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TRANSIENTS AT CHANGING THE CONFIGURATION OF THE DISCHARGE CIRCUIT OF THE CAPACITOR OF SEMICONDUCTOR ELECTRICAL DISCHARGE INSTALLATIONS WITH AN ELECTRO-SPARK LOAD

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The method of multi-parameter functions is used in order to simplify the analysis of transients during the discharge of a capacitor to the electro-spark load in semiconductor electric discharge installations at changing the discharge circuit configuration for control the duration of the pulse currents in the load. On the basis of the analysis of transients in the discharge circuit of a variable structure of such installations, exact analytical expressions for calculating electrical characteristics of the circuit are obtained. It is determined the appropriate values of the connection moment and value of the additional inductance, which must be connected during the discharge of the capacitor to reduce the duration of discharge currents and stabilize the technological process in the electro-spark load. References 11, figures 8, tables 2.
Keywords: capacitor discharge, transient, electro-spark load, discharge duration, method of multi-parameter functions.

Introduction. High currents and powers required for modern electro-pulse technologies, in particular the production of spark-erosion powders [1, 2] and force electro-hydraulic actions [3, 4], cannot be obtained directly from the power supply network. That is why capacitive energy stores with linear capacitors [5] and nonlinear ones [6] are used in electro-discharge installations (EDIs) for these technologies. Capacitor batteries are also widely used in high-voltage pulse units for electromagnetic impact generation [7] and industrial induction installations for metalworking [8] to adjust load power. The most energetically and technologically efficient and fast-changing processes in the load circuit of all the above-mentioned installations are oscillating transients. At the same time, non-technological aperiodic modes of long-term energy transfer at low power appear in the load circuit when load resistance increase stochastically [9], which can occur in all the above-mentioned installations.

In EDIs with reservoir capacitors, in particular in semiconductor (thyristor) installations for volumetric electro-spark dispersion of conductive materials, the most technologically and energy-efficient discharge mode for electro-spark load is the oscillatory discharge of the capacitor with its recharge up to 30% of the initial voltage [10]. In this case, there is a fast natural locking of the discharge semiconductor key, which allows you to quickly carry out the next charge of the capacitor and its subsequent discharge on the load. Thus, it is possible to realize the high frequency of charge-discharge cycles and the stability of the duration of discharge currents in the load of EDIs.

At the same time, the resistance of such a load as a layer of conductive granules during the discharge current can stochastically increase several times, resulting in the so-called blank discharge on the load, that is, a long discharge with low current without sparks [10]. As the active resistance of the load increases, the Q-factor of the discharge circuit decreases, so the oscillatory process of the capacitor discharge can turn into an aperiodic process, in which the discharge duration is much increased. This increase in discharge duration is unacceptable for two reasons. Firstly, in this case, it becomes impossible to realize the high frequency of charge-discharge cycles of current pulses, and, consequently, to ensure the high productivity of the technological process of obtaining spark-eroded powders. The stability of the technological process is disturbed. Secondly, the size of the dispersed particles of the obtained powder is undesirably increased.

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Therefore, in known technological installations for obtaining metal powders by the method of volumetric electro-spark dispersion is usually used constantly connected special resistance R_{bypass}, bypassing load [10]. The value of this resistance was chosen so as to ensure the oscillatory discharge of the capacitor to the load when its resistance changes in a wide range. However, when such bypass resistance is used, the energy loss in the discharge circuit could reach 60% of the total energy stored in the capacitor.

To reduce such significant energy losses, it was justified in [10] that it is reasonable to stabilize the duration of pulse currents in the load by connecting a bypass thyristor at a certain point in time instead of using the permanently connected bypass resistor R_{bypass}. The configuration of the discharge circuit during the discharge process of the capacitor changed and the discharge remained always oscillatory. In this case, energy losses became much lower (up to 25%).

Another technical solution for limiting the duration of aperiodic discharges in semiconductor EDIs containing a reservoir capacitor and electro-spark load was to connect an additional bypass *RL*-circuit in parallel to the capacitor at some point in the discharge transient. In this case, the configuration of the discharge circuit during the discharge process of the capacitor on load also changed in order to convert a long-lasting aperiodic discharge into a rapidly damping oscillatory discharge. The transients in the discharge circuit of the capacitor were analyzed under the condition of changing its configuration (using the classical method of adding and solving differential equations with constant parameters) and analytical expressions were obtained for the currents in the bypass circuit and the load circuit. These expressions made it possible to investigate transients in capacitor discharge circuits at different element parameters [10]. However, in view of the complexity of these expressions for calculating specific values of the electrical characteristics of the discharge pulses and optimization of the modes in the load circuit and the capacitor circuit, it would be justified to use other methods for analyzing transients in the discharge circuit, which changes its configuration during discharge.

