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DECREASE OF TRANSIENTS DURATION AND IMPROVEMENT OF DYNAMIC CHARACTERISTICS OF ELECTRICAL DISCHARGE INSTALLATIONS BY CHANGING THE STRUCTURE OF THEIR DISCHARGE CIRCUIT

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The features of changing the duration and nature of transients in electric-discharge installations (EDIs) when shunting the discharge circuit of their capacitor with an additional RL-circuit instead of by regulating the voltage feedbacks are determined. The dependences of pulsed currents and powers in the load of such installations when changing their structure are studied. Based on the mathematical simulation, the appropriate values of the time delay of connecting an additional shunt RL-circuit after the start of the capacitor discharge through the load and the energy-efficient parameters of the additional circuit are determined. The use of obtained results allows to reduce in practice the duration of the pulse currents and increase the pulse power in the load, that is, to increase the output dynamic characteristics of the EDI. In spark technology, this approach contributes to the production of electro-eroded powders with smaller sizes and better performance. References 12, figures 5, tables 2.
Keywords: transient, capacitor, discharge, pulse current, duration, power.

Changes in the duration of transients and dynamic characteristics in the output circuits of electric-discharge installations (EDIs) for spark erosion [1-3], electro-hydraulic [4] and induction [5] treatments of materials are usually investigated taking into account changes in their output voltage [4, 6], discharge parameters pulses [2, 7] and electrical resistance of the load [8]. However, connecting the shunt RL-circuit in parallel to the capacitor of the EDI at a certain moment of its discharge can prevent the occurrence of undesirable long aperiodic currents in the load, which significantly reduce the efficiency of the EDI and increase the particle size of the obtained powder [9-12]. Therefore, it is important to investigate the peculiarities of changing the parameters of impulse currents in the EDI under different conditions of shunting of the discharge circuit of their capacitor.

The aim of the work is to determine the conditions for changing the structure of the output circuit of the EDI, which reduce the duration of the pulse currents in the load and increase the output dynamic characteristics.

In the circuit diagram of discharge circuit of EDI for spark erosion shown in Fig. 1, the discharge of the reservoir capacitor C to the load resistance R_{load} is carried out through the inductive resistance and active one of the discharge circuit (L_1, R_1) after locking the semiconductor (thyristor) switch VT_1. The bypass R_2L_2-circuit was connected in parallel to the capacitor by switching on the thyristor switch VT_2 after start of the capacitor discharge some time later.

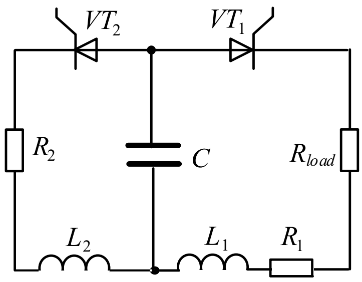

Fig. 1

The calculations on mathematical models and the analysis of pulse currents in the load of experimental EDI showed that the change in their dynamic characteristics significantly depends on the duration of the pause between switching on VT_1 and VT_2. For simulation the transients we used software packages MathLab Simulink. The parameters of the discharge circuit elements were chosen so that on the one hand they correspond to the real parameters of discharge circuit of experimental EDIs with electro-spark load [2, 5, 8, 12], in which $C = 10^{-4}$ F, $R_1 \approx 0.001$ Ohm, $L_1 \approx 10^{-6}$ H and on the other hand, that the discharge transient has an aperiodic nature due to increasing the load resistance to $R_{load} \geq 1$ Ohm. Initial voltage on capacitor was 1000 V. The bypass circuit parameters were chosen so that the aperiodic discharge of the capacitor was guaranteed to be transformed into an oscillatory one after turning on the thyristor VT_2 ($R_2 = 0.001$ Ohm and $L_2 = 5\cdot10^{-5}$ H).

The results of the studies are shown in Fig. 2, Fig. 3 and in Table 1. The i_C currents in the capacitor and i_{Rload} currents in the load that occur during the aperiodic discharge transient without connecting the by-

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pass R_2L_2-circuit and after switching on the VT_2 thyristor after pauses equal to 0.005; 0.025 and 0.1 msec are shown in Fig. 2 and Fig. 3 correspondingly.

