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Investigation of Effective Parameters on the Electro Explosive Fuses Operation

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ABSTRACT: Different parameters are effective on Electro Explosive Fuses (EFF) operation. Because of these fuses applications in high voltage generators, their recognition and investigation are of great importance. In this paper, firstly, related equations of fuse length and cross sectional area in various parts are completely presented. Then, these fuses behavior is modeled in PSpice using obtained equations. Electrical conduction model is used for modeling. After that, to evaluate efficiency of presented model, it is simulated and the effects of different parameters such as fuse length, cross sectional area and pulse generator circuit parameters are investigated. Finally, results obtained from modeling and simulations prove the importance of these parameters effects on the EEF operation.

Keywords: Fuse Cross Sectional Area, Electro Explosive Fuse (EEF), Fuse Length, PSpice.

INTRODUCTION

Regarding explosive fuses importance, recognition of effective parameters on their operations is so significant. The effects of varying a wide array of parameters have been studied, the metal foil thickness (Tasker, Goforth et al. 1998); the metal type; the metal temper; the current density (Tasker, Goforth et al. 2005). The various fuse parameters discussed in (Giesselmann, Heeren et al. 2000; Neuber 2005; Belt, Mankowski et al. 2006).The possibility of using an EEF-based system for driving an High Power Microwave (HPM) source has previously been shown for a Backward Wave Oscillator (BWO) (Polevin, Chernykh et al. 2006) and a virtual cathode oscillator (Kitsanov, Klimov et al. 2002) as a load.

Models have previously been developed to describe the behavior of wire explosions with equations (Sedoi, Mesyats et al. 1999; Tkachenko, Vorob'ev et al. 2003). These models can provide insight into the physical phenomena during the explosion process. However, for modeling and evaluating an Electro Explosive Fuse (EEF) and its interaction with the circuit, the primary parameter of interest is the EEF resistivity. Therefore, the model presented here is restricted to the resistivity of the conducting medium based upon the previously-demonstrated relationship between resistivity and the specific action or specific energy (Anderson, Neilson et al. 1959; Lindemuth, Brownell et al. 1985).The time-domain modeling of high-power circuits with dynamic resistive elements has been the subject of previous research (Tucker and Toth 1975; Lindemuth, Brownell et al. 1985; Heeren 2003).

In this paper, effects of different parameters such as fuse length fuse cross sectional area and circuit parameters on opening fuses operations have been investigated. For this purpose, firstly, fuse equations in different areas are obtained. Then, its behavior is modeled and simulated using these equations and PSpice. After that, the mentioned parameters impacts are studied using this model. Finally, the obtained results have been evaluated to access model efficiency.

Explosive Fuses and Their Effective Parameters

Explosive fuses are composed of several wire series with specific length are located in quenching material and they can be exploded in special current and it causes to cut current path. At first, these fuses operate as a resistance. During operation process, a lot of energy in fuse element is dissipated which leads to its temperature increasing and consequently fuse resistance temperature rising. Some fuse points are melted and then vaporized. These kinds of fuses are used as opening switches in inductive storage systems, pulse voltage generator and so on. Therefore, it is desirable that fuse operates in maximum current, because it causes to deliver maximum energy to load.

Fuse cross sectional area can be obtained as (Neuber 2005):

$$s_{fuse} = \sqrt{\frac{h}{a}} = \alpha\sqrt{t_{eq}}.I_{final} \qquad (1)$$

Where $\alpha = 1/\sqrt{a}$ is length proportionality constant which its value for copper is equal to $\alpha = 3.4\times10^{-9}\, m^2/A.s^{0.5}$ and I_{final} is fuse current at vaporization condition. Also, desired fuse length will be obtained as (Neuber 2005):

$$l_{fuse} = v.\beta.\frac{1}{\sqrt{t_{eq}}}.L_{store}.I_{final} \qquad (2)$$

β is size proportionality constant and its value for copper is equal to $\beta = 4.8\times10^{-3}\, A..s^{2.5}/kg.m$.

Different parameters are effective on explosive fuses operation which among them fuse cross sectional area, fuse length and circuit parameters can be mentioned. Fuse design will be studied in following parts.

