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Research Article

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Process parameter detection for electrochemical micromachining

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ABSTRACT

Based on electrochemical principle, an electrochemical micromachining system is developed and a novel detection theory of process parameters for the electrochemical micromachining is proposed. Based it, process parameters for the electrochemical micromachining are measured which includes electrolyte resistivity and the balance voltage. Besides it, an optimum solution concentration to obtain the best process accuracy of the electrochemical micromachining is determined. The research is useful for determining the process parameters for the electrochemical micromachining.

Key words: electrochemical micromachining, process parameters, optimum solution concentration, machining accuracy

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INTRODUCTION

With the development of science and technology，electrochemical technology has been widely used in many fields[1-4]. Electrochemical micromachining is an electrochemical dissolution process that has many advantages such as no cutting force, no tool wear, no deformation and no material hardening restrictions[5-7]. Electrochemical micromachining has gradually become one of the main processing methods for processing the micro devices in micro-electro-mechanical system (MEMS) [8-9].

In order to increasing machining accuracy of the electrochemical micromachining, the process parameters should be selected properly[10]. Wei et al proposed an identification method for the gap size by in-process analysis of machining current pulses and confirmed the feasibility of this method under unevenly distributed gap conditions by laboratory experiments[11]. Clifton et al used ultrasound as a passive, non-intrusive, in-line gap measurement system for electrochemical micromachining[12]. Muir, R.N. discussed development of an ultrasound technique that enables the continuous, uninterrupted collection of time-resolved data for dissolution valency, inter-electrode gap, and overpotential during electrochemical machining[13]. Kang, Min studied the measurement method based on machine vision to obtain the initial gap between the workpiece and tool-cathode[14].

So far, the studies about electrochemical micromachining measure technique mainly focus on the identification method for the gap size. However, the process parameters which have effects on the electrochemical micromachining accuracy also include electrolyte resistivity and the balance voltage, etc. The measure technique about these process parameters should be developed.

In this paper, an electrochemical micromachining system is developed and a detection theory of process parameters for the electrochemical micromachining which includes electrolyte resistivity and the balance voltage is proposed. Based it, these process parameters for the electrochemical micromachining are measured. Besides it, an optimum solution concentration to obtain the best process accuracy of the electrochemical micromachining is obtained. The research is useful for determining the process parameters for the electrochemical micromachining.

EXPERIMENTAL SECTION

Here, an electrochemical micromachining system is developed(see Fig.1). The micromachining system is mainly composed of machine tool and its control system.

In the machine tool, the gantry frame is used and the base is manufactured with the marble which can absorb vibration and reduce corrosion. Electrolytic processing tank is made with organic glass, which has high mechanical strength, corrosion resistance and good insulation performance.

The control system of electrochemical micromachining tool is shown in Fig.2. The macroscopic motions in axis x,y and z are driven by three stepper motors plus three ball screws. The minimum resolution ratio of feeding is 0.1μ m. The intelligent motion control card PCI-1243U is used as the core of motion control and programming. The microscopic motion is driven by a three-axis piezoelectric ceramic driver. Its minimum resolution is 0.6nm. This accuracy is enough to meet the processing speed of the micro electrochemical machining. The controller is composed of a power amplifier, position a sensor, a viewing screen and an interface. A D/A interface converter is used to output voltage signal to the controller.

Data acquisition card PCI-1243U is used in short-circuit monitoring system. The sampling rate of this card is 100KS/s, which can record the processing voltage timely. The control program of macro-micro motion platform and data acquisition is programmed by Visual Basic. The motion control card provides a number of sub functions. In the data acquisition card, the control software ActiveDAQ is used, and MSComm is used in D/A converter. By these control programs, short circuit returning, machining depth measurement, records of short circuit times, and macro-micro motion coordinate are achieved.

Whether the electrochemical machining is finished can be judged by calculating the processing depth. When the short circuit occurs, the voltage captured by data acquisition card is lower than the short-circuit threshold, and the tool pole is instructed to go back 5μm rapidly. Too many short circuit times can affect the accuracy of electrochemical micro-machining seriously. If it happens, the cathode feed speed should be reduced to decrease the short circuit times.