Table 1 reflects the change in obtained characteristics of the discharge transient (such as maximum currents in the capacitor $I_{C\,max}$, in the load $I_{Rload\,max}$, and in R_2L_2-circuit $I_{R2L2\,max}$; the recharge capacitor voltage $U_{C\,rech}$; discharge duration in the load τ; energy and average pulse power in the load: W_{load} and $P_{load\,av}$; capacitor energy utilization factor k_C) when the connection moment of the R_2L_2-circuit t_{con} changes. 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 beginning moment of the discharge transient ($W_{C0} = CU_{C0}^2/2 = 50$ J).

Analysis of the results in Fig. 2, Fig. 3 and in Table 1 confirms that the moment of connection of the bypass circuit significantly affects the nature of the discharge transient. It proceeds the faster the earlier the bypass circuit is connected. So connecting the bypass circuit at time $t_{con} = 0.005$ msec (0.025 and 0.1 msec) reduces the discharge time by 7.2 (6 and 3.6) times, respectively, compared to the mode without connecting. In this case, the average pulse power in the load increases 4.6 (4.5 and 3.5) times, respectively.

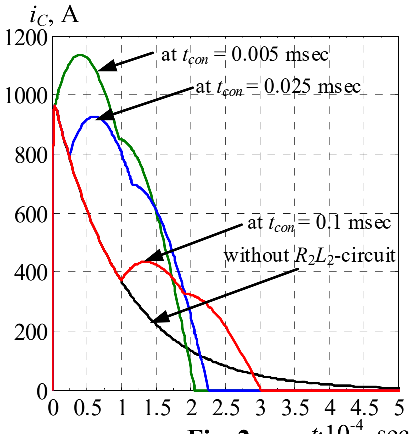

Fig. 2

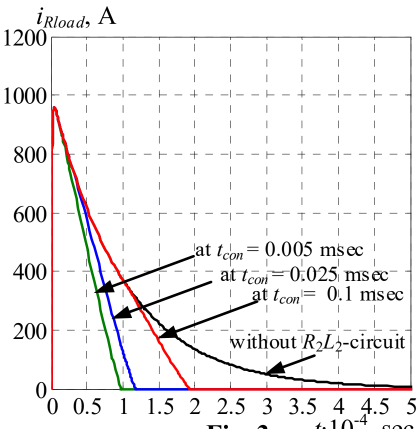

Fig. 3

It should be noted that the maximum load currents in all considered modes do not change ($I_{R\,load\,max} = 960$ A). The capacitor energy utilization factor k_C becomes the greater, the later the bypass circuit is connected. So, at $t_{con} = 0.025$ (0.1 msec), compared to $t_{con} = 0.005$ msec, the k_C value increases by 1.2 (1.5) times. This is explained by the fact that the later the circuit is connected, the greater part of the accumulated energy is already dissipated in the load and the smaller part of it will be used to recharge the capacitor to the reverse voltage.

Table 1

Characteristics of the discharge transient	Conditions of R_2L_2-circuit connection ($R_2 = 0.001$ Ohm, $L_2 = 5 \cdot 10^{-5}$ H): t_{con}, msec			
	0.005·msec	0.025 msec	0.1·msec	∞ msec (no connection)
$I_{C\,max}$, A	1135	963	963	960
$I_{Rload\,max}$, A	960	960	960	960
$I_{R2L2\,max}$, A	852	696	326	0
$U_{C\,rech}$, V	–599	–489	–228	0
τ, msec	0.10	0.12	0.20	0.72
W_{load}, J	31.6	37.6	47.0	49.7
$P_{load\,av}$, kJ/sec	323	321	246	71
k_C, r.u.	0.63	0.75	0.94	0.99

The most technologically and energy-efficient discharge mode for electro-spark load in EDIs with reservoir capacitors (in particular in semiconductor installations for volumetric spark dispersion of current-conducting materials) is the oscillatory discharge of capacitor with its recharge up to 30% of the initial voltage [6, 7]. Based on this, it is advisable to connect the bypass circuit at the time $t_{con} = 0.1$ msec. In this case, the discharge time will be reduced by 3.6 times (compared to the mode without circuit connection), the capacitor recharge voltage will be approximately 23% of its initial voltage (modulo), and the load energy W_{load} will be 1.5 (1.2) times greater than at $t_{con} = 0.005$ (0.025) msec, respectively.

