УДК 621.9.048
Doi: 10.31772/2712-8970-2023-24-4-760-767

Для цитирования: Удельные энергозатраты электро-контактно-химической обработки металлов вибрирующим инструментом в электролите / И. Я. Шестаков, В. И. Шестаков, И. В. Трифанов, И. А. Ремизов // Сибирский аэрокосмический журнал. 2023. Т. 24, № 4. С. 760–767. Doi: 10.31772/2712-8970-2023-24-4-760-767.

For citation: Shestakov I. Ya., Shestakov V. I., Trifanov I. V., Remizov I. A. [Specific energy consumption of electro-contact-chemical treatment of metals with a vibrating tool in the electrolyte]. *Siberian Aerospace Journal.* 2023, Vol. 24, No. 4, P. 760–767. Doi: 10.31772/2712-8970-2023-24-4-760-767.

Удельные энергозатраты электро-контактно-химической обработки металлов вибрирующим инструментом в электролите

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По удельному расходу энергии процессы формообразования располагаются в трёх энергетических уровнях. Электрофизические и электрохимические методы обработки металлов находятся на третьем уровне, где удельные энергозатраты составляют более *$6\cdot10^4$ Дж/см^3. Анализ литературных данных показал противоречивость удельных затрат некоторых авторов. Удельные энергозатраты электроконтактной обработки никак не могут быть соизмеримыс затратами при электрохимической обработке из-за разных размеров удаляемых частиц с поверхности обрабатываемой детали. Литературные данные по удельным энергозатратам электро-контактно-химической обработки металлов вибрирующим инструментом в электролите отсутствуют, поэтому проведены эксперименты с фиксацией осциллограмм тока, напряжения и межэлектродного зазора. Приведена методика расчёта удельных энергозатрат по осциллограммам процесса. Рассчитаны затраты энергии на вибрацию электрода-инструмента, которые на порядок меньше на электро-контактно-химическую обработку. При уменьшении амплитуды вибрации или увеличении напряжения на электродах процесс в межэлектродном зазоре переходит в размерную обработку дугой. При электро-контактно-химической обработке металлов вибрирующим инструментом в воде удельные энергозатраты равны (3,5–3,8)$\cdot10^5$ Дж/см^3, что соответствует электроконтактной обработке. Предполагается, что использование водных растворов нейтральных солей приведёт к снижению затрат энергии.*

Ключевые слова: удельные энергозатраты, электро-контактно-химическая обработка, вибрация, амплитуда, частота, осциллограмма, расчёт.

Specific energy consumption of electro-contact-chemical treatment of metals with a vibrating tool in the electrolyte

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According to the specific energy consumption, the shaping processes are arranged in three energy levels. Electrophysical and electrochemical methods of metal processing are at the third level, where the specific energy consumption is more than 6·10^4 J/cm^3. The analysis of the literature data showed the inconsistency of the specific costs of some authors. The specific energy consumption of electrical contact processing cannot be commensurate with the costs of electrochemical processing due to the different sizes of the particles removed from the surface of the workpiece. There are no literature data on the specific energy consumption of electro-contact-chemical treatment of metals with a vibrating instrument in the electrolyte, therefore, experiments have been carried out with the fixation of current, voltage and interelectrode gap oscillograms. The method of calculation of specific energy consumption according to the oscillograms of the process is given. The energy costs for vibration of the electrode-tool are calculated, which are an order of magnitude less for electro-contact-chemical treatment. When the vibration amplitude decreases or the voltage on the electrodes increases, the process in the interelectrode gap turns into dimensional arc processing. When electro-contact-chemical treatment of metals with a vibrating tool in water, the specific energy consumption is equal to (3.5–3.8) · 10^5 J/cm^3, which corresponds to electrocontact treatment. It is assumed that the use of aqueous solutions of neutral salts will lead to a reduction in energy costs.

Keywords: specific energy consumption, electro-contact-chemical treatment, vibration, amplitude, frequency, oscillogram, calculation.

Introduction

Specific energy consumption is one of the important indicators affecting the economic efficiency of the molding process. Specific energy consumption is defined in kWh/kg, J/cm^3. In [1; 2] it is recommended to determine the properties of metals per unit volume when revealing the regularities of metal behavior under various physical processes.

According to this characteristic, all the forming processes are arranged in three energy levels. The first level includes the processes that require a minimum of energy to break the bonding forces between only a part of atoms or molecules of the body. This level extends up to the melting energy of metals (Table 1), i.e., approximately up to 10^4 J/cm^3 [3].

