

FEATURES OF THE FORMATION OF MULTI-CHANNEL PULSE CURRENTS AND FAST-MIGRATING ELECTRIC SPARKS IN THE LAYER OF CURRENT-CONDUCTING GRANULES OF ELECTRIC-DISCHARGE INSTALLATIONSA.A. Shcherba^{1*}, N.I. Suprunovska^{1**}, M.A. Shcherba^{2***}¹ Institute of Electrodynamics National Academy of Science of Ukraine,

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The paper reveals the electro-physical features of the formation of multi-channel pulse currents and fast-migrating electric sparks in the layer of current-conductive granules of electric-discharge installations (EDIs) with reservoir capacitors. Such features make it possible to increase many times the productivity of the electric-spark dispersion of metal granules during single discharge current of reservoir capacitors, which flows between the electrodes of EDIs. Theoretical substantiation and experimental confirmation of multi-channel spark discharges in the layer of conductive granules are presented. The influence of the capacitance and charge voltage of reservoir capacitors on the nature of transient processes in the discharge circuit of the EDIs is investigated. The dependence of the effective value of the active load resistance of the EDIs on the value of the pre-charge voltage of its reservoir capacitors and the value of its capacitances has been experimentally determined. It is proved that an increase in the averaged Q-factor of the discharge circuit with an increase in the charge voltage of the capacitor bank of EDI is caused by a decrease in the effective value of the active resistance of the layer of metal granules when spark-generating discharge currents flow through it. References 21, Figures 6.

Key words: pulse current, electric-spark discharge, electric discharge installation, capacitive energy storage, metal granular layer, electric-spark dispersion.

The main feature of electric-discharge installations (EDIs) with reservoir capacitors is the ability not only to accumulate, store and strictly dose the transmission of electric power from the supply network to the technological load, but also to realize the largest pulse currents and short-term powers in it in comparison with other energy storage devices [1–6]. For a long time, EDIs were created to generate low-voltage (voltage up to 1 kV) [2–4, 6] or high-voltage (voltage up to 50 kV) [1, 5] discharge pulses that form large pulse currents in the interelectrode gaps (IEGs) filled only with the dielectric liquid. During the discharge of EDIs capacitors, the pulsed currents arose, which formed short-term single-channel electroplasma formations [4] with a temperature of the order of 10 thousand °K [6] in the liquid between the electrodes.

Using low-voltage EDIs, it became possible to realize an electrophysical phenomenon, which was called electrical discharge machining of metals [3, 4] and which began to be used for precision electric erosion machining of metal products (in general, conductive ones) of the highest strength and refractoriness [2–4]. The use of high-voltage EDIs, in capacitors of which accumulated electricity up to 10⁵ J, made it possible to realize the phenomenon known as the high-voltage electrohydraulic effect [5]. This effect arises in the liquid between the electrodes during the formation of an electroplasma channel, which expands at a supersonic speed and with a very rapid release of electric power and a shock increase in pressure. In order to increase the intensity of electrohydraulic phenomena in high voltage EDIs, the exothermic solid and liquid dispersed additives are used [7]. Improvement of high-voltage EDIs made it possible to implement highly

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efficient electro-hydraulic technologies for restoration of pre-wellbore zones of oil and water wells, cleaning of metal castings weighing from 100 g to 200 tons, destruction of large-sized granite and concrete structures, crushing of porcelain, glass and other very strong (but non-plastic) products, industrial waste etc.

It was also substantiated that electric-spark machining can be a promising method for dispersion of the refractory, superhard and ductile metals, alloys and composites to obtain micro- and nanoparticles with unique operational properties [3, 6, 8]. This method allows to obtain powder micro- and nanostructured magnetic materials with shape memory [9], dispersion-strengthened refractory alloys [10, 11], surface active hydroxides, oxides, carbides, and nitrides [8–11]. The possibility of processing industrial metal waste into highly dispersed powders with a highly developed active surface increased the relevance of this line of research. However, the formation of single-channel spark-discharge processes in IEG of electric discharge installations did not allow increasing the productivity of producing electric-eroded powders to the volumes required for the development of industrial technologies, despite an increase in IEG length and increasing the voltage of discharge pulses to 20 kV [8].