Fig.1 Electrochemical micro-machining tool

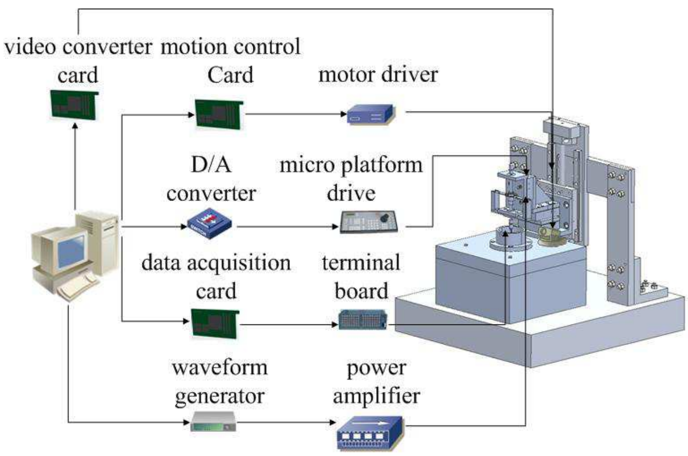


Fig.2 Electrochemical micro-machining system

An equivalent circuit of two electrodes immersed in electrolyte is shown in Fig.1. From Kirchhoff's voltage law, we know

$$\varphi + \mathrm{R}_e(I_c + I_r) = \Phi \tag{1}$$

Where φ is voltage of the double layers on the electrode, R_e is electrolyte resistance, $R_e = d\rho$, ρ is electrolyte resistivity, d is separation between two electrodes, Φ is the voltage between two electrodes, I_c is the capacitance charging current, $I_c = C_d \dfrac{d\varphi}{dt}$, C_d is the capacity of the double layers on the electrode, t is time, I_r is the current of the electrochemical reaction.

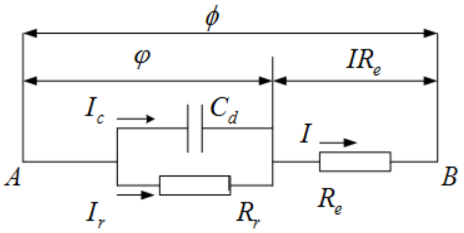


Fig.3 Equivalent circuit of two electrodes immersed in electrolyte

Under DC power(I_c=0 and I= I_r), Eq.(1) is changed into following form

$$\varphi + \rho d I = \phi \tag{2}$$

and

$$I = 2i_0 \sinh\left[\beta\left(\varphi - \varphi_p - \varphi_R\right)\right] \tag{3}$$

Where i_0 is the exchange current density, $\beta = \dfrac{\alpha n F}{RT}$, α is transfer coefficient, φ_p is balance voltage, φ_R is the voltage on the resistance of the power circuit.

Under a given current, two separations between two electrodes are given, and then two voltages between two electrodes are measured. Thus, the electrolyte resistivity can be obtained as below

$$\rho = \frac{\phi_2 - \phi_1}{(d_2 - d_1)I} \tag{4}$$

Substituting Eq.(4) into (2), the voltage of the double layers on the electrode can be given as below

$$\varphi = \phi_1 - \frac{\phi_2 - \phi_1}{d_2 - d_1} d_1 \tag{5}$$

From Eq.(3), we know

$$\varphi_{R_2} - \varphi_{R_1} = \frac{1}{\beta} \ln \frac{(\phi_1 - \varphi) d_2}{(\phi_2 - \varphi) d_1} \tag{6}$$

Where $\begin{cases} \varphi_{R_1} = I_1 R \\ \varphi_{R_2} = I_2 R \end{cases}$.

From Eq.(6), we know

$$R = \frac{1}{\beta(I_2 - I_1)} \ln \frac{(\phi_1 - \varphi) d_2}{(\phi_2 - \varphi) d_1} \tag{7}$$

Substituting Eqs.(4),(5) and (7) into (3), the balance voltage can be calculated as

$$\varphi_P = \frac{1}{2\beta}\ln u \tag{8}$$

Where $u = \dfrac{(\phi_2 - \varphi_2)d_1 e^{\beta(\varphi_1 - \varphi_{R_1})} - (\phi_1 - \varphi_1)d_2 e^{\beta(\varphi_2 - \varphi_{R_2})}}{(\phi_2 - \varphi_2)d_1 e^{-\beta(\varphi_1 - \varphi_{R_1})} - (\phi_1 - \varphi_1)d_2 e^{-\beta(\varphi_2 - \varphi_{R_2})}}$.