Fuse Modeling

Fuse consists of some thin wire strings which are located in arc quenching material such as sand or manganese powder. To select fuse suitable cross sectional area and fuse length, its behavior can be simulated in PSpice software by which circuit operation including fuse can be analyzed. For recommended model, it is assumed that current increasing time rate is in microsecond range. In this range, fuse wires are thermal insulator and they do not transfer any thermal before fuse explosion. Presented model cannot be used for power system protective fuses. Generally, explosion consists of two parts. In first part, solid wire is warm due to input heat until a part of fuse is exploded. In this case, the whole wire isn't exploded and instability will happen. In second part, resistance is extremely increased and the whole fuse will be exploded. Fuse behavior in these parts can be simulated. Approximate behavior of fuse resistivity can be modeled by following equation:

$$h = \int_0^t J_{wire}(t)^2\, dt \qquad (3)$$

$$\rho(t) = \begin{cases} 1 + A\left(\dfrac{h}{h_e}\right)^{2.5} & if\ h \le h_e \\ A + \exp\left(C.\dfrac{h}{h_e} - C\right)^{2.5} & otherwise \end{cases} \qquad (4)$$

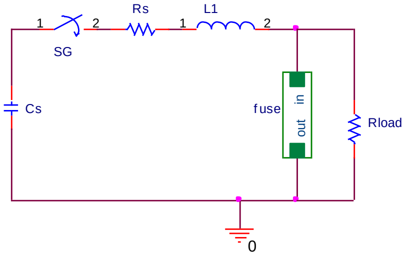

Figure 1. High voltage pulse generator based on electro explosive opening switch

In (4) h_e is fuse element blow limit. Fuse behavior in two steps of opening versus time is shown by above equation. Resistance value is determined by integral of current action or h. If h is equal or greater than h_e value, first step will be finished. Constants used in (4), for copper, silver and aluminum are similar to Table.1. Fuse subcircuit is shown in Fig. 2. In this figure, fuse current is measured and it is modeled as a controlling voltage source using (4).

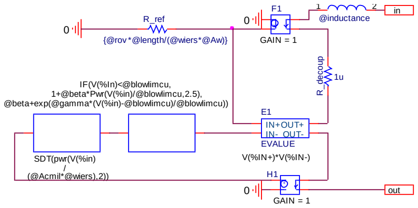

Figure 2. Subcircuit of fuse

Table 1. List of modeling constants for Copper, Silver and Aluminum for wires surrounded by impact beads, and a maximum current density of 1011 A/m2 [5]

	Description	Copper	Silver	Aluminum
H_e [10^{17} $A^2 s/m^4$]	Blow limit	1.6	1.03	0.59
A	Scalar constant	23.9	36	19
B	Exponential parameter before vaporization	2.3	4.5	2.3
C	Exponential parameter after vaporization	118	100	85

Simulation Results

In this section, fuse simulation results and the effects of different parameters on its operation are investigated. Parameters which are studied are:

- Fuse cross sectional area
- Fuse length
- Circuit parameters for instance capacitor and leakage inductance

To study and simulation of these parameters, a capacitor voltage pulse generator circuit is used which is shown in Fig. 1. In this circuit, capacitor is charged to a specific level and it is discharged using a gap spar in load and at this time, fuse at a special current will operate in discharging process. During this time, a little energy is dissipated and only little percentage of that is transferred to load.

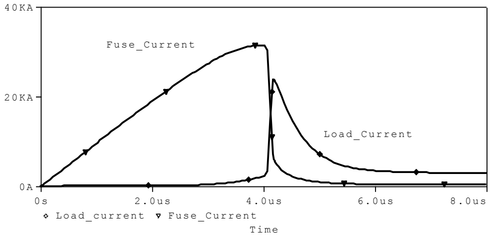

Figure 3. Fuse and load current waveforms

In Fig. 1, first by fuse modeling, pulse voltage generator is simulated using 8 fuse wire strings of AWG35 with 14.3 cm length. In Fig. 3, fuse and load current is shown. According to this figure, fuse operates at current value about 32kA and causes to transfer current to load. When this current flows through load, voltage shown in Fig. 4 will be created in it. The amplitude of this voltage is 238.38kV and it's rising and falling time are 129 nsec and 537 nsec respectively. Obtained results are considered as reference values. Different parameters effects on fuse operation will be investigate in following parts.

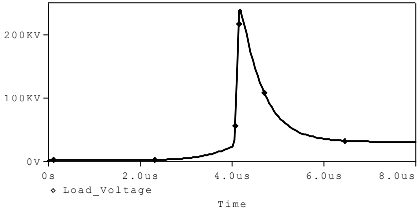

Figure 4. Load voltage waveform

Effects of fuse cross sectional area on its operation

Cross sectional area has considerable effect on fuse operation. The bigger the cross sectional is, the more energy is needed for melting. Therefore, fuse will operate in higher current and time which will significantly affect waveforms of different parts. Cross sectional area can be changed by increasing or deceasing fuse string numbers. So, to study this parameter effect, fuse strings is increased from 8 to 15 and fuse is simulated.