Therefore, the **purpose of the work** was to apply the method of multi-parameter functions to simplify the analysis of transients in a discharge circuit of a semiconductor electrical discharge installation with an electro-spark load when the configuration of the circuit changes during discharge; obtaining exact analytical expressions for the electrical characteristics of the discharge circuit of the installation, as well as determining the appropriate connection moment and the value of the inductance of the additional bypass circuit, which is connected in parallel to the capacitor in order to convert a long-lasting aperiodic discharge into a rapidly damping oscillatory discharge.

Analysis of discharge transients of capacitor when it is bypassed by the *RL*-circuit at a certain moment of discharge. A circuit diagram of a thyristor EDI with electro-spark load is presented in Fig. 1. In this installation the charge of the reservoir capacitor *C* is carried out from the shaper of direct voltage (*SDV*) in the circle *SDV*-R-*VT*-*C*-*L*-*SDV*, and the capacitor discharge is realized in the circle C-VT_1-R_{load}-R_1-L_1-C. The R and R_1 resistors and L, L_1 inductors are the active resistances of the wires and the inductances of the charge circuit and discharge one, respectively. The R_{load} resistance is the active resistance of load. The VT and VT_1 thyristors are the semiconductor keys of the charge circuit and discharge one, respectively. In order to stabilize the duration of the discharge pulse in the EDI (that is, to eliminate long-term aperiodic discharges in the case of increasing load resistance), the VT_2 thyristor is switched on at a certain time of the discharge of capacitor *C* and an additional bypass *RL*-circuit (VT_2-R_2-L_2) is connected. Thus the configuration of the discharge circuit was changed during the capacitor discharge.

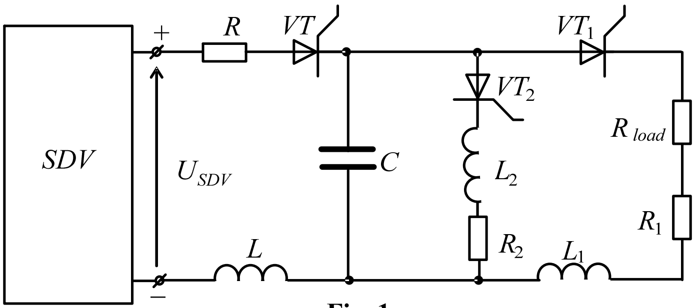

Fig. 1

In order to analyze the discharge transient in such an installation, we used the method of multiparameter modulating functions, which are included in the algorithmic equations for the analysis of steady-state and transient processes in branched electrical circuits with semiconductor switches and reactive elements [11]. This method makes it possible to simplify the analysis of transients in electrical circuits without taking into account losses in key elements. The method is implemented using numerical calculation methods in mathematical package Mathcad.

According to this method, the transient discharge of capacitor *C* on load R_{load} at connecting the *RL*-circuit (VT_2-R_2-L_2) at some point in time was considered. Losses in thyristor keys were not taken into account.

It was believed that the VT thyristor of charge circuit remained locked during the discharge of the capacitor. The VT_1 thyristor of discharge circuit was switched on at time t_1, and the VT_2 thyristor of bypass circuit was switched off at time t_2. The discharge on R_{load} load is ended at time t_3 (when the VT_1 thyristor locked because the current in the load decreased to zero), and the discharge of the capacitor through the RL-circuit is finished at time t_4 (the VT_2 thyristor locked due to the current in RL-circuit decreased to zero).

The load current at the first time interval $t_1 \ldots t_2$ (VT_1 thyristor is switched on and VT_2 is switched off) i_{load1} was determined from the second order differential equation

$$d^2 i_{load1}(t)/dt^2 = -(R_1 + R_{load}) di_{load1}(t)/L_1 dt + i_{load1}(t)/L_1 C. \tag{1}$$

Solution (1) was found in the Mathcad mathematical package by the numerical Runge-Kutta method at a fixed time interval $t_1 \ldots t_2$ in the form of a $\mathbf{I_{load1}}$ matrix of instantaneous values of $i_{load1}(t)$ and their derivatives, calculated at time moments of this interval with the selected step p_1, as

$$\mathbf{I_{load1}} = rkfixed\left(i_{load1}, t_1, t_2, p_1, D_{load1}\right), \tag{2}$$

where D_{load1} is the column-vector of intermediate solutions regarding the load current in the first time interval: $i_{load1}(t)$. The current $i_{load1}(t)$ is the dependence of column of the instantaneous values $i_{load1}(t)$ in the $\mathbf{I_{load1}}$ matrix on time t (related with step p_1).