The second level includes processes that require energy inputs to break the bonds between all atoms and molecules of the body. Casting is a characteristic process for this condition. It is not clear why reaming and grinding are located in this level, because there is no breaking of bonds between all atoms and molecules. Metal removal occurs in the form of chips [4]. The second energy level is located between the melting energy of 10^4 J/cm^3 and the vaporization energy of metals $6 \cdot 10^4$ J/cm^3.

Table 1

Energy levels of shaping processes

Energy level	Shaping method	Specific energy consumption, J/cm^3
I	Cold deformation	$1 \cdot 10^1$–$4 \cdot 10^1$
	Stamping	$2 \cdot 10^1$–$6.5 \cdot 10^1$
	Cold extrusion	$5.5 \cdot 10^2$–$8.5 \cdot 10^2$
	Turning	$1.7 \cdot 10^3$–$2.5 \cdot 10^3$
	Broaching	$2.5 \cdot 10^3$–$3.7 \cdot 10^3$
	Milling	$5 \cdot 10^3$–$7.5 \cdot 10^3$
II	Hot deformation	$9 \cdot 10^3$–$3.4 \cdot 10^4$
	Casting	$1.4 \cdot 10^4$–$2.5 \cdot 10^4$
	Reaming	$1.2 \cdot 10^4$–$3 \cdot 10^4$
	Grinding	$5.5 \cdot 10^4$–$7 \cdot 10^4$

Ending of Table 1

Energy level	Shaping method	Specific energy consumption, J/cm^3
III	Dimensional electrochemical treatment	$4.25\cdot10^5$–$4.35\cdot10^5$
	Treatment:	
	anodic mechanical	$1.7\cdot10^5$–$5.2\cdot10^5$
	electrocontact	$2.3\cdot10^5$–$4.6\cdot10^5$
	electropulse	$3.5\cdot10^5$–$7.1\cdot10^5$
	electrospark	$1.1\cdot10^6$–$2.9\cdot10^6$
	ultrasonic	$6\cdot10^5$–$3.6\cdot10^6$
	light-beam	$2.8\cdot10^7$–$4.7\cdot10^7$

In the third energy level there are processes, which require energy for complete destruction of bonding forces between all atoms or molecules of the body. Characteristic for this level are dimensional electrochemical treatment, electrospark and electro-pulse treatments, treatment with electron and light beams. This level is located above the vaporization energy of metals, i.e. above $6\cdot10^4$ J/cm^3.

As the hardness and strength of materials increase, energy consumption increases (Fig. 1) [4] and treatment productivity decreases. Modern metals and alloys have a tensile strength of more than 200 MPa, so high energy consumption of electro-treatment is quite justified, as other shaping methods become uncompetitive in terms of productivity.

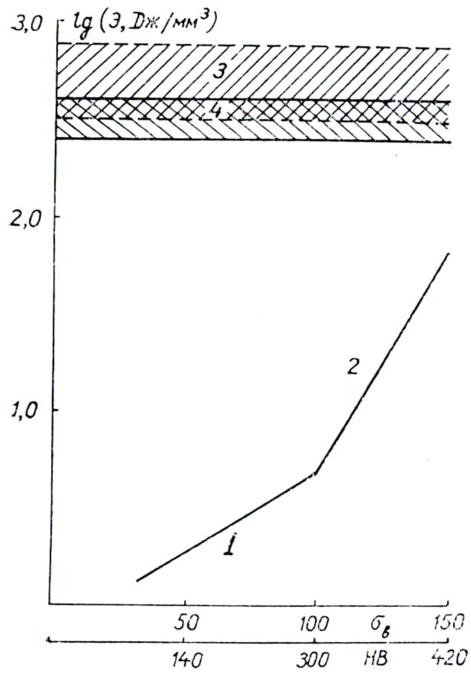

Рис. 1. Энергоёмкость некоторых видов обработки:
1 – обработка лезвийным инструментом; *2* – шлифование;
3 – электроимпульсная; *4* – ЭХО

Fig. 1. Energy intensity of some types of processing
1 – blade tool processing; *2* – grinding; *3* – electric pulse; *4* – electrochemical treatment

Analysis

The data given in [4-6] and Tables 1-3 do not agree with the values of specific energy consumption during electrochemical processing presented by the authors [7; 8] (Table 4). According to these authors, the costs at electrochemical treatment are 9–40 times higher than at electrocontact treatment. Tables 1 and 2 show that the specific energy consumption of electrocontact and electrochemical treatments are commensurable, which does not correspond to reality because the removal of metal from the treated surface occurs with different particle sizes, in the first case in the form of molten metal droplets, in the second case in the form of metal ions.

Detailed indicators of varieties of electrophysical treatment methods are given in the reference book [6] Table 3.