RESULTS AND DISCUSSION

Using above-mentioned electrochemical micromachining system and detection theory, the measure of electrolyte resistivity is done. Here, a stainless steel plate 20μm thick is used with workpiece and a tungsten wire 100μm in diameter is used as tool pole. The electrolyte is $NaNO_3$ and the solution concentration is 0.1%, 0.3%, 0.5%, 1%, 3% and 5%, respectively. The speed of cathode is set 0.01 μ m/s. For a given solution concentration, several different separations between two electrodes are given by control system of electrochemical micromachining tool, and the voltages and currents between two electrodes can be measured. Substituting the measure data into Eq.(4), the electrolyte resistivity can be obtained(see Fig.4a).

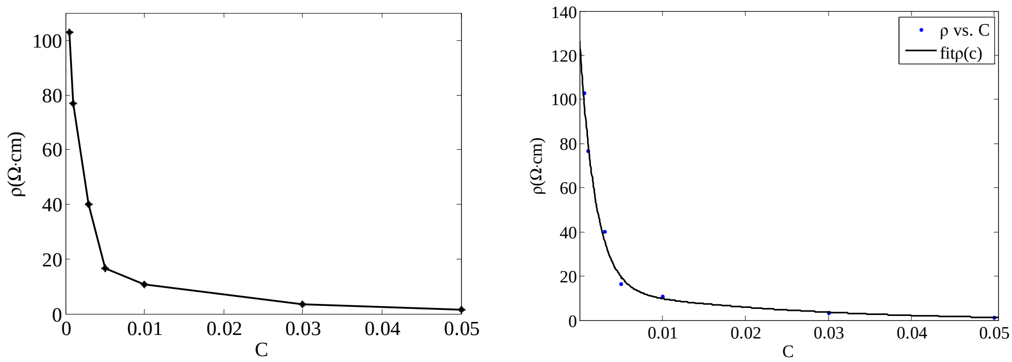
Using the measure data in Fig.4a, the equation of the electrolyte resistivity as a function of the solution concentration can be given by numerical regression method as below

$$\rho = a_1 e^{-\left(\frac{C-b_1}{c_1}\right)^2} + a_2 e^{-\left(\frac{C-b_2}{c_2}\right)^2} \tag{9}$$

where a_1=1.747e^{17}, b_1=-0.1361, c_1=-0.2302, a_2=111.2, b_2=-0.1051, c_2=-0.07293.

By Eq.(9), the electrolyte resistivity as a function of the solution concentration can be calculated(see Fig.4b).

Fig.4 shows that the fitting curve of the electrolyte resistivity is in good agreement with the measure cure. The results show the electrolyte resistivity drops with increasing the solution concentration. For small solution concentration, the electrolyte resistivity decreases more significantly with the solution concentration. For large solution concentration, the electrolyte resistivity decreases slowly with the solution concentration.



(a) measure cure **(b) fitting curve**

Fig.4 Changes of the electrolyte resistivity with solution concentration

Using above-mentioned micromachining system and detection theory, the measure of balance voltage is done as well. Here, a stainless steel plate 20μm thick is used with workpiece and a tungsten wire 100μm in diameter is used as tool pole. The electrolyte is $NaNO_3$ and the solution concentration is 0.1%, 0.5%, 1%, 5% and 15%, respectively. The speed of cathode is set 0.01 μ m/s. For a given solution concentration, several different separations between two electrodes are given by control system of electrochemical micromachining tool, and the voltages and currents between two electrodes can be measured. Substituting the measure data into Eq.(8), the balance voltage can be obtained(see Fig.5). Fig.5 shows that the balance voltage drops with increasing the solution concentration. For small solution concentration, the balance voltage reduces quickly with the solution concentration.

