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Relationships between bridge foil parameters and input pulse current

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Abstract

The electrical exploding of a bridge foil consists of four stages: solid, liquid, gas and plasma. Most of the energy absorbed by the bridge foil comes from joule heating; therefore, it is great important to study the influence of the parameters of the bridge foil on its electrical exploding process. In order to improve the energy efficiency of the exploding foil initiation system (EFIs) and obtain the relation between the bridge foil parameters and input pulse current, the deposited energy and the peak power in the process of electrical explosion of square waveform bridge foil was investigated. The result of this study could provide guidance for the optimization design of exploding foil initiation system.

Keywords: bridge foil geometry; input pulse current; parameters matching; energy utilization efficiency

1. Introductions

The exploding foil initiator system (EFIs) consists of pulsed power supply and slapper detonator[1]. The mechanism of (EFIs) is that when a high current pulse is passed through the bridge foil it is vaporized, the metal plasma expanded into the barrel rapidly, causing the insulating foil to form a flyer which is accelerated down the barrel. The flyer can reach high speed, impacting the explosive and causing detonation. The EFIs has been attracted great attention by lots of weapon experts because of its advantages such as security, reliability, and synchronism. In recent years, the miniaturization of the EFIs is major research direction, and the key point of the miniaturization is the reasonable matching of parameters of bridge foil and the pulse power supply, so improve the efficiency (η=deposited energy by bridge foil /energy stored by capacitor) has very important significance.

The design of the bridge foil parameters is very important. Domestic researchers only did some qualitative analysis that when the bridge foil explosion time is the time when the current at first peak, the EFIs efficiency is high[2-3], and they do not consider how to design the foil parameter more reasonable such as shape and size to improve efficiency. So in this paper, it can improve efficiency by using the square wave form foil to reduce explosion time.

2. Process and mechanism of bridge foil electrical exploding

The mechanism of the bridge foil electrical exploding is generally expressed as follows: when a high pulse current is passed through the bridge foil[4], because of the joule heating, the bridge foil temperature, resistance, voltage will rise rapidly, due to joule heating. For the short time of electrical exploding, the bridge foil can maintain its shape and keep heating until it is vaporized. Since the restraining of the surrounding area and the electromagnetic field which is created by high pulse current, the copper vapor can not expand immediately, but will be heated in the overheat condition, and the

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temperature will exceed the boiling point. Henceforth, the destruction of the dynamic equilibrium makes the beginning of the vaporization, because the expansive force of the copper vapor is higher than the resultant of electromagnetic and surrounding area. The vaporization starts from the exploding surface. For the high pressure of the copper vapor makes the obstruction of the electron's movements, the resistance will increase and the current will fall quickly.

The current and voltage curves in the electrical exploding were measured, so as to judge whether it is matching the parameters of pulsed current[5]. If the burst time is too short (relative to time of the peak value of pulsed current), it indicates that the energy utilization efficiency is too low, and the higher pulsed energy is bad for the miniaturization of EFIs. The energy which is absorbed by the exploding foil and the power in the explosion time can be calculated by the curve of the current and voltage in the process of electrical exploding, which are the key parameters of EFIs[6]. Based on the certain value of the deposited energy and power of the explosion in the electrical exploding, a new type of the bridge foil can reduce the initial energy of the capacitor and increase the efficiency of the EFIs.

3. Experiments

Three square wave form bridge foils which have different thickness and initial resistance were studied, compared with a traditional square form bridge foil. The capacitance of the pulse power supply is 0.075μF, and the inductance L and the resistance of the circuit R can be calculated by the curve of the short-circuit current. Fig. 2 shows the short-circuit current waveform. The parameters of the pulse current initiating the traditional square form foil are defined as C=0.22μF, and the inductance L=170nH. the charging voltage is V0=2500V. The current of the initiation system can be measured by Rogowski coil and the voltage of the bridge foil was measured using high-voltage detector. The Fig.1 shows the sketch plan of the experiment.

The parameters of the exploding foil are showed in table 1. Fig.3 shows the shape of the bridge foil.

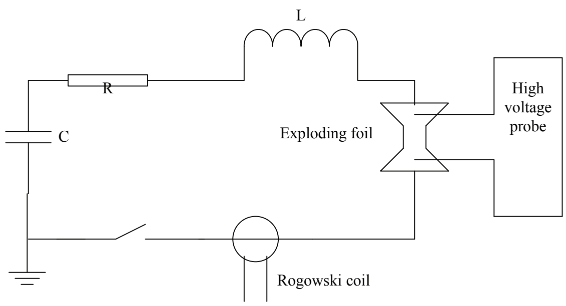

Fig. 1. Sketch plan of the experiment.

