

# Experimental Study on the Inner Wall Ring Groove of 1J116 Soft Magnetic Alloy Based on Electrochemical Machining

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**Abstract**—In this study, electrochemical processing was introduced into the inner wall ring groove of 1J116 soft magnetic alloy to obtain higher processing precision. A single factor experimental study was carried out for the processing and forming laws and mechanisms. The effects of pulse voltage, duty cycle, pulse frequency, and electrolyte pressure on material removal rate and groove width and groove depth of the inner wall were analyzed. The results show that the effects of pulse voltage, duty cycle, pulse frequency and inlet pressure on the material removal rate are positively correlated. The groove width and groove depth of the inner wall ring groove increase with the increase of process parameters, in order to achieve higher The processing accuracy requires a reasonable range of process parameters.

**Keywords**—Component; ECM; 1J116 Soft Magnetic Alloy; MRR; Inner Ring Groove

## I. INTRODUCTION

1J116 soft magnetic alloy has high initial permeability and very low coercivity. It is a kind of excellent weak magnetic field functional material. It is mainly used in aerospace, power electronics and other fields, especially as magnetic shielding material, it is widely used in the manufacture of the outer cover and shell parts of various inertial guidance platforms [1,2].

In the processing of 1J116 soft magnetic alloy, its processing performance is poor because of its high nickel content and high processing viscosity. Especially for the processing of inner ring groove. Traditional cutting tools are characterized by high temperature, large cutting force, severe work hardening, difficult chip removal and easy tool collapse. In recent years, with the innovation and development of special processing technology and equipment, electrochemical processing gradually shows its advantages[3]. Electrochemical Machining (ECM) has many advantages, such as high productivity, no tool wear, no

cutting stress, etc[4]. It is suitable for the processing of difficult-to-machine materials and complex parts. It has been widely used in aviation, aerospace and die manufacturing industries [5,6]. The process parameters in electrochemical machining have an important influence on the machining accuracy of the inner ring groove of 1J116 soft magnetic alloy. Choi et al [7]. studied the effect of pulse width on electrochemical machining grooves. The results show that the depth of micro-ring grooves is 60  $\mu\text{m}$  when the pulse width is 0.1 s. Kunar et al [8]. improved the surface quality of the workpiece by optimizing the process parameters such as duty cycle, pulse frequency, processing voltage and electrolyte concentration. Rathod et al [9]. studied the effects of processing parameters such as processing voltage, pulse frequency, duty cycle, electrolyte concentration and electrode scanning speed on the surface quality and processing accuracy of micro-grooves.

At present, the electrochemical processing of 1J116 soft magnetic alloy mainly focuses on the accuracy of hole processing, but little attention has been paid to the accuracy of inner ring groove. In this paper, the rule of forming ring groove on the inner wall of 1J116 soft magnetic alloy by electrochemical processing is studied. The effects of pulse voltage, duty cycle, pulse frequency and electrolytic pressure on the material removal rate and slot width of the inner ring groove of 1J116 soft magnetic alloy were analyzed by single factor experiments. In order to provide experimental and theoretical basis for subsequent research or actual production.

## II. THEORETICAL MODEL

According to the electric field theory, the potential distribution is given by the Laplace equation:

$$\nabla^2 \varphi = 0 \quad (1)$$

Where,  $\varphi$  is the potential.

The relationship between current density  $J$  and potential  $\varphi$  is derived from Ohm's law.

$$J = k \frac{\partial \varphi}{\partial n} \quad (2)$$

Where,  $n$  is the unit vector perpendicular to the workpiece surface;  $k$  is the conductivity of the electrolyte.

Because the motion of the flow field is considered as "turbulence", the velocity distribution of electrolyte in the simulation is represented by the standard model, which is called N-S equation by using continuity equation and momentum equation [10].