The load current at the second time interval $t_2 \ldots t_3$ (VT_1, VT_2 thyristors are unlocked) $i_{load2}(t)$ was determined from the system of differential equations

$$i_{C2}(t) = i_{load2}(t) + i_{RL2}(t), \qquad i_{C2}(t) = -C du_{C2}(t)/dt, \tag{3, 4}$$

$$u_{C2}(t) = L_1\, di_{load2}(t)/dt + (R_1 + R_{load}) i_{load2}(t), \qquad u_{C2}(t) = L_2\, di_{RL2}(t)/dt + R_2\, i_{RL2}(t), \tag{5, 6}$$

where $i_{C2}(t)$, $i_{load2}(t)$, $i_{RL2}(t)$ are the capacitor current, load current and RL-circuit current at the second time interval, respectively, and $u_{C2}(t)$ is the capacitor voltage at this interval.

After transformations of equations (3) – (6), the following third order differential equation was derived

$$d^3 i_{load2}(t)/dt^3 = -\left[B\, d^2 i_{load2}(t)/dt^2 + F\, di_{load2}(t)/dt + G i_{load2}(t)\right]/A, \tag{7}$$

where $A = L_1 L_2 C$, $B = L_2 C(R_1 + R_{load}) + L_1 C R_2$, $F = L_1 + L_2 + C(R_1 + R_{load}) R_2$, $G = R_1 + R_{load} + R_2$.

Solution (7) with respect to load current was determined by a numerical method (Runge-Kutta method at a fixed time interval $t_2 \ldots t_3$) in the form of an $\mathbf{I_{load2}}$ matrix containing four columns that represent time, instantaneous values of load current and its derivatives, and p_2 rows, defining a given number of points at a fixed interval $t_2 \ldots t_3$

$$\mathbf{I_{load2}} = rkfixed\left(i_{load2}, t_2, t_3, p_2, D_{load2}\right), \tag{8}$$

where D_{load2} is the column-vector of intermediate solutions regarding the load current in the second time interval: $i_{load2}(t)$. The current $i_{load2}(t)$ is the dependence of column of the instantaneous values $i_{load2}(t)$ in the $\mathbf{I_{load2}}$ matrix on time t (related with step p_2).

The current through the RL-circuit $i_{RL2}(t)$ at this time interval was determined from the third-order differential equation obtained after transformations of equations (3) – (6)

$$d^3 i_{RL2}(t)/dt^3 = -\left[B\, d^2 i_{RL2}(t)/dt^2 + F\, di_{RL2}(t)/dt + G\, i_{RL2}(t)\right]/A. \tag{9}$$

Solution (9) with respect to current $i_{RL2}(t)$ was determined similarly to solution (7) in the form of an $\mathbf{I}_{\boldsymbol{RL2}}$ matrix containing four columns that represent time, instantaneous values of current through the RL-circuit and its derivatives, and p_2 rows defining a given number points at a fixed interval $t_2 \ldots t_3$

$$\mathbf{I}_{\boldsymbol{RL2}} = rkfixed\left(i_{RL2}, t_2, t_3, p_2, D_{RL2}\right). \tag{10}$$

The load current at the third time interval $t_3 \ldots t_4$ (the VT_2 thyristor is unlocked and VT_1 is locked) is zero, and the i_{RL3} current through the RL-circuit is determined from the second order differential equation

$$d^2 i_{RL3}(t)/dt^2 = -R_2 di_{RL3}(t)/L_2 dt + i_{RL3}(t)/L_2 C. \tag{11}$$

Solution (11) was found similar to solution (1) by the Runge-Kutta numerical method at a fixed time interval $t_3 \ldots t_4$ in the form of an $\mathbf{I}_{\boldsymbol{RL3}}$ matrix of instantaneous current values $i_{RL3}(t)$ and their derivatives calculated at time points of this interval with the selected step p_3 as

$$\mathbf{I}_{\boldsymbol{RL3}} = rkfixed\left(i_{RL3}, t_3, t_4, p_3, D_{RL3}\right), \tag{12}$$

where D_{RL3} is the column-vector of intermediate solutions regarding current through the RL-circuit at the third time interval: $i_{RL3}(t)$. The current $i_{RL3}(t)$ is the dependence of column of the instantaneous values i_{RL3} in the $\mathbf{I}_{\boldsymbol{RL3}}$ matrix on time t (related with step p_3).