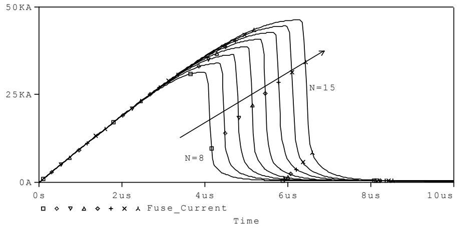

Figure 5. Effect of fuse cross sectional area variation on the fuse current waveform

According to Fig. 5, it can be pointed out that by increasing string numbers from 8 to 15, fuse current is increased from 31.415 kA to 46.316 kA. In other words, increasing fuse string numbers leads fuse to operate at higher current. Also fuse operation time will be increased from 3.97 msec to 6.27 msec due to fuse requirement of higher temperature to operate. However, fuse operating time can be changed using other parameters such as leakage inductance. Load voltage is shown in Fig. 6. According to this figure, by increasing fuse string number, voltage is generated at higher time and output voltage is increased as well.

Maximum Output voltage, rising and falling time for different fuse string numbers are listed in Table. 1. The effect of fuse string numbers increasing on generated pulse characteristics can be evaluated using this table.

Table 2. Amplitude, rising and falling time of output voltage for different fuse wires

Fuse Strings	Maximum Output Voltage	Falling time	Rising Time
8	238	538	129
9	239	571	105
10	247	580	103
11	271	544	99
12	275	561	107
13	276	583	99.4
14	295	556	127
15	298	564	116

Effects of fuse length variation on its operation

Fuse length variation can also affect its operation. To investigate this impact, fuse length is increased from 10 cm to 80 cm. fuse current is plotted in Fig. 7.

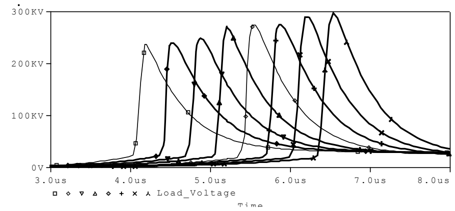

Figure 6. Effect of fuse cross sectional area variation on the load voltage waveform

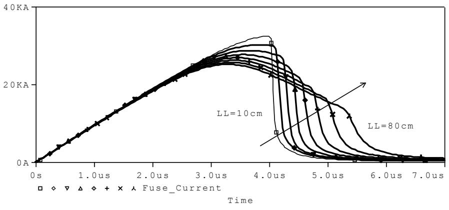

Figure 7. Effect of fuse length variation on the fuse current waveform

The important note is that by increasing fuse length, it will operate at the time after peak current which at this time; fuse current is low and transferred current to load is less. Hence, this note should be taken into consideration in fuse design that fuse operates at peak current in order that current transferred to load and consequently generated load voltage is maximized. Load voltage waveform is shown in Fig. 8. Generated voltage amplitude is variable. To better comparison, load voltage waveform and fuse current are plotted in Fig. 9. This figure indicates that fuse operates at higher time (lower current).

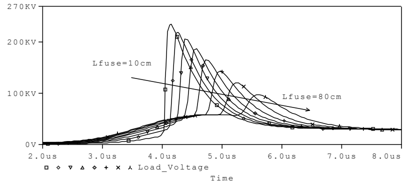

Figure 8. Effect of fuse length variation on the load voltage waveform

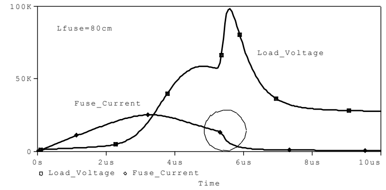

Figure 9. Load voltage and fuse current with 80 cm fuse length

Effects of circuit parameters on pulse waveform

The parameters of pulse voltage generated circuit have also influence on fuse operation. The most important parameters are leakage inductance and storage capacitor which will be analyzed in following parts.

Circuit inductance variation

To investigate this effect on fuse operation, this inductance value is changed from 1mH to 7 mH and its impact on waveforms is evaluated. Fuse current waveform is shown in Fig. 10.

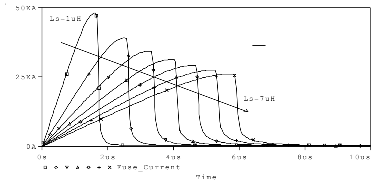

Figure 10. Effect of circuit leakage inductance variation on the fuse current waveform

According to this figure, leakage inductance increasing causes fuse current slope to be decreased. As a result, the time to obtain energy for fuse melting will be increased. For instance, for inductance value of 1 mH, this time is about 1.63 msec. However, for 7 mH inductance, this time will be increased up to 5.81 msec. Also, peak current is decreased from 48 kA to 26 kA which should be considered.

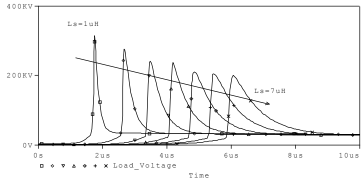

Figure 11. Effect of circuit leakage inductance variation on the load voltage waveform

Leakage inductance variation impact on load voltage is shown in Fig. 11. These waveforms characteristics are listed in Table. 3. According to this table results, leakage inductance increasing leads to decrease output voltage amplitude and increasing of rising and falling time.