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j} (\rho u_j) = 0 \quad (3)$$

$$\frac{\partial}{\partial t} (\rho u_t) + \frac{\partial}{\partial x_j} (\rho u_j u_i) =$$

$$\frac{\partial}{\partial x_j} (-p \delta_{ij} + \mu_{eff} (\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i})) + F_i \quad (4)$$

where,  $i, j = 1, 2, 3$ ;  $\rho$  is the fluid density;  $t$  is the time;  $u_i, u_j$  are the fluid velocity component;  $x_j$  is the coordinate component;  $F_i$  is the volume force component;  $\sigma_{ij}$  is the stress tensor;  $p$  the pressure;  $\mu$  the molecular viscosity;  $\delta_{ij}$  is the unit tensor, when  $i \neq j$ ,  $\delta_{ij} = 0$ , when  $i = j$ ,  $\delta_{ij} = 1$ .

Where,  $\mu_{eff}$  represents the effective viscosity and we have  $\mu_{eff} = \mu + \mu_t$ ,  $\mu_t$  is turbulent viscosity

$$k: \quad \frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_j} (\rho u_j k) =$$

$$\frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G - \rho \epsilon \quad (5)$$

$$\epsilon: \quad \frac{\partial}{\partial t} (\rho \epsilon) + \frac{\partial}{\partial x_j} (\rho u_j \epsilon) =$$

$$\frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_j} \right] + \frac{\epsilon}{k} (C_{\epsilon 1} G - C_{\epsilon 2} \rho \epsilon) \quad (6)$$

According to Faraday's law, the removal rate of the anode workpiece is

$$v = \eta \omega J \quad (7)$$

Where,  $\eta$  is the current efficiency;  $\omega$  is the chemical equivalent;  $J$  is the current density.

### III. EXPERIMENT

#### A. Experimental platform

The structure of ECM experimental system is shown in Figure 1. The machine tool used in this paper is DJL-02 five-axis NC electrochemical machining machine tool (see figure

2). It is mainly composed of machine tool body, high power regulated power supply, numerical control system, control system and electrolyte circulation system. Processing power supply adopts intermittent discharge mode of pulse power supply and numerical control system is FANUC system. The control system has real-time display and control of the operation status of power supply, real-time monitoring of current in the process of processing and control of electrolytic hydraulic pressure. The electrolyte circulation system consists of electrolyte pump, solenoid valve, electric regulating valve, filter and pressure gauge, etc. It can be used for electrolysis. The electrolyte is renewed by filtering impurities in the solution.

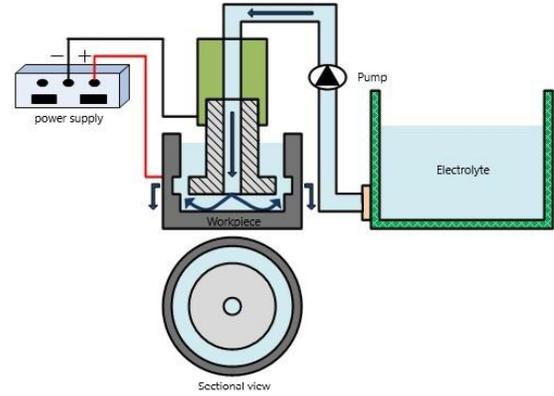


Figure 1. Schematic diagram of ECM experiment



Figure 2. DJL-02 Five-Axis Linkage NC ECM Machine Tool

The material used in the experiment is 1J116 soft magnetic alloy. Table 1 lists the chemical composition of 1J116 soft magnetic alloy.

TABLE I. CHEMICAL COMPOSITIONS OF 1J116

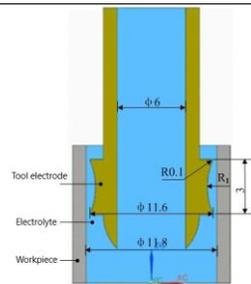
Components	C	P	S	Mn	Si	Al	Fe
Percent s(%)	0.03	0.015	0.015	0.01	0.15	15.5	84.28

#### B. Experimental method

Pulse voltage (10, 12, 14, 16, 18V), duty cycle (10, 30, 50, 70, 90%), pulse frequency (100, 300, 500, 700, 900 Hz) and electrolytic hydraulic pressure (0.1, 0.2, 0.3, 0.4, 0.5 Mpa) were used as the main processing parameters in

electrochemical processing. Single factor experiments were carried out. When single variable was changed, other parameters were all intermediate values. The processing parameters of the experiment are listed in Table 2. The weight change of the anode material and the width of the inner wall groove were recorded.