The total load current (in the first and second time intervals) $i_{load} = i_{load1}(t) + i_{load2}(t)$ was calculated as the sum of the currents found in (2) and (8)

$$\mathbf{I_{load}} = \mathbf{I_{load1}} + \mathbf{I_{load2}}. \tag{13}$$

The total current iny RL-circuit (in the second and third time intervals) $i_{RL} = i_{RL2}(t) + i_{RL3}(t)$ was calculated as the sum of the currents found in (10) and (12)

$$\mathbf{I}_{RL} = \mathbf{I}_{RL2} + \mathbf{I}_{RL3}. \tag{14}$$

Current in the capacitor was defined as the sum of currents in the load and in the RL-circuit

$$\mathbf{I}_C = \mathbf{I_{load}} + \mathbf{I}_{RL} \tag{15}$$

Thus, we have determined the electrical characteristics during transient process of discharge of the EDI capacitor at changing the configuration of its discharge circuit. In Mathcad you can also get graphical time dependences of all currents considered by expressions (13)–(15).

Determining the influence of connection moment of bypass *RL*-circuit on the course of the discharge transient. We have studied the transient features of the discharge of capacitor on load in EDI, presented in Fig. 1, depending on the moment of connection of the bypass RL-circuit (VT_2-L_2-R_2). The transients were simulated in software packages MathLab. The parameters of the discharge circuit elements of such installation (C-VT_1-R_{load}-R_1-L_1-C) were chosen so that on the one hand they correspond to the real parameters of installations with electro-spark load (C=10^{-4} F, R_1=0.001 Ohm, L_1=10^{-6} H), and on the other hand, that the discharge has an aperiodic character (due to increasing the load resistance to R_{load} = 1 Ohm).

The voltage of the capacitor at the beginning of its discharge was U_{C0} = 1000 V. The parameters of the bypass RL-circuit were chosen such that the aperiodic capacitor discharge process was transformed into oscillatory one. Active resistance R_2 = 0.001 Ohms, inductance $L_2 = 6\cdot10^{-5}$ H.

The results of the studies are shown in Fig. 2–5 and in Table. 1. In Fig. 2 we can see the capacitor current during the aperiodic discharge process without connecting the bypass RL-circuit ($i_{C\text{ without }RL}$) as well as the currents in the capacitor, load and RL-circuit (i_C, i_{Rload}, i_{RL}) with the connection of this RL-circuit at time t_2 = 0.105 ms (taking into account the pause between the capacitor charge and capacitor discharge, which is shown in the graphs by the fact that the discharge starts at t_1 = 0.1 ms).

Fig. 3 and 4 represent the currents i_C, i_{Rload}, i_{RL} at t_2 = 0.125 and 0.2 ms, respectively. Fig. 5 shows the voltage variation u_C on the capacitor for all modes considered. The time moments t_3 and t_4 represent the end of the discharge in the load and in the capacitor respectively.

Table 1 shows the change in the characteristics of the discharge transient (peak currents in the capacitor $i_{C\,max}$ and in the load $i_{Rload\,max}$; the recharge capacitor voltage $U_{C\,rech}$; the discharge duration in the load $\tau = t_3 – t_2$; the energy W_{load} and the average pulse power $P_{load\,av}$ in the load, capacitor energy utilization factor k_C) when time t_2 changes.