The problem was solved after the development of design principles of semiconductor EDIs and stabilization their modes, which ensure the formation and adaptive regulation of dynamic processes of fast-migrating electric sparks in a layer of contacting metal granules in an IEG filled with a flowing dielectric liquid [12]. Stochastic change in EDIs electrical resistance [13, 14] was taken into account by purposeful pulse-to-pulse regulation of charge and discharge voltages across EDIs capacitors [15], taking into account the energy losses in their electrical circuits [16]. The effect of the duration of the discharge pulses [17], as well as the influence of the nonlinear characteristics of the electrical resistance of the load on the energy efficiency of the EDIs can be reduced by using supercapacitors [18] (the capacity of which increases with increasing voltage between their plates [19]) in EDIs circuits. In [20], it was substantiated the efficiency of regulation of the volume of the electric-spark plasma in the IEG, which allows changing both the value of the IEG electric resistance and the productivity of the electric-spark dispersion of metals.

At the same time, the work [9] proved the need for additional experimental studies of the distinctive features of the formation of pulsed currents in the layer of metal granules, as well as determining the regularities of the implementation of the conditions for their high-performance spark-erosion dispersion. It was also pointed out that it was necessary to substantiate the influence of the electrical characteristics of the discharge pulses on the features of the electric-spark erosion of the granular layer, the stability and energy efficiency of the realized spark erosion dispersion processes.

Therefore, **the aim** of this study is to clarify the features and regularities of the formation of discharge-pulse currents and fast-migrating electric sparks in a layer of metal granules and to establish the influence of the electrical characteristics of discharge pulses and technological load on energy efficiency, stability of modes and productivity of volumetric electric-spark dispersion (VESD) of a layer of conductive granules in the IFG of EDI.

To achieve this aim, we have developed a laboratory EDI. The structural diagram this EDI is shown in Fig. 1. Its main elements were: a discharge pulse former (DPF), containing an intermediate capacitive energy storage (CES) and a semiconductor discharge switch;

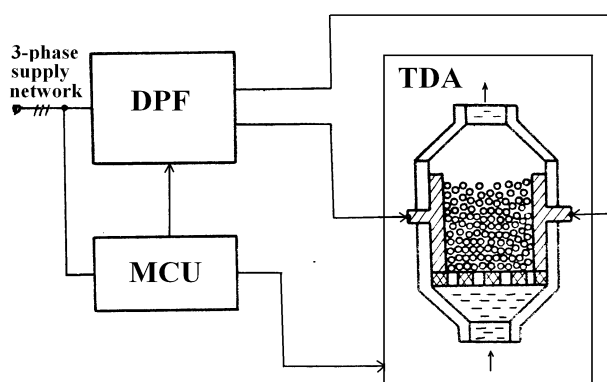


Fig. 1

a technological dispersion apparatus (TDA), the IEG of which was filled with a layer of conductive granules and a flowing dielectric liquid, as well as a mode control unit (MCU) for both DPF and TDA.

When developing DPF, TDA and MCU, it was necessary to take into account that the electrical resistance of the layer of conductive granules during the flow of a single pulse current of the CES discharge can change stochastically over a wide range [12–14]. Therefore, one of the tasks in the development of industrial EDIs was to identify and use the dependencies between the functional characteristics of the DPF and TDA, which made it possible to im-

plement the optimal electrical and technological modes of the entire installation.

To realize high performance of EDIs, the power supply of the TDA was carried out in such a way that the spark erosion processes occurred simultaneously on the largest possible number of metal granules.

Preliminary studies have shown that the voltage drop across one spark-erosive contact between conductive metal granules is usually 15–30 V, while when multi-channel spark-discharge currents are formed in the granular layer, the voltage drop between the electrodes in IEG increases to hundreds of volts [12]. This fact predetermined the advisability of increasing the voltage at the DPF output to several hundred volts.

Assessment of the main characteristics, as well as the energy and technological modes of the EDI was of great importance for the study. For efficient electric spark dispersion of a layer of granules, it is necessary that the supply of energy from the DPF to the zones of electrical contacts between the granules is carried out faster than the removal of heat from them. The simultaneous supply of electric energy to many zones of possible dispersion of metal granules predetermined the need to obtain rate of current rise up to 500 A/ μ s in the DPF output circuits at current amplitudes of hundreds and thousands of amperes.

