Circuit Inductance Influence on Shock Wave Generation under Electrical Explosion of Foil

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Abstract – Circuit inductance influence on pressure wave generation during electrical explosion of Cu foil was experimentally investigated. Pressure wave is significantly increased when the circuit inductance decreasing. For circuit inductance L_c < 100 nH physical limit for pressure wave ($P_m \cong 1.17$ GPa) increasing was founded.

1. Introduction

Shock waves initiated by electric explosion of conductors in gas and, especially, in the condensed media, find wide application in engineering and technologies due to a possibility purposefully to operate their characteristics in wide ranges. The pressure wave characteristics are changed by RLC-circuit parameters, sizes and material of the exploding conductor. For flat or composite (non-flat) shock wave generation in the condensed matters electric explosion of foil (EEF) is used. Advantage of the given method is formation of the shock wave with uniformly spatial pressure distribution on a surface of object. Thus the sample can have the composite geometrical form.

RLC-circuit parameters influence (the parameters determining rate of energy input into conductor) on shock wave pressure generation experimentally is not investigated. Some attempts were undertaken by authors of monographies [1-3], but the solved practical problems did not assume to record the shock wave profile and studying the influence of energy input rate on it.

In this study we investigated the circuit inductance influence (witch consist of the foil inductance and ballast inductance) on profiles of the shock wave pressure and the voltage pulse from electric explosion of Cu foil.

2. Experimental set-up

The electrical RLC-circuit used in the present work for investigation of the circuit inductance influence on pressure wave generation during electrical explosion of Cu foil is shown in Fig. 1. The schematic image of the experimental stand for measurement of the shock wave structure is given in Fig. 2. The capacity of a capacitor bank C_o was 79 μF (IC-50-3). Rate of energy input into the foil was varying by increasing or decreasing of circuit inductance L_c. The variation of circuit inductance L_c was carried out due to change of load (foil) inductance L_f and due to inclusion additional ballast inductance L_b ($L_c = L_f + L_b$) in the circuit (Fig. 1). Ballast inductance was the inductance sum, consisting of inductance of a circuit without load (inductance of cables, collector, wireway and capacitor bank) and addition inductance. In case of absence of additional inductance, the L_b means only the inductance of a circuit without load. The surface discharge switch was used for switching the electric circuit (see Fig. 2) [4].

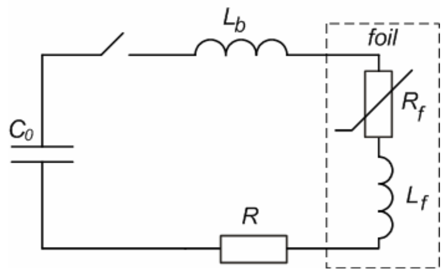

Fig. 1. RLC-circuit for electric explosion of a foil

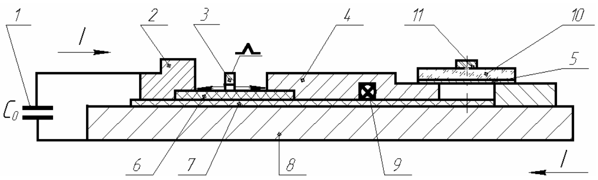

Fig. 2. The schematic image of the experimental apparatus: 1) capacitor bank, 2) high voltage electrode, 3) initiating electrode, 4) collector, 5) exploding foil, 6) dielectric for surface discharge, 7) insulation, 8) electrical pathway (wireway), 9) Rogovski coil; 10) polymethylmethacrylate plate (substrate), 11) the gauge of pressure

Experiments were carried out at bank voltage U_o 30 kV. The foil inductance - 5 varied due to change of distance up to the opposite electrical pathway (wireway) - 8 (see Fig. 2). The copper foil - 5 thickness of 18 μm had the sizes 100Ч100 mm. The distance from foil up to the opposite electric pathway - 8 changed in a range 15 … 40 mm (inductance of foil L_f was 19 … 76 nH). Additional inductance was connected to the collector - 4 and exploding foil - 5 (in Fig. 3 additional inductance is not shown). The value of ballast inductance L_b was 16, 190, 500 and 1530 nH. We considered the foil inductance L_f is not depended on time t up to the moment of explosion. The foil inductance estimation had completely coincided with experimentally measured. The value L_f was determined from an earlier calibration of the circuit with an unexploded copper conductor (results of short circuit experiments with unexploded equivalent copper plate [4]). A Rogovski coil – 9 was used to measure the current flowing through the foil *I(t)*. A resistive divider was used to measure the voltage developed across the foil $U_f(t)$. The error of measurements was 10 %.