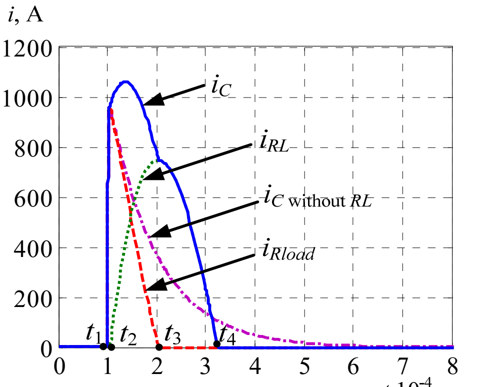

Fig. 2

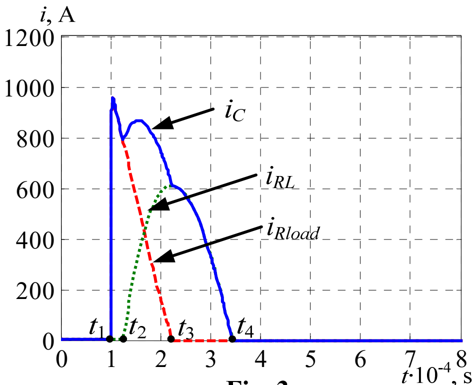

Fig. 3

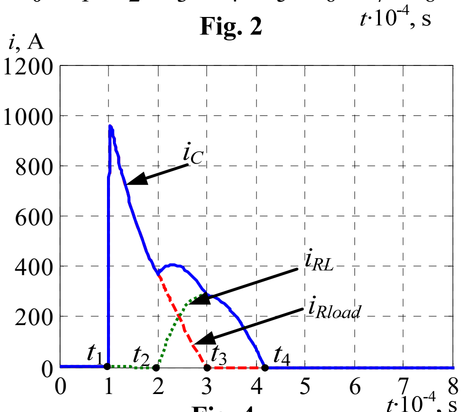

Fig. 4

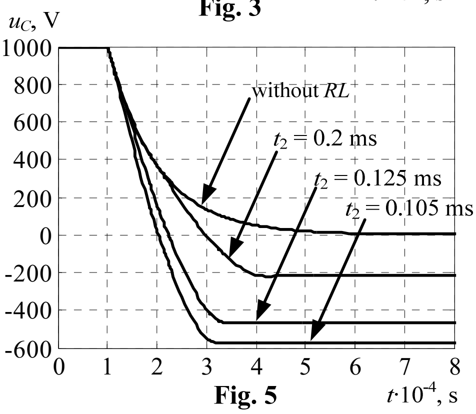

Fig. 5

The average pulse power in the load was calculated as $P_{load\ av} = W_{load} / \tau$, and k_C–by the formula $k_C = W_{load} / W_{C0}$, where W_{C0} is the energy in the capacitor at the moment of beginning of the discharge transient process ($W_{C0} = CU_{C0}^2/2 = 50$ J).

Table 1

Characteristics of discharge transient	Connection conditions of *RL*-circuit: t_2, ms			
	$t_2 = 0.105 \cdot$ ms	$t_2 = 0.125$ ms	$t_2 = 0.2 \cdot$ms	Without *RL*-circuit connection
$i_{C\ max}$, A	1060	959	959	959
$i_{Rload\ max}$, A	959	958	958	959
$U_{C\ rech}$, V	–575	–470	–218	0
τ, ms	0,10	0,12	0,20	0,72
W_{load}, J	32,66	38,25	47,01	49,62
$P_{load\ av}$, kJ/s	326,6	318,75	235,1	68,92
k_C , r.u.	0,65	0,77	0,94	0,99

The analysis of these figures and the data of the table 1 confirm that the moment of connection of the bypass circuit has a significant impact on the course of the discharge transition.

The sooner the *RL*-circuit is connected, the faster it occurs. For example, connecting the *RL*-circuit at time $t_2 = 0.105$ ms (0.125 and 0.2 ms) reduces the discharge time by 7.2 (6 and 3.6) times, respectively, compared to the mode without connecting *RL*-circuit. In this case, the average pulse power in the load increases 4.7 (4.6 and 3.4) times, respectively. It should be noted that the maximum load currents in all the modes considered are practically unchanged ($i_{Rload\ max} = 958 \div 959$ A).

Regarding the capacitor energy utilization factor k_C, the later the *RL*-circuit is connected, the higher it is. Thus, at $t_2 = 0.125$ (0.2 ms) compared to $t_2 = 0.105$ ms, the value of k_C increases by 1.2 (1.5) times, respectively. This is because the later the circuit is connected, the greater part of the capacitor energy is already dissipated in the load, and the smaller part of it will be used to recharge the capacitor to reverse voltage.