The semiconductor DPF with a bank of reservoir capacitors with a total capacity of 15 mF, which were charged up to a voltage of 300 V, was made to carry out experimental studies. A high-speed thyristor ТБ 353-1000, which can withstand voltages up to 1600 V and surge currents up to 10 kA at a rate of their rise up to 1 kA/ μ s, was used as a switch of discharge currents in the DPF. The interelectrode gap in the TDA was filled with tap water and a layer of touching aluminum granules up to 80 mm high. The IEG length was about 40 mm, and the electrodes width was 60 mm.

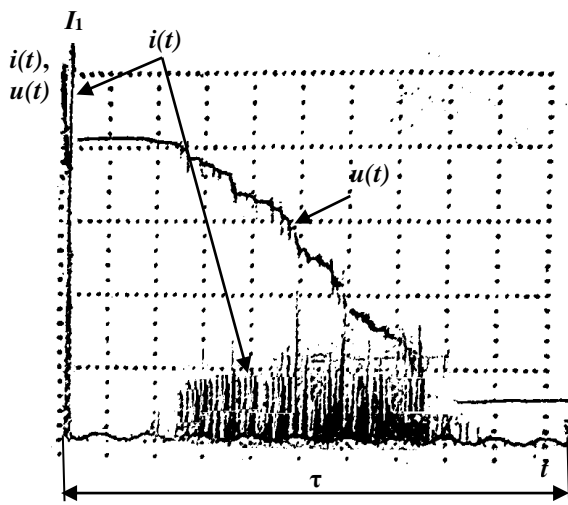


Fig. 2

Fig. 2 shows the time variation of the voltage $u(t)$ between the IEG electrodes and the current $i(t)$ in the layer of aluminum granules for the discharge of the DPF capacitors pre-charged up to a voltage of 300 V. The discharge duration is up to 180 ms. The inductance of the discharge circuit was about 1.5 μ H, the value of scale divisions on the oscillograms for voltage, current and time were 75 V/div, 400 A/div, and 15 ms/div.

An analysis of changes in the total discharge current $i(t)$ between the electrodes of the IEG showed that after the first current pulse $I_1 > 2$ kA with a duration of less than 3 ms, a currentless pause with a duration of more than 40 ms is observed, and then discharge currents with a much lower amplitude (in comparison with the first current pulse I_1) and having deep amplitude modulation are observed.

These results showed the possibility of the appearance of large currents and electrohydraulic phenomena in the IEGD during the discharge of a large-capacity CES, which is pre-charged to low voltages (300 V), i.e. pre-charge up to high (several tens of kV) voltages is not required. Such currents can create electrohydraulic phenomena of prolonged rupture of contacts of granules with electrodes and rather long-continued (more than 40 ms) currentless pauses, and then even more long-duration currents of low amplitudes.

That is why, we have concluded about the energy and technological appropriateness of forming high-frequency discharge currents of shorter duration (on the order of several and tens of microseconds) with an controlled relative pulse duration of pulse currents in a layer of metal granules.

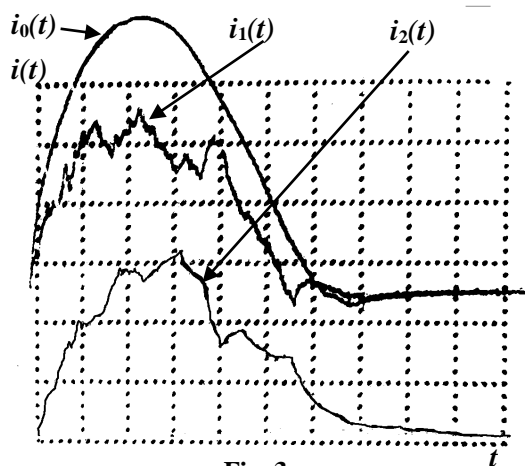


Fig. 3

But there was a question about the possibility of the formation of multi-channel discharge-pulse currents and fast-migrating electric spark phenomena in such a layer of granules.

The possibility of realizing such currents and phenomena was experimentally confirmed by studies in the discharge of one storage capacitor with a capacity of 200 μ F, pre-charged to a voltage of 500 V, into two parallel-connected IEGs filled with a layer of contacting aluminum granules and water.

There are the oscillograms of currents $i_1(t)$ and $i_2(t)$ arising between the electrodes of the first IEG and the second IEG, as well as the resulting current $i_0(t) = i_1(t) + i_2(t)$ in the common part of the discharge circuits of both IEGs during the

above-mentioned discharge of the 200 μF capacitor, in Fig. 3. The value of scale divisions for current and time is 850 A/div and 10 $\mu\text{s}/\text{div}$.