The rate of energy input into foil (heating rate) *dE/dt* was calculated by using the following equation:

$$dE(t)/dt = I(t) \times (U_f(t) - L_f\, dI(t)/dt) \qquad (1)$$

The pressure pulse from electrical explosion of copper foil was measured by cylindrical quartz sensor - 11 (differentiating mode [5]) (see Fig. 2). The pressure wave propagated through polymethylmethacrylate plate (substrate) - 10 (it has a thickness of 3 mm); the pressure was measured on a free surface of the polymethylmethacrylate plate. The pressure gauge 30 mm in diameter has a thickness (height) of 5 mm. Duration of pressure wave registration was 0,85 µs.

3. Results of experiments

Fig. 3(a) presents pulses of power *dE/dt* (dynamics of heating rate changing for different circuit inductances L_c) calculated from (1). The time profiles of pressure wave generated from electric explosion of foil for different circuit inductances L_c are shown in Fig. 3(b). For illustrativeness the pressure wave beginnings are shown in one point - for the moment of time 2,45 µs. Dependence of the shock wave amplitude P_m generated from EEF on circuit inductance $L_c=L_f+L_b$ is given in Fig. 4(a). In Fig. 3(b) and 4(a), the peak pressure of the shock wave increases up to limit $P_m \cong 1{,}17$ GPa as the circuit inductance L_c is decreased. Duration of the pressure pulse front t_{Pf} also is kept constant (see Fig. 3(b) and 4(b)). Obtained "saturation" for amplitude and form of the shock wave at values of circuit inductance L_c = 35,5 … 91 nH, obviously, testifies to realization of extreme possible rate of physical processes which determine the foil explosion.

There is another qualitative peak voltage dependence on L_c (see Fig. 4). In the range of inductances varied it was not possible to find out peak voltage saturation. At increase of circuit inductance for account L_f (first four points – L_c = 35,5; 40; 91; 120 nH) and L_b (other points – L_c = 220; 530; 1560 nH), the peak voltage changes ambiguously. For increasing L_c due to inclusion additional ballast inductance L_b=190 nH in a circuit (L_c=220 nH) there was the peak voltage increasing (see Fig. 4(a)). Thus, voltage pulse is ambiguously connected to circuit inductance L_c and depends, besides L_f and L_b, also on their ratio. Fig. 4 illustrates that in case of varying only L_f or only L_b pressure pulse and voltage pulse have a relationship.

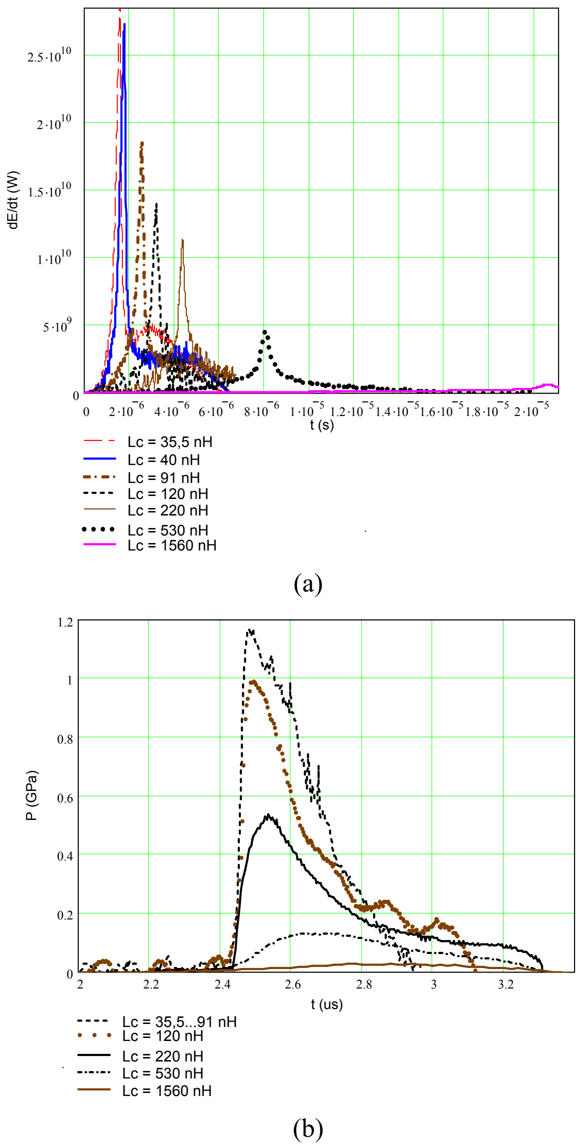

Fig. 3. Power (a) and pressure wave profiles (b) at various circuit inductances L_c