TABLE II. EXPERIMENT PARAMETERS

Experiment parameter	values
Size of cathode	
Size of anode	φ11.8
Cathode material	H62 brass
Anode material	1J116 Soft Magnetic Alloy
Electrolyte	10% wt NaCl+16% wt NaNO3+2% wt NaClO3
Initial Machining Gap	0.1 mm
Electrolyte temperature	30°C
Processing time	3 min

IV. RESULT AND DISCUSSION

A. Pulse voltage

Pulse voltage is one of the key parameters of pulse power supply. Generally, increasing pulse voltage, that is to say, increasing the energy supply of ECM, will accelerate the material removal rate of the workpiece, and at the same time, the machining gap will also increase. So it is very important to study the pulse voltage for material removal rate and structure formation.

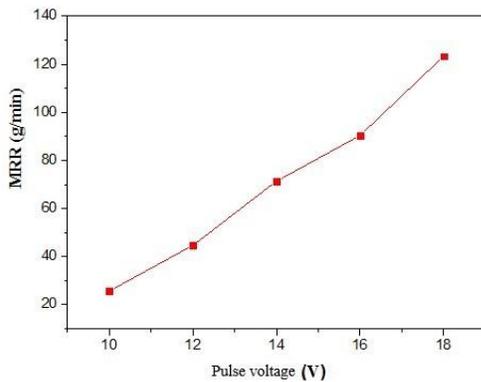


Figure 3. Relation between Pulse Voltage and Material Removal Rate

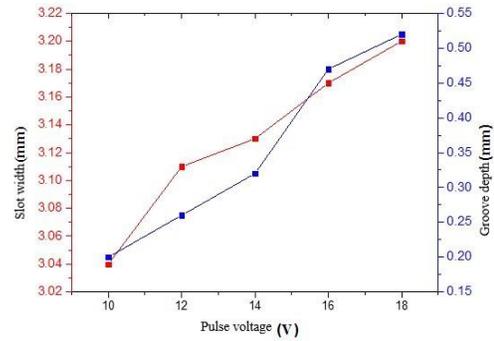


Figure 4. Effect of Different Pulse Voltages on Workpiece Forming

Figures 3 and 4 show that with the increase of pulse voltage, the material removal rate MRR increases, and the width and depth of the ring groove also increases. According to the formula of material removal rate, as the processing voltage increases, the current density is also increasing. This is because the resistance is basically unchanged in the circuit formed by electrolyte, electrode and external power supply, so the current will also increase continuously when the voltage is increased. According to the formula of material removal rate according to Faraday's law, the higher the current density is, the higher the current density is. With the increase of material removal rate, the width and depth of ring groove will increase.

B. Duty cycle

Duty cycle is one of the key parameters of pulse power supply. Discharge time, i. e. pulse time, can ensure the smooth progress of ECM. At the same time, pulse interval provides the time for electrolyte renewal. Therefore, duty cycle plays an important role in ECM.