It should be noted that a decrease in the current $i_1(t)$ in the first IEG causes an increase in the current $i_2(t)$ in the second IEG, and vice versa, which is natural when the electrical resistance of one of the two electrical circuits connected in parallel to one voltage source changes.

Therefore, the currents $i_1(t)$ and $i_2(t)$, which flow in parallel electrical circuits between two pairs of electrodes, are mutually dependent currents and they have a serrated shape. At the same time, their total pulse current, which is represented by the oscillogram $i_0(t)$, has a shape well smoothed by the inductance of the common part of the discharge circuit of the DPF capacitor. Such shape is typical for all DPF discharge currents, if the capacitance and charge voltage of the DPF capacitor are selected so that the average Q-factor of the DPF discharge circuit is not less than 0.5.

Note that each discharge of a pre-charged DPF capacitor caused the simultaneous flow of pulsed currents similar to $i_1(t)$ and $i_2(t)$ in the layers of both IEGs, as well as the appearance of fast migrating spark erosion phenomena of different intensities and durations in the layers of aluminum granules of both IEGs.

Similar dependences of pulse currents and spark erosion phenomena took place when one IEG was connected to the reservoir capacitor of DPF, and the layer of conductive granules in the IEG was divided into two parts by a vertical dielectric partition located perpendicular to the electrodes of the IEG.

Fig. 4 shows a high-speed shadow photograph of the rapid migration of electrospark phenomena in a symmetric two-dimensional layer of lead granules (that is, in the layer one horizontal size of which was one granule) during the course of one discharge of a capacitor with a capacity of 100 μF , pre-charged to a voltage of 1200 V [12].

Features of the formation of single-channel and multi-channel currents in the IEG of EDI.

The main reason for spark-erosion damage on the surfaces of electrodes [2–4] and metal granules, which are in contact both with the electrodes and with each other [6, 8, 12, 20], is the presence of micro-zones of electrical contacts with conductive bridges of the smallest section and, accordingly with the highest current density. Since the rate of energy release in such micro-zones is higher than the rate of its heat removal into the environment, the concentration of energy, and, consequently, the temperature in these micro-zones increases, causing the processes of melting, evaporation and plasma formation.

The temperature in such electric spark-plasma formations can reach 10 thousand $^\circ\text{K}$ [6], i.e. it can be much higher than the melting and evaporation temperature of all known metals, their alloys and composites. Therefore, at present, there are no conductive materials that are absolutely resistant to the effects of electro-erosive (in fact, electro-plasma) phenomena.

When high pulse currents are generated in the IEG of EDI, the processes of melting, evaporation and plasma formation occur very quickly and have an explosive character in the aforementioned micro-zones.

The liquid (in particular, water) in IEG prevents the expansion of the electro-plasma channel, thereby preventing a decrease in the energy density in the channel, but contributes to the appearance of high shock pressures at the interface of different aggregate and phase states of the substance. This leads to the ejection of nano- and micro-volumes of metal into the surrounding liquid.

The main distinguishing condition for the formation of single-channel spark-discharge currents in the IEG is the fact that its pre-breakdown electrical resistance is not less than the pre-breakdown resistance of the contacting electrodes, and is necessarily greater than this resistance if there is a layer of series-connected conductive granules in the IEG. This condition is feasible for long small-section IEGs, in which the number of series-connected contacts between the granules exceeds the number of parallel-connected contacts between them in the perpendicular section. Then an increase in the productivity of electric spark dispersion of granules is possible only by increasing the number of series-connected contacts between the granules and, accordingly, by increasing the output voltage of the EDI, as in [8]. This way of improving EDIs allows slightly (several times) to increase their productivity, but in many respects complicates their maintenance due to the need to form high-voltage discharge pulses and apply increased safety measures.

A distinctive condition for the formation of multi-channel spark-discharge currents in an IED is that its pre-breakdown electrical resistance is necessarily less than the pre-breakdown resistance of the contacting electrodes. This condition is feasible for short IEGs and a large section of the layer of conductive granules, in which the number of parallel-connected contacts between the granules in the perpendicular section is much greater than the number of series-connected contacts between the electrodes. The increase in the productivity of electric spark dispersion of granules is carried out precisely by increasing the number of parallel-

connected granules and, accordingly, the magnitude of the pulsed current in the layer of granules between the electrodes of the IEG, and the output voltage of the EDI does not exceed 1000 V, as in [12, 14, 18].

