Simulation of Electrochemical Micromachining by Nanosecond Voltage Pulses

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Electrochemical micromachining (ECMM) with using nanosecond voltage pulses between a tool electrode and a workpiece enables one to form complex-shaped three-dimensional structures with submicrometer precision. The principle is based on the dependence of double-layer charging time on the interelectrode gap (local separation between the electrodes). This results in a highly localized region for electrochemical dissolution or deposition. This technique is used for local anodic dissolution of various metals and silicon as well as for local metal electrodeposition.

The accuracy and productivity of ECMM depend significantly on the operating conditions, in particular, on the interelectrode gap, the pulse-on time and pulse frequency. The pulse-on time can be estimated using an approximate equation for the time constant for electric double layer charging [1]:

$$\tau = CS / \sigma \qquad (1)$$

Here C is the specific capacity of electric double layer; S is the interelectrode gap; and σ is the conductivity of electrolyte solution.

The results of modeling and the experimental data [2, 3] give much lower times of double-layer charging. This complicates choosing appropriate machining mode.

In this work, the transport processes in the electrolyte solution and charging-discharging of electric double layer are analyzed theoretically. As a result, an approximate analytical equation for the time constant for double-layer charging is obtained:

$$\tau = \frac{2RTC}{nFi_{\mathrm{F,SS}}} \ln \frac{i_{\mathrm{F,SS}}}{i_0} \qquad (2)$$

Here, $i_{\mathrm{F,SS}}$ is the Faraday current density for the charged electric double layer; i_0 is the exchange current density; n is the number of electrons involved in the electrochemical reaction; R is the gas constant; and T is the temperature.

The results of numerical calculations agree well with the approximate analytical equation (2).

Thus, the proposed model of electrochemical micromachining by nanosecond voltage pulses can be used for justified choice of pulse-on time in ECMM.

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References

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