As noted above, the most technologically and energy-efficient discharge mode for electro-spark load is the oscillatory discharge of capacitor with its recharge up to 30% of the initial voltage. On this basis, it is advisable to connect the *RL*-circuit at the time $t_2 = 0.2$ ms. In this case, the discharge time will be reduced by 3.6 times, the capacitor recharge voltage will be approximately 22% of its initial voltage (modulo), and the load energy W_{load} will be 1.2 (1.4) times greater than at $t_2 = 0.105$ ($t_2 = 0.125$) ms, respectively. The impulse power in the load will be slightly lower than in the case of an earlier *RL*-circuit connection, but the capacitor energy utilization factor will be 1.5 (1.2) times higher.

However, if the main purpose of the dispersion process is to minimize the particle size of spark-eroded powders, then it is advisable to connect the *RL*-circuit as early as possible ($t_2 = 0.105$ ms), since many works have proved a proportional relationship between the discharge duration and the size of spark-eroded particles.

Another factor affecting the transient of the capacitor discharge on the load is the magnitude of the inductance and active resistance of the *RL*-circuit. Active resistance R_2 is the active resistance of the connecting wires and the wire wound on the coil of this circuit. The resistance R_2 is low compared to the load resistance and changes insignificantly when the value of the circuit inductance L_2 changes (since the inductance changes in proportion to the square of the number of wound turns, while the active resistance is proportional to the length of the wound wire). Therefore, it was assumed that R_2 is invariable when the inductance of the L_2 circuit is changed.

Determining the influence of inductance value in bypass *RL*-circuit on the course of the discharge transient. The features of the transient of the capacitor discharge on the load depending on the inductance value L_2 of the bypass *RL*-circuit were studied. The parameters of the elements of the discharge circuit except L_2 were chosen the same as in the previous study. The moment of connection of the circuit was taken $t_2 = 0.2$ ms. Transitions were investigated at three different values of inductance L_2: 120; 60; 10 μH. The results of the study are shown in Fig. 6–8 and in Table. 2.

Fig. 6–8 show the changes in the currents i_C, i_{Rload} and i_{RL} at three values of L_2 (120, 60, 10 μH), and Table 2 represents the change in the characteristics of the discharge transient (similar to Table 1) when L_2 changes.

An analysis of these Figures and Table 2 shows that with a decrease in the inductance of the *RL*-circuit, the maximum current in it increases. Thus, at $L_2 = 10$ μH, the maximum current in the *RL*-circuit ($i_{RL\ max}$) reaches approximately the same value as the maximum current in the load $i_{Rload\ max}$ (the second peak in Fig. 8). Therefore, further reduction of L_2, which will further increase the maximum current in the *RL*-circuit, is impractical because of the limited capability of thyristor switch.

As for the energy released in the load, with a change in L_2 from 120 to 60 (10) μH, it decreases by only 1.4 (5.4)%. At the same time, the discharge duration in the load decreases more significantly: accordingly by 13 (35)%, whereby the average impulse power in the load increases by 13 (46)%.

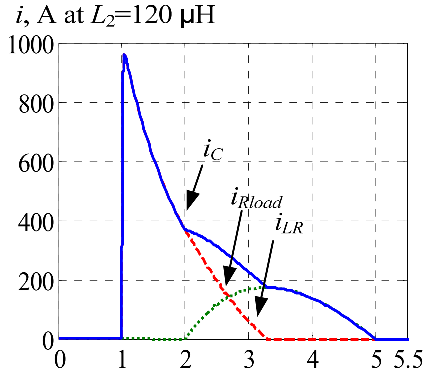

Fig. 6

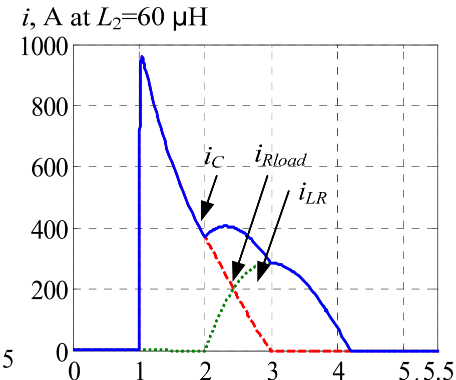

Fig. 7

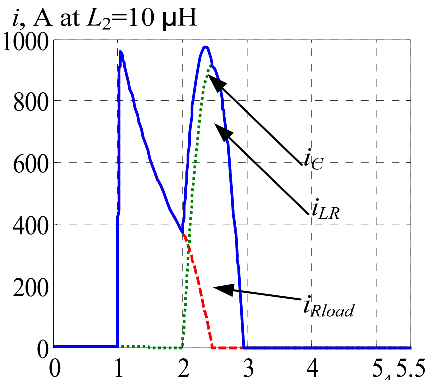

Fig. 8

Table 2

Characteristics of discharge transient	Inductance L_2 of RL-circuit, μH		
	120	60	10
$i_{C\,max}$, A	959	959	974
$i_{Rload\,max}$, A	958	958	958
$U_{C\,rech}$, V	–187	–218	–283
τ, ms	0.23	0.20	0.15
W_{load}, J	47.68	47.01	45.26
$P_{load\,av}$, kJ/s	207.3	235.1	301.7
k_C , r.u.	0.95	0.94	0.91