It should be noted that in this case, the pre-breakdown electrical resistance of the layer of conductive granules is much less than the resistance of one contact between them, since the number of parallel circuits between the electrodes (which is determined by the area of the electrodes and the cross section of the granule layer) can be many times greater than the number of contacts connected in series between the IEG electrodes. Moreover, an increase in the number of parallel-connected contacts between the granules creates conditions for the formation of multi-channel and fast-migrating spark-discharge currents in the layer of metal granules between the electrodes of the IEG, creating conditions for a multiple increase in the productivity of the EDI.

The study of oscillograms of spark-discharge currents with a duration of 1 μ s to 1 ms in a layer of conductive granules between the TDA electrodes and oscillograms of voltage drops in the IEG of single TDA or several ones connected in parallel to the output of single DPF showed that during single spark-discharge pulse the electrical resistance of the granule layer can randomly change several times [8, 12-14]. Moreover, such a change is possible both before and after the initiation of sparks in the layer. This is evidenced by the high-frequency modulation of the current and voltage curves on the oscillograms shown in Fig. 2 and 3. That is why, in most cases, when analyzing transient processes in the DPF discharge circuit, the effective value of the active resistance of the spark-erosion load $R_{load\ eff} = const$ is introduced. During single discharge pulse, this resistance consumes the same power as the real resistance of the layer of conductive granules.

Dependence of the effective value of the resistance of the spark-erosion load on the value of the pre-charge voltage of the reservoir capacitor of EDI. Our studies have revealed the functional dependence

of the nature of spark-erosion discharges in the layer of conductive granules between the electrodes on the value of the pre-charge voltage of the EDI reservoir capacitor.

In Fig. 4, *a* and *b* we can see the oscillograms of the time variation of the voltage drop $u(t)$ between the electrodes and the spark-discharge current $i(t)$ in the layer of aluminum granules between these electrodes

at two values of the capacitor pre-charge voltage U_{1C} and U_{2C} ($U_{1C} < U_{2C}$). The capacitance of the capacitor was 50 μ F, and all other parameters of the discharge circuit of the EDI did not change. The division values were 20 V/div, 212 A/div, and 5 μ s/div in Fig. 4, *a*, and 50 V/div, 426 A/div and 5 μ s/div in Fig. 4, *b*.

Since the real load resistance of the EDI changes during the discharge of the capacitor, we made the assumption that the discharge in which the voltage across the capacitor does not change its polarity can be called an aperiodic discharge. A critical discharge is a discharge in which the capacitor voltage tends to zero, and during an oscillatory dis-

