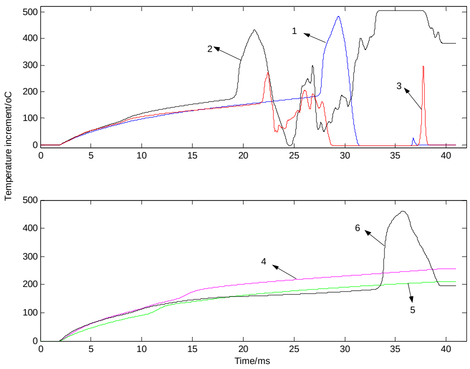

Fig. 2 Ignition curves of red matches

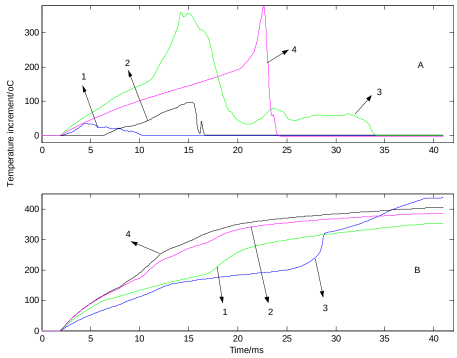

Fig. 3 Curves of Rejects and Double Wires

6 Relationship between Nondestructive Inspection and Firing Performance

The constant current value is fixed on 0.08A. The durative time electrified is lasting for 0.1s. The sampling interval setting is 2.0×10^{-5}s. These red matches are tested by the nondestructive inspection. After that, the 30 red matches continue to be tested by the firing experiment under 0.28A. When fired, the black match is earmarked as '√ '. Then, we calculate electrothermal parameters of the nondestructive inspection experiment arrange experimental data in a seriation and compare them with the results of the firing experiment to analyze the relationship between eletrothermal parameters and firing performance. These experimental results are listed in Table 4.

In Table 4, six firing red matches are among retral ten heads with a higher temperature and among anterior fourteen heads with a smaller heat loss coefficient, furthermore, next to anterior places.

7 Discussions

From before-mentioned statistic results, we can eliminate the commercial electric detonators with double bridge wires, especially without a well-contacted interface between a bridge wire and charges. It is not easy to be realized by a conventional testing. The contacted status between a bridge wire and charges carries much weight on the inspection results. With an ill contact, exempli gratia some small air bubbles, the temperature of a bridge wire moves up too high and one of the charges too low yet. Under the same condition, firing products have higher temperature increments, bigger temperature constants and smaller heat loss coefficients.

Table 4 The relationship of electrothermal parameters and firing performance

Number	Temperature increment /℃	Result	Number	Constant of temperature /$\times10^{-3}\cdot s^{-1}$	Result	Number	Heat loss coefficient/$\times 10^{-4}W\cdot℃^{-1}$	Result	Number	Heat capacity/$\times 10^{-6}J\cdot℃^{-1}$	Result
7	24.6		19	8.45	√	5	4.39	√	19	4.53	√
20	26.1		2	10.3		13	4.52	√	16	5.18	
15	26.5		11	10.6		16	4.62		5	5.54	√
29	26.5		14	10.7		22	4.63	√	22	6.01	√
14	26.8		27	10.8		9	4.73		27	6.12	
23	27.3		25	11.1	√	21	4.73		21	6.39	
2	27.3		16	11.2		19	5.36	√	17	6.39	
26	27.8		7	11.4		3	5.45		25	6.49	√
12	28.5		17	11.4		1	5.49		13	6.58	√
18	28.5		15	11.7		17	5.59		3	6.79	
11	28.8		10	12.1		8	5.63	√	9	6.82	
30	29.0		23	12.5		27	5.64		11	6.95	
28	29.2		26	12.5		24	5.69		8	7.30	√
6	29.3		3	12.5		25	5.84	√	10	7.36	
4	30.0		5	12.6		12	6.04		14	7.54	

17	30.2		28	12.8		10	6.07		1	7.61
24	30.2		18	12.8		4	6.13		26	7.73
10	30.3		8	13.0	√	26	6.20		24	8.02
1	30.8		22	13.0	√	6	6.23		4	8.05
3	31.0		4	13.1		30	6.28		2	8.13
25	31.4	√	30	13.2		18	6.44		30	8.26
27	32.3		6	13.4		28	6.46		18	8.27
8	32.6	√	21	13.5		11	6.56		28	8.30
19	34.3	√	29	13.7		14	7.05		6	8.34
21	35.3		1	13.8		29	7.43		12	8.63
9	35.3		20	13.9		20	7.55		7	9.17
22	37.8	√	24	14.1		2	7.89		15	9.53
16	37.8		12	14.3		23	7.90		23	9.87
5	38.1	√	9	14.4	√	7	8.02		29	10.2
13	38.7	√	13	14.6	√	15	8.15		20	10.5

8 Conclusions

The investigation concerns the transient pulse testing for commercial electric detonators. The critical ignition condition and the testing system are discussed. It is concluded that the transient pulse technique can be used not only in the nondestructive inspection, but also in the firing performance testing. The transient pulse testing can display the dynamic process of nondestructive inspection and firing reliability of mining detonators.