Dependences of pulse front durations of pressure t_{Pf} and voltage t_{Uf} on circuit inductance also correlate among themselves – if the circuit inductance L_c increases the pulse front durations are increased (see Fig. 4(b)).

It is necessary to note, the pressure wave under electrical explosion in water was investigated in paper [6]. According to that work the peak pressure of the shock wave and the peak voltage have a linear relationship for cylindrical conductors (wires). Changing of the material of a wire, its length and diameter the angle of linear dependence $P_m = f(U_m)$ changes only.

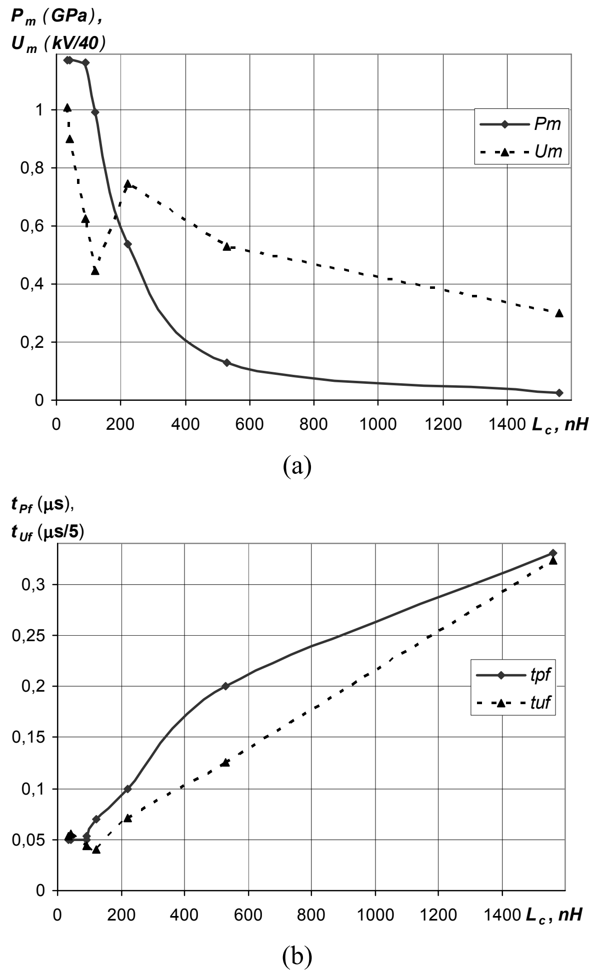

Fig. 4. Circuit inductance influence on amplitudes (a) and front durations (b) of pressure and voltage pulses

The relationships between the peak pressure and the peak voltage and also between their front durations are resulted from the same destruction process that determines both the pressure pulse and the voltage pulse from electrical explosion of conductors.

4. Conclusion

For flat or composite (non-flat) shock wave generation in the condensed matters electric explosion of foil is used. The RLC-circuit inductance increases (for L_c > 100 nH), the peak pressure of the shock wave is significantly decreased.

The peak pressure of the shock wave increases up to limit $P_m \cong 1{,}17$ GPa as the circuit inductance L_c is decreased. At the same time, the pressure pulse front duration t_{Pf} also is kept constant. Obtained "saturation" for amplitude and form of the shock wave at values of circuit inductance L_c = 35,5 … 91 nH, obviously, testifies to realization of extreme possible rate of physical processes which determine the foil explosion (physical restriction on shock wave increasing).

The minimal pressure pulse front duration is ~50 ns, and duration of a pulse on FWHV ~230 ns.

The relationships between the peak pressure and the peak voltage, and also between their front durations are resulted from the destruction process that determines both the pressure pulse and the voltage pulse from electrical explosion of conductors.

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