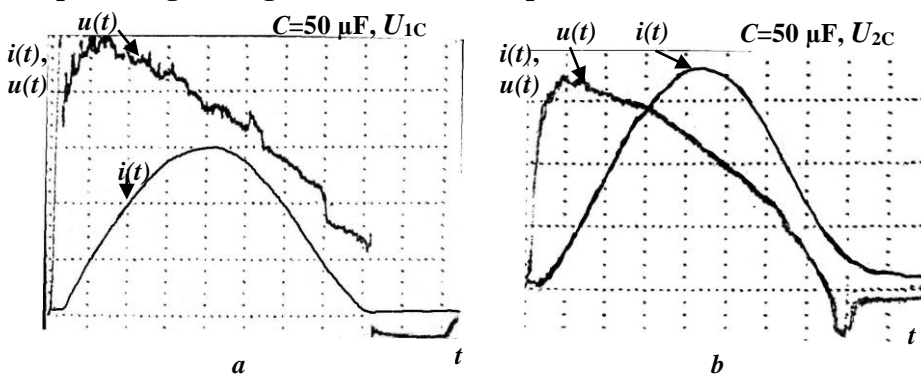


Fig. 4

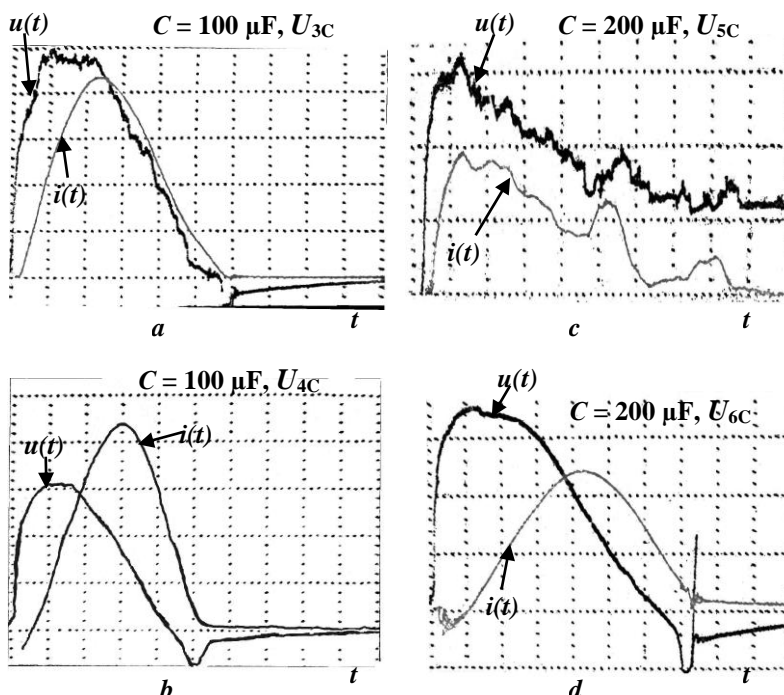


Fig. 5

charge, the voltage changes its polarity.

As you can see in Fig. 4, when the capacitor is charged to a voltage U_{1C} , its discharge in the IEG is aperiodic, and when the capacitor is charged to a voltage $U_{2C} > U_{1C}$, its discharge is oscillatory.

Similar dependences are shown in Fig. 5. When a capacitor with a capacity of 100 μF (200 μF) is charged to a voltage of U_{3C} (U_{5C}), its discharge is aperiodic, and when a capacitor is charged to $U_{4C} > U_{3C}$ ($U_{6C} > U_{5C}$), its discharge becomes oscillatory (see oscillograms in Fig. 5 *a, b* (5 *c, d*)). The division values were 50 V/div, 426 A/div and 10 μs /div in Fig. 5, *a*; 100 V/div, 850 A/div 10 μs /div in Fig. 5, *b*; 50 V/div, 426 A/div and 20 μs /div in Fig. 5, *c*; 100 V/div, 2,2 kA/div and 10 μs /div in Fig. 5, *d*.

The oscillograms shown in Fig. 4 and 5, confirm that an increase in the capacitor pre-charge voltage leads to the fact that the aperiodic discharge of the capacitor can change to an oscillatory one. And an increase in the capacitance of a capacitor leads to an increase in the pre-charge voltage value, at which the discharge changes from aperiodic to oscillatory ($U_{6C} > U_{4C} > U_{2C}$).

From the point of view of the energy processes, the most favorable discharge mode is a mode close to the critical discharge (with a circuit quality factor $Q \approx 0.5$). In this case, the energy of the capacitor is almost completely released in the spark-erosion load, and the discharges are not long-term, which makes it possible to realize high average powers.

For the current in the transient process of the capacitor discharge, we can write the expression [21]:

$$i(t) = U_C \cdot (e^{p_1 t} - e^{p_2 t}) / 2L \sqrt{(\delta^2 - \omega_0^2)}, \quad (1)$$

where $\delta = R_{load\ eff} / 2L$, $\omega_0 = 1 / \sqrt{LC}$, $p_{1,2} = -\delta \pm \sqrt{\delta^2 - \omega_0^2}$, U_C – initial capacitor voltage.

For critical transient of capacitor discharge, when $R_{load\ eff} \approx 2\sqrt{L/C}$ and $p_1 = p_2 = -\delta$, we obtain the indeterminate form 0/0 in the expression (1). Evaluating the indeterminate form according to L'Hospital rule by differentiating the numerator and denominator with respect to $p_1 \approx p_2$, we obtain:

$$i(t) = \lim_{p_1 \rightarrow p_2} (U_C (e^{p_1 t} - e^{p_2 t}) / L(p_1 - p_2)) = U_C t e^{-\delta t} / L. \quad (2)$$

To find the time point t_{max} , when the current reaches its maximum value i_{max} , we determine the derivative $\partial i / \partial t$ from expression (2) and equate it to zero:

$$\partial i / \partial t = U_C e^{-\delta t} (1 - \delta t) / L = 0. \quad (3)$$

From expression (3) we obtain that $t_{max} = 1 / \delta = 2L / R_{load\ eff}$. Thus, the duration of the current rise to the maximum value in the spark-erosion load is proportional to the inductance of the discharge circuit and is inversely proportional to its active resistance. Consequently, an increase in time of the current rise to its maximum value with an increase in the voltage U_C , shown in Fig. 5 and 6, confirms a decrease in the value $\delta = R_{load\ eff} / 2L$.