In all considered cases the capacitor recharge voltage does not exceed 30% of its initial voltage (this is the condition of the most technologically and energy-efficient discharge mode for the electro-spark load), and the capacitors' energy utilization factors are high (more than 0.9).

Taking into account all the above considerations, the most appropriate choice is the inductance L_2 = 60 μH, since in this case the maximum current in the circuit does not exceed 30% of the maximum currents in the capacitor and the load at sufficiently high other characteristics of the transient.

Conclusions. 1. Using the method of multiparameter functions, the analysis of transients in the discharge circuit of a semiconductor discharge installation with electro-spark load at changing the configuration of the circuit (at bypass *RL*-circuit connection) during discharge was performed. 2. Exact analytical expressions for the electrical characteristics of the discharge circuit of the installation were obtained. 3. It is shown that the factors affecting the transient of the capacitor discharge to load are the connection moment and the value of the inductance in the *RL*-circuit, which is connected in parallel to the capacitor in order to convert a long-term aperiodic discharge into a rapidly damping oscillatory discharge. 4. The influence of these factors on the course of the discharge transients is investigated and the appropriate connection moments and values of the inductance in the *RL*-circuit for the discharge circuit parameters of real installations with electro-spark load are determined.

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ПЕРЕХОДНЫЕ ПРОЦЕССЫ ПРИ ИЗМЕНЕНИИ КОНФИГУРАЦИИ ЦЕПИ РАЗРЯДА КОНДЕНСАТОРА ПОЛУПРОВОДНИКОВОЙ ЭЛЕКТРОРАЗРЯДНОЙ УСТАНОВКИ С ЭЛЕКТРОИСКРОВОЙ НАГРУЗКОЙ

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Применен метод многопараметрических функций для упрощения анализа переходных процессов разряда конденсатора на электроискровую нагрузку в полупроводниковых электроразрядных установках при изменении конфигурации разрядной цепи с целью регулирования длительности импульсных токов в нагрузке. На основе проведенного анализа переходных процессов в разрядной цепи переменной структуры таких установок получены точные аналитические выражения для расчета ее электрических характеристик. Определены целесообразные значения момента подключения и величины дополнительной индуктивности, которую необходимо подключать во время разряда конденсатора для уменьшения длительности разрядных токов и стабилизации технологического процесса в электроискровой нагрузке. Библ. 11, рис. 8, табл. 2.
Ключевые слова: разряд конденсатора, переходный процесс, электроискровая нагрузка, длительность разряда, метод многопараметрических функций.

УДК 621.3.011

ПЕРЕХІДНІ ПРОЦЕСИ У РАЗІ ЗМІНЕННЯ КОНФІГУРАЦІЇ КОЛА РОЗРЯДУ КОНДЕНСАТОРА НАПІВПРОВІДНИКОВОЇ ЕЛЕКТРОРОЗРЯДНОЇ УСТАНОВКИ З ЕЛЕКТРОІСКРОВИМ НАВАНТАЖЕННЯМ

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Використано метод багатопараметричних функцій задля спрощення аналізу перехідних процесів розряду конденсатора на електроіскрове навантаження в напівпровідникових електророзрядних установках у разі змінення конфігурації розрядного кола з метою регулювання тривалості імпульсних струмів у навантаженні. На основі проведеного аналізу перехідних процесів у розрядному колі змінної структури таких установок отримано точні аналітичні вирази для розрахунку його електричних характеристик. Визначено доцільні значення моменту підключення та величину додаткової індуктивності, яку необхідно підключати під час розряду конденсатора для зменшення тривалості розрядних струмів та стабілізації технологічного процесу в електроіскровому навантаженні. Бібл. 11, рис. 8, табл. 2.
Ключові слова: розряд конденсатора, перехідний процес, електроіскрове навантаження, тривалість розряду, метод багатопараметричних функцій.

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