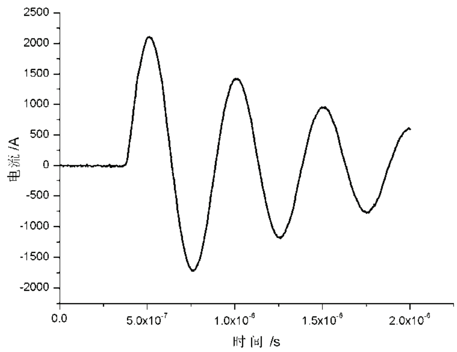

Fig. 2. Short-circuit discharge current waveform.

Table 1. Parameters of the bridge foils

Number	Length/μm	Width/μm	Thickness/μm	Initial resistance/mΩ
1#	1500	100	6	66
2#	1500	100	4	100
3#	1500	100	2.5	287
Square form bridge	300	300	4	26

4. Results of experiments and discussion

Fig.4 shows the curves of the current and voltage in the electrical exploding; the burst time tb, peak value of exploding current ib and peak value of exploding voltage Vb, deposited energy in bridge foil W, the power Pb at the burst time and the efficiency are listed in the Table 2.

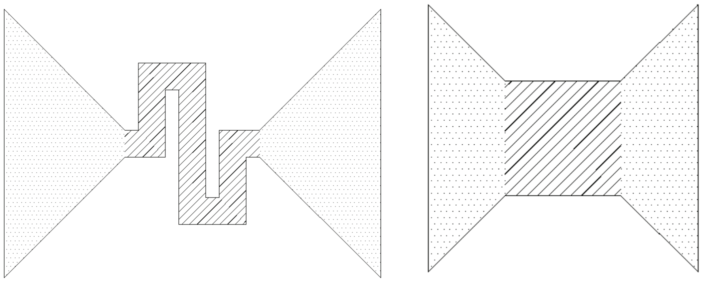

Fig. 3. Sketch plan of the square wave form exploding foil and square form exploding foil.

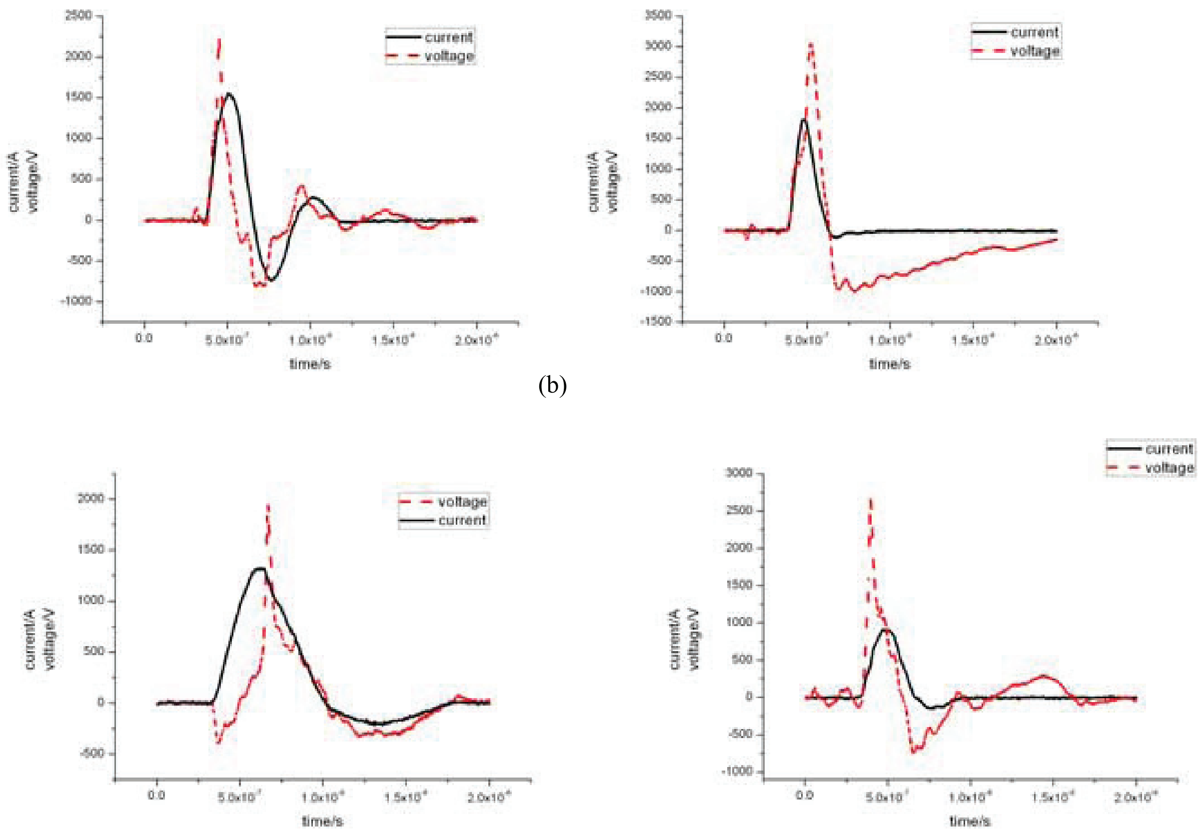

Fig. 4. Curves of the electrical parameters of (a) number 2 foil, (b) number 1 foil, (c) square form foil and (d) number 3 foil.