At $t = t_{max} = 2L / R_{load\ eff}$, the value of the current $i(t_{max}) = 2U_C / e R_{load\ eff}$, i.e. the maximum current in the IEG *does not depend on* the inductance and capacity of the discharge circuit.

Analysis of Fig. 5 *a, b* (6 *c, d*) shows that with an increase in U_C by 1.2 (2) times, the value of i_{max} increases by 2 (6.5) times, on the basis of which it can be concluded that an increase in the pre-charge voltage of the capacitor UC leads to a decrease in the effective value of the active resistance of the spark-erosion load (and, consequently, to an increase in the Q -factor of the discharge circuit).

Our experimental studies have shown that, from an energy point of view, the most favorable discharge mode of a capacitor is a mode close to a critical discharge. However, from a technological point of view, more stable, faster and more controllable modes are oscillatory discharge modes of a capacitor with a small recharge voltage (voltage of reverse polarity) on its plates. In this case, a decrease in the inductance of the discharge circuit causes a decrease in the duration of the discharge currents and an increase in their maximum values. But, unfortunately, the reduction of such inductance is limited by severe design constraints.

The revealed dependence of the resistance of the spark-erosion load on the charge voltage of the capacitor made it possible to form an opinion about the deviation of the current mode from the specified one based on the change in the nature of the discharge and to neutralize this deviation by changing the charge voltage of the capacitor.

On the basis of the revealed regularities, the concept of synthesis of electric discharge installations with a reservoir capacitor for VESD of metals was developed. This concept is based on the use of non-zero initial conditions of transient processes in the circuits of such installations, as well as taking into account the dependence of the effective resistance of the IEG on the charge voltage of the reservoir capacitor, and introducing the negative voltage feedback in these installations. The application of this concept made it possible

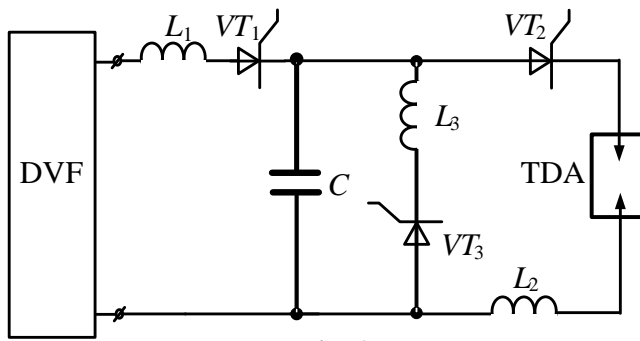


Fig. 6

to reduce both the instability of transient processes in the circuits of such EDIs and the losses arising in them.

Fig. 6 shows the electrical circuit diagram that performs this stabilization. The circuit contains a direct voltage former (DVF), from which the oscillatory charge of the capacitor C is carried out through the choke L_1 when the thyristor VT_1 is turned on. After completing the charge and turning on the thyristor VT_2 , the capacitor is discharged to the interelectrode gap of the TDA. The constructive inductance of the current-conducting wires of the

discharge circuit and TDA is shown in the diagram by element L_2 . The oscillatory discharge of a capacitor in a circuit with a semiconductor element (thyristor) is completed by recharging the capacitor to a voltage of reverse polarity, which contributes to the rapid turn-off of the thyristor VT_2 . The choke L_3 and the thyristor VT_3 form a reverse recharge circuit to the voltage U_{0C} of the capacitor C . It is the values of U_{0C} that affect the value of the voltage U_C of the subsequent charge of the capacitor (which will be the initial voltage of next discharge of capacitor).

The voltage of the oscillatory charge of the capacitor under the condition of its nonzero initial voltages can be determined from the expression [12]

$$u_C(t) = U_{DVF} - (U_{DVF} - U_{0C}) \cdot e^{\frac{-\omega_{01}t}{2Q_1}} \times \left(\frac{1}{2Q_1 \sqrt{1 - 1/4Q_1^2}} \sin \omega_{01} \sqrt{1 - \frac{1}{4Q_1^2}} t + \cos \omega_{01} \sqrt{1 - \frac{1}{4Q_1^2}} t \right), \quad (4)$$

where U_{DVF} is the voltage at the DVF output, Q_1 is the Q -factor of charge circuit, $\omega_{01} = 1/\sqrt{L_1 C}$.