The pulse power in the load will be slightly less than with an earlier connection of the bypass circuit, 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 size of the obtained spark eroded powders, then in this case it would be advisable to connect the bypass circuit as early as possible ($t_{con} =$ 0.005 msec), since in many papers the proportional relationship between the discharge duration and the size of the particles is proved.

Another factor influencing the nature of the capacitor discharge transients to the load is the values of the inductance and the active resistance of the connected bypass circuit.

Active resistance R_2 is the active resistance of the connecting wires and the wires wound on the coil of this circuit. The resistance R_2 is two orders of magnitude lower than the load resistance ($R_2 \approx 0.001$ Ohm, $R_{load} \geq 1$ Ohm). That is why a change in R_2 several times with a change in the inductance L_2 by an order of magnitude or more did not actually affect the course of the discharge process. Therefore, we assumed that R_2 is constant when the inductance L_2 is changed.

We studied the transients of capacitor discharge to the load, depending on the magnitude of the bypass inductance L_2. The parameters of the elements of the discharge circuit except L_2 were chosen the same as in the previous study. The connection moment of the bypass circuit was accepted t_{con} = 0.1 msec. Transitions were investigated at three different values of inductance L_2: 100; 50; 5 μH. The results of the study are shown in Fig. 4, Fig. 5 and in Table 2 (similar to Table 1). Fig. 4 and 5 show the capacitor currents and the load ones, respectively, during the aperiodic discharge process without connecting the bypass circuit and with connecting this circuit at different values of its inductance L_2: 5; 50; 100 μH.

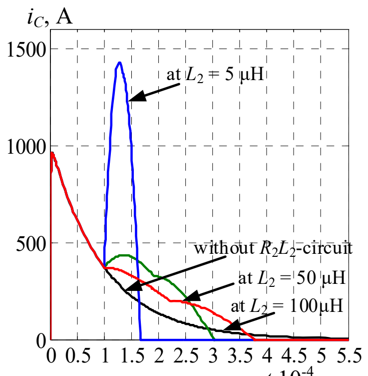

Fig. 4

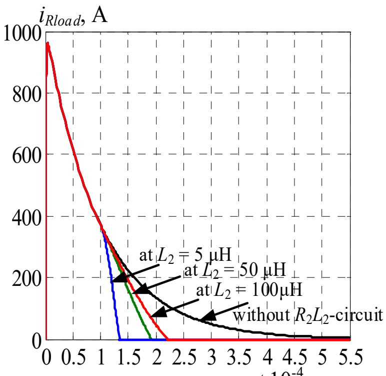

Fig. 5

Analysis Fig. 4, Fig. 5 and Table 2 shows that the maximum current in bypass circuit increases with decreasing the inductance in this circuit. Thus, at L_2 = 5 μH, the discharge current in the capacitor has two maxima (the second maximum is caused by an increase in the current in the bypass circuit up to $I_{R2L2\,max}$, which is 43% greater than the maximum current in load $I_{Rload\,max}$).

Table 2

Characteristics of the discharge transient	Inductance L_2 of bypass circuit, μH		
	100	50	5
$I_{C\,max}$, A	963	963	1428
$I_{Rload\,max}$, A	961	961	961
$I_{R2L2\,max}$, A	199	326	1375
$U_{C\,rech}$, V	–196	–227	–303
τ, msec	0.22	0.19	0.13
W_{load}, J	47.7	47.0	44.9
$P_{load\,av}$, kJ/sec	217	247	345
k_C, r.u.	0.95	0.94	0.90

That is why further reduction of L_2, which will lead to an even greater increase in the maximum current in the bypass circuit and therefore in the capacitor, is impractical because of the limited capabilities of semiconductor switches.

With regard to the energy released in the load, with a change in L_2 from 100 to 50 (5) mH, it decreases by only 1.5 (5.9)%. In this case, the discharge duration in the load decreases more significantly: by 14 (41)%, respectively, which leads to an increase in the average pulse power in the load by 14 (59)%.