Table 2

Specific energy consumption of electric methods of treatment

№	Treatment	Specific energy consumption, J/cm^3
1	Electrospark	11–29
2	Electropulse	3.5–7.1
3	Electrochemical	4–6
4	Electrocontact	2.3–4.6

Table 3

Main properties of electrophysical methods of metal processing

Treatment method	Average specific productivity, cm^3/s	Average specific energy consumption, J/cm^3
Electrosparking:		
rough	$9.3 \cdot 10^{-3}$–$1 \cdot 10^{-2}$	$(4.3–7.2) \cdot 10^5$
finishing	$8 \cdot 10^{-4}$–$1.6 \cdot 10^{-3}$	$(1.4–2.0) \cdot 10^6$
precision	$1.7 \cdot 10^{-6}$–$1.7 \cdot 10^{-5}$	$(2.0–2.5) \cdot 10^6$
Electroimpulse:		
rough	$1.7 \cdot 10^{-2}$–$1.8 \cdot 10^{-1}$	$(3.5–7.1) \cdot 10^5$
finishing	$8 \cdot 10^{-4}$–$8 \cdot 10^{-3}$	$(2.6–5.8) \cdot 10^5$
Electrocontact:		
cutting	$1.6 \cdot 10^{-2}$–$1.3 \cdot 10^{-1}$	$(0.3–1.2) \cdot 10^5$
turning	$1.6 \cdot 10^{-2}$–$6.5 \cdot 10^{-1}$	$(1.2–1.4) \cdot 10^5$
skinning	15–17	$(2.3–4.6) \cdot 10^5$
piercing	$8.3 \cdot 10^{-3}$–$2.5 \cdot 10^{-2}$	$(0.12–5.8) \cdot 10^4$

In Table 3, the specific energy consumption for electrical contact piercing of holes is questionable, which is an order of magnitude lower than for other types of this processing. The removal of erosion products from the holes is difficult during electrocontact piercing, so additional energy consumption is required.

Table 4

Specific energy consumption of certain electrochemical methods of treatment

№ п/п	Treatment	Specific energy consumption, J/cm^3*10^5
1	Electrochemical	2.52–5.61[5]; 5.61–11.2[6]
2	Electrical discharge	1.68–3.36
3	Electrocontact	0.28–0.56

More data on electrochemical treatment specific energy consumption in kWh/kg are available in the reference book [9]. Taking into consideration the density of metals the calculation of energy consumtion per volume item of material being processed was fulfilled. Table 5 shows the results of this calculation for some metals.

Table 5

Specific energy consumption of electrochemical dimensional treatment of metals in aqueous solutions of neutral salts, J/cm^3 10^5

Metal	25%NaCl	30%$NaNO_3$	15%Na_2SO_4
Steel U10	1.96	6.44	70.84
Steel 35HGS	3.28	3.84	28.03
Steel 4H5V2FS	3.12	4.37	34
Aluminium	1.55	1.94	65.5
Nickel	2.14	22.3	39.2
Titanium alloy BT8	3.49	5.33	258

Table 5 shows that the lowest specific energy consumption is characteristic of electrochemical treatment in aqueous sodium chloride solution. This is explained by the presence of activating chlorine anion in the electrolyte which favours the formation of intermediate complex compounds [10]. During electrochemical treatment in aqueous sodium sulphate specific energy consumption increases by 10-15 times the reason for which is passivation of the anode [11]. This phenomenon is especially characteristic of titanium alloy BT8 since titanium is an active metal, its standard electrode potential is 1.2 V [12] and its surface always has an oxide film.

Methodology

Experimental studies were carried out on an electrotreatment unit with a linear electrodynamic motor described in the scientific journal [13]. To fix the electrode tool a fixture was made to ensure the flow of water (weak electrolyte) through the interelectrode gap. The methodology of experimental studies is described in [14]. The treated metal is HVG steel. However this paper doesn't provide a methodology for calculating the specific energy consumption of electro-contact-chemical treatment of metals in the electrolyte based on oscillograms of the process.