Since in EDIs for VESD of metals the quality factor is usually $Q_1 > 10$, then (4) can be simplified to the form:

$$u_C(t) = U_{DVF} - (U_{DVF} - U_{0C}) \cdot e^{\frac{-\omega_{01}t}{2Q_1}} \left(\frac{1}{2Q_1} \sin \omega_{01} t + \cos \omega_{01} t \right). \quad (5)$$

The maximum charge voltage of the capacitor is calculated as

$$U_{Cmax} = U_{DVF} + (U_{DVF} - U_{0C}) \cdot e^{\frac{-\pi}{2Q_1}}. \quad (6)$$

Thus, with an increase in U_{Cmax} , the Q -factor of the discharge circuit Q_2 also increases (due to a decrease in the effective value of the active resistance of the spark-erosion load). The consequence of the increase in Q_2 will be an increase in the value of U_{0C} , which will lead to a decrease in U_{Cmax} (see (6)) with the subsequent charge (see (6)).

Similarly, if the voltage U_{Cmax} decreases, then the quality factor of Q_2 will also decrease, which causes a decrease in U_{0C} and, therefore, an increase in U_{Cmax} in the subsequent charge of the capacitor.

The revealed dependences and the implementation on their basis of stabilization of modes in installations for VESD of metals allows in practice to increase the productivity and quality of the obtained dispersed

spark-eroded powders. The definition of these dependencies has a significant impact on the design principles of industrial EDIs.

Conclusions. The features and regularities of spark processes during the discharge of a reservoir capacitor through technological load, which is a layer of conductive granules (usually metal granules) immersed in a dielectric liquid between the electrodes of the electric discharge installation, have been determined. The influence of the main characteristics of such a load on the efficiency of its power supply has been clarified. The theoretical substantiation and experimental confirmation of a new phenomenon are presented: the generation of multi-channel spark discharges in a layer of conductive granules, rather than single-channel spark discharges as in electrical discharge machining. The dependence of the effective value of the active resistance of the load of the electric discharge installation on the value of the pre-charge voltage of its reservoir capacitor has been found. It is proved that an increase in the quality factor of the discharge circuit with an increase in the voltage of the capacitor charge is caused precisely by a decrease in the effective value of the active resistance of the load. On the basis of the revealed dependencies we have developed and implemented the design principles of high-performance electric discharge installations with parametric stabilization of their modes for volumetric electro-spark dispersion of a layer of conductive granules immersed in a dielectric liquid between the electrodes.

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ОСОБЛИВОСТІ ФОРМУВАННЯ БАГАТОКАНАЛЬНИХ ІМПУЛЬСНИХ СТРУМІВ І ШВИДКО МІГРУЮЧИХ ЕЛЕКТРОІСКРІНЬ В ШАРІ СТРУМОПРОВІДНИХ ГРАНУЛ ЕЛЕКТРОРОЗРЯДНИХ УСТАНОВОК

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У роботі показані електрофізичні особливості формування багатоканальних імпульсних струмів і швидко мігруючих електроіскрінь в шарі струмопровідних гранул електророзрядних установок (ЕРУ) з накопичувальними конденсаторами. Такі особливості дають змогу багаторазово збільшувати продуктивність іскроерозійного диспергування металевих гранул за час протікання одного розрядного струму накопичувальних конденсаторів між електродами ЕРУ. Наведено теоретичне обґрунтування і експериментальне підтвердження багатоканальності іскрових розрядів в шарі струмопровідних гранул. Досліджено вплив величини ємності і напруги заряду накопичувальних конденсаторів на характер перехідних процесів в розрядному колі ЕРУ. Експериментально встановлено залежність ефективного значення активного опору навантаження ЕРУ від величини напруги попереднього заряду її накопичувальних конденсаторів і величини їхньої ємності. Доведено, що збільшення усередненої добротності розрядного контуру з підвищенням напруги заряду батареї конденсаторів ЕРУ викликається зменшенням ефективного значення активного опору шару металевих гранул при протіканні в ньому іскроутворюючих розрядних струмів. Бібл. 21, рис. 6.

Ключові слова: імпульсний струм, електроіскровий розряд, електророзрядна установка, ємнісний накопичувач енергії, шар металевих гранул, електроіскрове диспергування.

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