In all cases considered, the reverse recharge voltage of the capacitor practically does not exceed 30% of its initial voltage (the condition for the most effective discharge mode to the spark load), and the capacitor energy utilization factors are high ($k_C \geq 0.9$). Thus, the most appropriate choice is the inductance L_2 = 50 μH, at which the maximum current in the circuit does not exceed 35% of the maximum currents in the capacitor and in the load with sufficiently high other transient characteristics.

Conclusions. Simulation and analysis of transients in the discharge circuit of a semiconductor electric-discharge installation with a spark load showed that using the additional *RL*-circuit in parallel to the capacitor of the installation, we can convert a long aperiodic discharge of the capacitor into a rapidly decaying oscillatory one, in which the load current increases and its duration decreases. It is substantiated that the main factors influencing such changes are the moment of connection and the inductance value of the additional *RL*-circuit. In this paper, the expedient moments of connecting such a circuit and the value of its inductance are determined for the parameters of the discharge circuit of actually operating installations for electro-spark dispersion of a layer of metal granules in liquids during the formation of charging voltages up to 1000 V.

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ЗМЕНШЕННЯ ТРИВАЛОСТІ ПЕРЕХІДНИХ ПРОЦЕСІВ І ПІДВИЩЕННЯ ДИНАМІЧНИХ ХАРАКТЕРИСТИК ЕЛЕКТРОРОЗРЯДНИХ УСТАНОВОК ЗМІНЕННЯМ СТРУКТУРИ ЇХНЬОГО РОЗРЯДНОГО КОЛА

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Визначено особливості змінення тривалості та характеру перехідних процесів в електророзрядних установках (ЕРУ) уразі шунтування кола розряду їхнього конденсатора додатковим RL-ланцюгом, а не регулюванням зворотних зв'язків за напругою. Досліджено залежності імпульсних струмів та потужностей у навантаженні ЕРУ за зміненням їхньої структури. На основі математичного моделювання визначено доцільні значення затримки в часі підключення додаткового RL-ланцюга після початку розряду конденсатора на навантаження та енергоефективні параметри додаткового ланцюга. Використання отриманих результатів дає змогу зменшити на практиці тривалість імпульсних струмів та збільшити імпульсну потужність у навантаженні, тобто підвищити вихідні динамічні характеристики ЕРУ. В електроіскрових технологіях такий підхід сприяє отриманню електроерозійних порошків з меншими розмірами та кращими експлуатаційними характеристиками. Бібл. 12, рис. 5, табл. 2.

Ключові слова: перехідний процес, конденсатор, розряд, імпульсний струм, тривалість, потужність.

УМЕНЬШЕНИЕ ДЛИТЕЛЬНОСТИ ПЕРЕХОДНЫХ ПРОЦЕССОВ И ПОВЫШЕНИЕ ДИНАМИЧЕСКИХ ХАРАКТЕРИСТИК ЭЛЕКТРОРАЗРЯДНЫХ УСТАНОВОК ИЗМЕНЕНИЕМ СТРУКТУРЫ ИХ РАЗРЯДНОЙ ЦЕПИ

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Определены особенности изменения длительности и характера переходных процессов в цепях электроразрядных установок (ЭРУ) при шунтировании цепи разряда их конденсатора дополнительной RL-цепочкой, а не регулированием обратных связей по напряжению. Исследованы зависимости импульсных токов и мощностей в нагрузке ЕРУ при изменении их структуры. На основе математического моделирования определены целесообразные значения временной задержки подключения дополнительной шунтирующей RL-цепи после начала разряда конденсатора на нагрузку и энергоэффективные параметры дополнительной цепи. Использование полученных результатов позволяет уменьшить на практике длительность импульсных токов и увеличить импульсную мощность в нагрузке, т.е. повысить выходные динамические характеристики ЭРУ. В электроискровых технологиях такой подход способствует получению электроэрозионных порошков с меньшими размерами и лучшими эксплуатационными характеристиками. Библ. 12, рис. 5, табл. 2.

Ключевые слова: переходный процесс, конденсатор, разряд, импульсный ток, длительность, мощность.

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