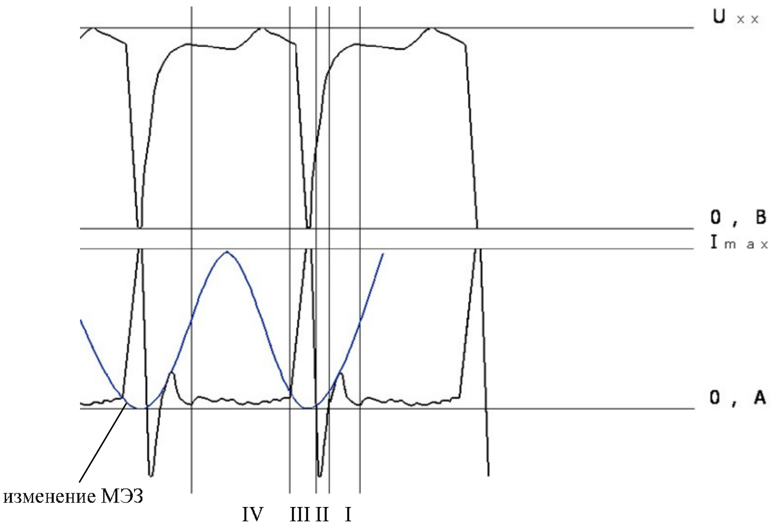

Рис. 2. Осциллограмма напряжения и тока ЭКХО

Fig. 2. Oscillogram of the voltage and current of the electro-contact-chemical treatment

Calculation of specific energy consumption based on the oscillogram. Typical oscillogram of current, voltage and interelectrode gap during electro-contact chemical treatment with vibrating electrode-tool in water is shown in Fig. 9. The data were obtained at an average electrode voltage of 16.7 V and a tool oscillation amplitude of 0.75 mm. At the oscillation amplitude of 0.25 mm and the average velocity of water flow in the interelectrode gap of 1 m/s and less, the current and voltage oscillogram characteristic of dimensional arc machining is observed [15; 16].

The oscillogram is divided into sections I, II, III, IV. Section I is the pre-breakdown period - the time of streamer formation - the discharge channel. Section II - breakdown of the interelectrode gap, III - contact of electrodes, IV - period when the current is caused by anodic dissolution of the treated metal (electrochemical treatment). The square of each triangle is determined, thus the amount of electricity passed in each period (sections I - IV) will be known. Next, the average voltage value at each section is determined from the oscillogram data.

For section I we have

$$q_I = \frac{1}{2} h_I a_I M_I M_\tau ,$$

Where h_I is the height of the triangle of section I; a_I is the length of the base of the triangle of section I; M_I is the current scale, M_I=2.5 A/mm; M_τ is the time scale, M_τ=0.48 ms/mm.

After calculating the amount of electricity for all sections we get

$$q_I = 56,25 \cdot 10^{-3} \text{ Кл}; \; q_{II} = 76,6 \cdot 10^{-3} \text{ Кл};$$

$$q_{III} = 600 \cdot 10^{-3} \text{ Кл}; \; q_{IV} = 162 \cdot 10^{-3} \text{ Кл}.$$

Average voltage at the sections is

$$U_I = 24,3 \text{ В}; \; U_{II} = 17,5 \text{ В}; \; U_{III} = 11,3 \text{ В}; \; U_{IV} = 25,7 \text{ В}.$$

Pulse energy at the sections is

$$Q_I = 1,351 \text{ Дж}; \; Q_{II} = 1,348 \text{ Дж}; \; Q_{III} = 6,78 \text{ Дж}; \; Q_{IV} = 4,155 \text{ Дж}.$$

Taking into account the frequency of oscillation of the electrode-tool (50 Hz), processing time and the volume of removed metal, the specific energy consumption is determined as follows

$$W = [(Q_1 + Q_2 + Q_3 + Q_4) * f * t] / V,$$

where f is the oscillation frequency, s^{-1}; t is the treatment time, s; V is the volume of removed metal, cm^3.

Specific energy consumtion is $W = (3.5–3.8) \cdot 10^5$ J/cm^3.

In addition to the electrical energy consumed for the electro-machining process, it is necessary to take into account the energy consumption for the vibration of the electrode-tool. This energy is determined by the well-known formula

$$W_в = m * f^2 * A^2,$$

where m is the mass of the electrode-tool with the device for its fixing, kg; A is the amplitude of vibration of the electrode-tool, m. After substituting the data into the above formula it turns out that the energy consumption for the vibration of the tool electrode is an order of magnitude less than for the processes of electro-contact-chemical treatment.

Conclusion

Specific energy consumption is an important indicator when selecting a method of treatment of metals and alloys. For materials difficult to be machined by mechanical methods, the alternative is the methods of electrical treatment. The analysis of literature data has shown that indicators on specific energy consumption are contradictory, and for the combined electro-contact-chemical method of processing by vibrating electrode in water this characteristic is practically absent. Calculation by oscillograms of the process shows that specific energy consumption of electro-contact-chemical treatment by vibrating electrode in water corresponds to electro discharge treatment and electrochemical treatment in aqueous solution of sodium chloride or sodium nitrate. At electro-contact-chemical treatment in aqueous solution of the above mentioned salts it is necessary to expect decrease of specific energy consumption as energy losses on heating of electrolyte decrease due to decrease of its electrical resistance, and chlorine and nitrate ions reduce activation energy of the treated metal.

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