Table 2. Result of the electrical parameters

number	t_{peak}/ns	t_b/ns	V_b/kV	i_b/kA	W/mJ	P_b/W	η/%
1#	90	134	3.043	1.43	199	4.1×10^6	85
2#	124	73	2.224	1.196	56	2.66×10^6	24
3#	150	68	2.648	0.416	17.43	1.1×10^6	7.5
Square form foil	282	340	1.936	1.216	67	2.35×10^6	21

In the process of electrical exploding, due to the inductance of the bridge foil, a high voltage UL ($U_L = L\frac{\mathrm{d}i}{\mathrm{d}t}$) will be induced which may be several times as the charge voltage U0. So one of the three following conditions will be occurred.

(1) There is no pause time in the current. Since the length of the bridge foil is rather short, the induced voltage could break down the surrounding medium, and the plasma can be formed with the copper vapor.

(2) There is pause time in the current. Since the length of the bridge foil is rather long, the induced voltage could not break down the surrounding medium, so the current is absolutely discharge by the breakdown of the copper vapor. Because of the pressure and density of the copper vapor, there is a moment when the copper vapor is not ionized. After the copper vapor is ionized, the current rise, and appear the exploding flash.

(3) Nearing matching state. If the design of the foil geometric parameters (such as shape, thickness, size and so on) is rational, the situation 1 and 2 will not appear, the energy discharged from the capacitance will be used in ionizing the copper vapor, not ionizing the surrounding medium, and in this situation, the current will not be damping concussion but critical damping.

So the nearing matching state is the state when the energy utilization efficiency of EFIs is the maximum. According to the theory and experiment, we can see that the current of number 1 foil is not the damping concussion curve, but the critical damping curve. Fig.5 shows it.

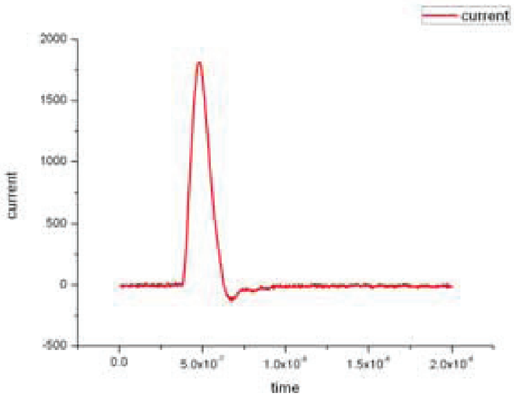

Fig. 5. Exploding current of number 1 foil.

And the table 2 shows the deposited energy absorbed by the exploding foil and the power of the exploding moment of the number 1 foil are exceeding the square form foil. We can calculate the energy utilization efficiency of the number 1 foil is 85%, but the square form foil is only 24%. So this system which matches the number 1 foil and short period pulse current can significantly increases the efficiency. As the initial resistance increased, the deposited energy and the power are correlating diminished, because of the shorten time of the burst. The shorter burst time is, the less energy the foil use. Instance for the numbers 3 foil, the burst time is 68ns, which is less than the peak current time 82ns, so a large portion of capacitor energy is not released and will dissipate; but the burst time of number 1 foil is 134ns, which is longer than the peak current 44ns, it means that the capacitor energy of the first quarter discharge cycle is used in the exploding foil. So the parameters of number 1 foil are matching the parameters of the pulsed current. And number 2 and number 3 foil should match the pulsed current which has much shorter discharge cycle, but there is certain difficulty in developing the lower capacitor and lower inductance of the discharge circuit.

5. Conclusions

The miniaturization of EFIs is the trend of development. According to the experiments, the following major conclusions can be drawn:

(1) Compared with the square form foil, the system using new type of exploding foil which has square wave form bridge, matching the short period discharged pulse current can reduce the capacitor energy and increase the efficiency. The efficiency is up to 85%;

(2) The higher the initial resistance of the bridge foil is, the shorter the pulsed current discharge cycle need. Although there is certain difficult to develop the high voltage capacitor which has lower capacitance and inductance, it can provide the guidance for the miniaturization of EFIs.

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