The relationship between the firing performance and the nondestructive inspection is discussed. Rosenthal modeling is effective to calculate the electrothermal parameters. Also, a farther research is needed to consummate the transient pulse testing for commercial detonators and other EEDs.

References

[1] L.A.Rosenthal. Electrothermal Characterization of Electroexplosive Device[C]. Proc. of the 4th Electric Initiation Symposium. Philadelphia USA, 1963

[2] L.A.Rosenthal, V.J.Menicheli. Nondestructive Testing of Insensitive Electroexplosive Devices by Transient Techniques[R]. JPL Technical Report 32-1553, 1972

[3] L.A.Rosenthal, V.J.Menichelli. Response of EED to Impulsive Waveforms[C]. Proc. of the 7th Symposium on E&P. Philadelphia USA, 1971

[4] V.J.Menichelli, L.A.Rosenthal. Fault Determination in EEDs by Nondestructive Techniques[R]. JPL Technical Report 32-1533, 1972

[5] V.J.Menichelli, L.A.Rosenthal. Intermination of Nondestructive Testing to Fault Determination[C]. Proc. of the 7th Symposium on E&P. Philadelphia USA, 1971

[6] B.R.Steele, A.C.Strasburg. New Methodology for Transient Pulse Testing[C]. Proc. of the 8th Symposium on E&P. LosAngeles USA, 1974

[7] W.J.Sipes. Thermal Response Testing of EEDs[C]. Proc. of the 9th Symposium on E&P. Philadelphia USA, 1976

[8] A.C.Strasburg. Methodology for Computation of Interface Parameters of a Hot Wire Explosive Device from the Electrothermal Response Analog[R]. SLA73-1034 Sandia Lab, 1973

[9] V.J.Menichelli. Computerized Thermal Transient Test Console[C]. Proc. of 9th Symposium on E&P. Philadelphia USA, 1976

[10] Pasadena Scientific Industries. Model 605B Thermal Transient Test Set Installation and Operation. Pasadena, California 91105, 1979

[11] J.R.Cook. Development of Transient Pulse Thermal Tester for EED Production Line[C]. Proc. of the 11th Symposium on E&P. Philadelphia USA, 1981

[12] L.A.Rosenthal. Thermal Transient Measurements in Thin Films[C]. Proc. of the 11th Symposium on E&P. Philadelphia USA, 1981

[13] O.L.Burchett, A.C.Strasburg, A.C.Munger. Electrothermal Response Testing of EED with Electrically Conducting Explosives[C]. Proc. of the 7th International Pyrotechnics Seminar, 1980

[14] C.T.Davey, J.F.Heffron. Electrothermal Analytical Response Inspection of Electroexplosive Device[R]. ADA112 328, 1980
[15] C.T.Davey, J.F.Heffron. Digital Analysis of Electrothermal Parameters of Electroexplosive Devices[R]. Proc. of the 15th International Annual Conference of ICT, Karlsrube Germany, 1985
[16] J.G.Taylor. Thermal Property Determination for Bridge wire ignition Modeling[C]. Proc. of the 12th Symposium on E&P, San Diego, California USA, 1984
[17] M.W.Leeuw, E.A.Bal, W.C.Prince. Parametric Analysis of the Reliability of Igniter Systems-PARIS [J]. Review of Scientific Instruments, 1992(6), pp. 63
[18] G.H.Oarga, C.Cepisca, S.D.Grigorescu. The Automatic Testing of the Electro Thermal Characteristics of High Voltage Fuses [J]. Cucrarile ICPE, 1995(1~2)
[19] Xie Xinghua, Hu Yi. Controlling and Nondestructive Inspection of Firing Sensitivity of Commercial Electric Detonators. Journal of Huainan Institute of Technology, 1999(4), pp. 39 -43
[20] Xie Xinghua, Peng Xiaosheng, Yan Shilong. Explosive Coupling of Blasting Caps in Air. Theory and Practice of Energetic Materials. Beijing: Science Press, 2001, pp. 313-318
[21] Xie Xinghua, Peng Xiaosheng. Non-herd Explosion between Detonators. In: Progress in Safety Science and Technology. Beijing: Science Press, 2002, pp. 1145-1147,
[22] XIE Xinghua. Detonation Safety of Blasting Caps. Journal of Coal Science and Engineering (CHINA), 2002(2), pp. 98-102
[23] Xie Xinghua, Li Hanxu. Combustion Principles. Xuzhou: China Mining University Press, 2002.9
[24] XIE Xinghua, PENG Xiaosheng & HU Xuexian. Transient Pulse Testing of Commercial Electric Detonators. In: Theory and Practice of Energetic Materials Vol.Ⅴ. Beijing: Science Press, 2003, pp. 294-299
[25] XIE Xinghua, PENG Xiaosheng & HU Xuexian. Electrothermal Responsibility of Bridge Wire in Media. In: Theory and Practice of Energetic Materials Vol.Ⅴ. Beijing: Science Press, 2003, pp.288-293