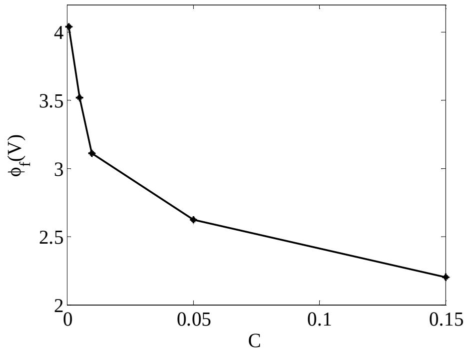


Fig.5 Balance voltage as a function of solution concentration

From above-mentioned measure results, ones can know that the electrolyte resistivity and the balance voltage decrease with increasing solution concentration. It shows that there is an optimum solution concentration to obtain the best process accuracy of the electrochemical micromachining. For illustrating it, following tests are done.

Here, a stainless steel plate 20μm thick is used with workpiece and a tungsten wire 50μm in diameter is used as tool pole. The electrolyte is $NaNO_3$ and the solution concentration is 0.05%, 0.1%, 0.2%, 0.3%, 0.5%, 1%, 2% and 3%, respectively. The speed of cathode is set 0.02 μ m/s. For a given solution concentration, the diameter of the hole etched is measured. The machining accuracy is defined as half of the difference between the hole and the tool diameters. The results are given in Figs.6 and 7. They show:

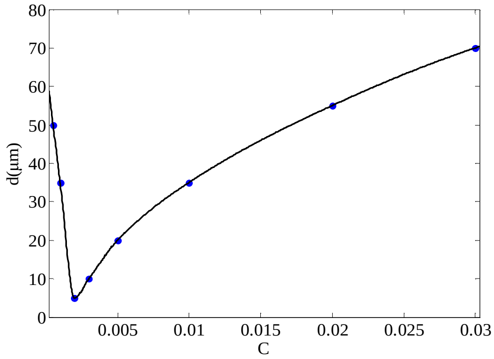
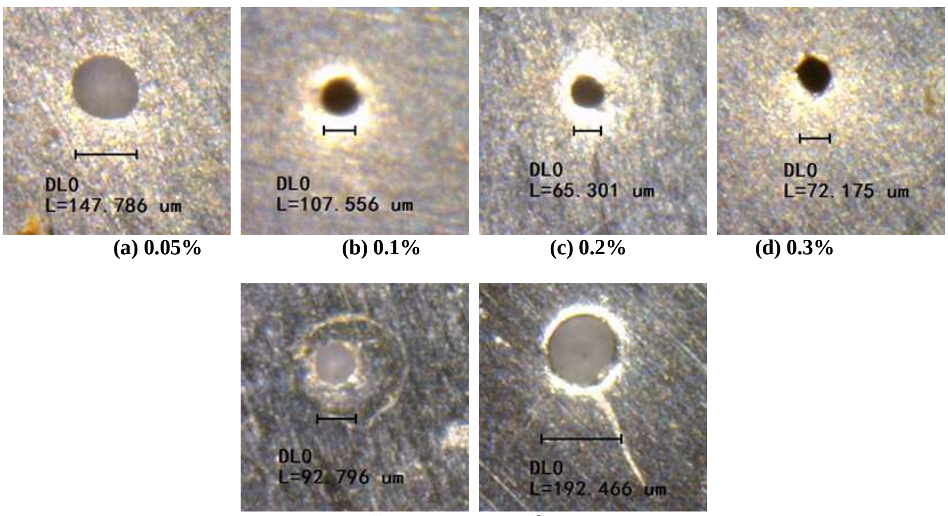


Fig.6 Machining accuracy as a function of solution concentration



(a) 0.05% **(b) 0.1%** **(c) 0.2%** **(d) 0.3%**

(e) 0.5% **(f) 3%**

Fig.7 Hole diameters for several solution concentrations

For the solution concentration of 0.05-0.2%, machining clearance between the hole and the tool reduces significantly with increasing the solution concentration. For the solution concentration of 0.2-5%, machining clearance between the hole and the tool grows significantly with the solution concentration. An optimum machining accuracy occurs at the solution concentration of 0.2%.

CONCLUSION

In this paper, an electrochemical micromachining system is developed and a novel detection theory of process parameters for the electrochemical micromachining is proposed. Based it, process parameters for the electrochemical micromachining are measured which includes electrolyte resistivity and the balance voltage. Besides it, an optimum solution concentration to obtain the best process accuracy of the electrochemical micromachining is obtained. The research is useful for determining the process parameters for the electrochemical micromachining.

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