Table 3. Amplitude, rising and falling time of output voltage for different leakage inductance value

Fuse Strings	Maximum Voltage	Falling time	Rising Time
1	315	146	76
2	275	282	82
3	241	440	119
4	238	538	129
5	210	729	132
6	204	846	135
7	200	952	159

Storage capacitor variation

Capacitor changing can also affect fuse operation and output voltage waveform parameters as well. In this case, capacitor value is increased from In this case, capacitor value is changed from 5 mF to 25 mF and its effects on current waveform is investigated which is shown in Fig. 12. According to this figure, capacitor increase has insignificant impact. For instance, if capacitor value is increased to 10, 15, 20 and 25 mF, it has no considerable influence on fuse current waveform as it is shown in Fig. 13.

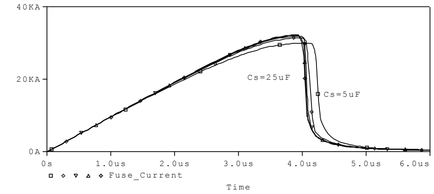

Figure 12. Effect of capacitor variation on the fuse current waveform

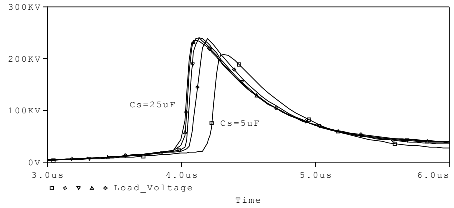

Figure 13. Effect of capacitor variation on the load voltage waveform

CONCULSION

In this paper, different parameters effects on fuse operation have been investigated. For this purpose, first of all, fuse equations as well as effective parameters have been presented. Besides, equations have been determined in order to select and design optimal value of these parameters. Moreover, in another part, fuse has been modeled by resistivity model and after that has been simulated using PSpice. In addition, parameters such as cross sectional area, fuse length and circuit parameters have been evaluated. To investigate cross sectional area effect, fuse string wire has been changed. Results have shown that this parameter could change generated voltage amplitude, falling and rising time. Cross sectional area increase can also increase fuse operational time. Furthermore, fuse length increase can affect fuse operation. Finally, pulse generated circuit parameters such as capacitor and leakage inductance has been simulated and their effects have been investigated and tested.

REFERENCES

D. G. Tasker, *et al.*, "New studies of explosively formed fuse opening switches," *IEEE International on Plasma Science, 1998. 25th Anniversary. IEEE Conference Record,* 1998.

D. G. Tasker, *et al.*, "High Current, Low Jitter, Explosive Closing Switches," *IEEE Pulsed Power Conference,* pp. 517 - 520, 2005.

D. Belt, *et al.*, "Design and implementation of a flux compression generator nonexplosive test bed for electroexplosive fuses," *Rev. Sci. Instrum,* vol. 77, 2006.

M. Giesselmann, *et al.*, "Experimental and analytical investigation of a pulsed power conditioning system for magnetic flux compression generators," *IEEE Trans. Plasma Sci,* vol. 28, pp. 1368–1376, 2000.

A. A. Neuber, "Explosively Driven Pulsed Power Helical Magnetic Flux Compression Generators," *Springer-Verlag Berlin Heidelberg,* 2005.

S. D. Polevin, *et al.*, "HPM pulses generated by S-band resonant relativistic BWO with power supply based on MCGs," *in Proc. 3rd Euro-Asian Pulsed Power Symp,* 2006.

S. A. Kitsanov, *et al.*, "S-band vircator with electron beam pre modulation based on compact pulse driver with inductive energy storage," *IEEE Trans. Plasma Sci,* vol. 30, pp. 1179-1185, 2002.

V. S. Sedoi, *et al.*, "The current density and the specific energy input in fast electrical explosion," *IEEE Trans. Plasma Science,* vol. 27, pp. 845-850, 1999.

S. I. Tkachenko, *et al.*, "Parameters of wires during electric explosion," *Applied Physics Letters,* vol. 82, pp. 4047-4049, 2003.

G. W. Anderson, *et al.*, "Use of the "action integral" in exploding wire studies in Exploding Wires," *Eds. New York, NY: Plenum Press,* 1959.

I. R. Lindemuth*, et al.*, "A computational model of exploding metallic fuses for multi mega joule switching," *J. Appl. Phys,* vol. 57, pp. 4447–4460, 1985.

T. J. Tucker and R. P. Toth, "A computer code for the prediction of the behavior of electrical circuits containing exploding wire elements," *Sandia Nat. Lab., Albuquerque, NM, Tech. Rep. SAND-75-0041,* 1975.

T. Heeren, "Power Conditioning for High Voltage Pulse Applications," *M.S. thesis, Texas Tech Univ., Lubbock, TX,* 2003.