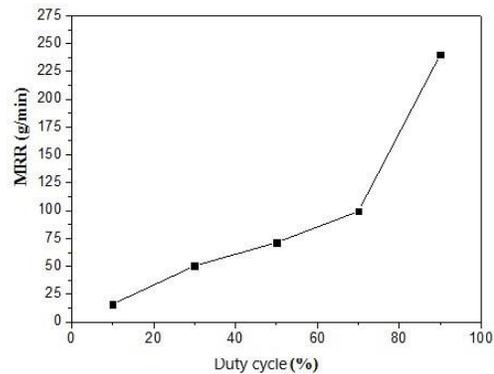


Figure 5. Relation between duty cycle and material removal rate

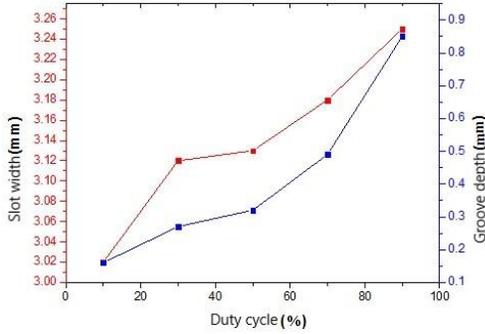


Figure 6. Effect of Different Duty Ratio on Workpiece Forming

Fig. 5 and 6 show that with the increase of duty cycle, the material removal rate MRR increases slowly and then increases rapidly, the width and depth of the ring groove increase first and then remain basically unchanged, and then increase rapidly, and the overall trend of increase is maintained. From this, it can be seen that the material removal rate, width and depth of the ring groove basically maintain the same law, because when duty cycle increases, not only electrolysis is carried out. The liquid provides the renewal time, and the discharge time is increasing gradually. So according to the formula of material removal rate, when the duty cycle increases, the proportion of discharge time to pulse period increases, which will certainly promote the increase of material removal rate, groove depth and groove width. Similarly, according to the double-layer theory, with the increase of duty cycle, the longer the charging time of double-layer capacitors, the greater the energy provided to ECM, which will inevitably lead to the increase of material removal rate, cell depth and cell width.

C. Pulse frequency

Pulse frequency is one of the key parameters of pulse power supply. For the number of discharges per unit time in electrochemical machining, the number of discharges determines the size of material removal rate. Therefore, it is necessary to study the effect of pulse frequency on material removal rate and the formation of inner wall structure.

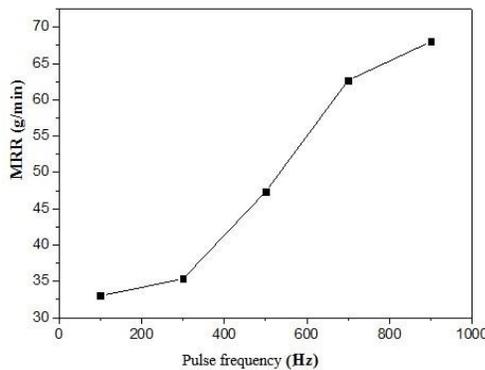


Figure 7. Relation between Pulse Frequency and Material Removal Rate

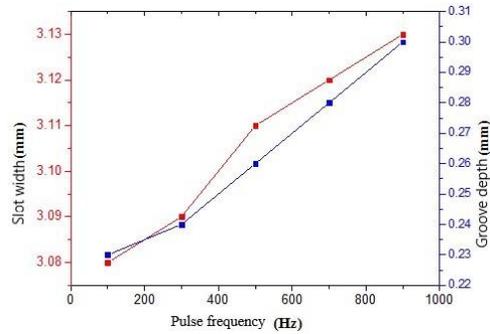


Figure 8. Workpiece Forming at Different Pulse Frequencies

From figs. 7 and 8, it can be seen that with the increase of pulse frequency, the material removal rate MRR increases slowly at first and then rapidly, and the width and depth of the ring groove increase gradually. From the formula of material removal rate, it can be seen that when the pulse frequency increases, that is, the number of discharges per unit time increases, the material removal rate, groove depth and groove width will inevitably increase. Similarly, according to the theory of double-layer, with the increase of pulse frequency and the renewal speed of electrolyte, the energy of double-layer capacitor will increase, which will inevitably lead to the increase of material removal rate, cell depth and cell width.

D. Electrolyte pressure

The electrolyte inlet pressure is one of the key parameters of the flow field. It not only determines the boundary conditions of the electrolyte, but also determines the distribution of the processing gap pressure. In addition, when the pressure of the electrolyte is greater than the adhesion of the material, it will definitely cause changes in material removal rate and workpiece formation, so it is indispensable to study the effect of electrolyte inlet pressure on material removal rate and workpiece formation.

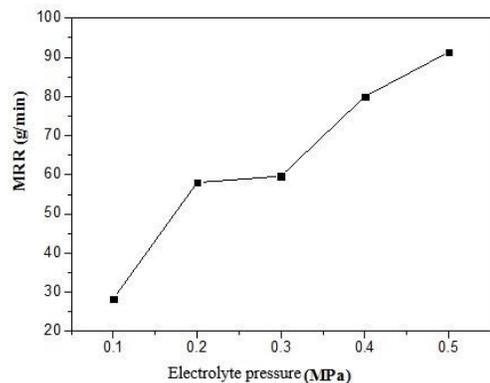


Figure 9. Relationship between inlet pressure and material removal rate

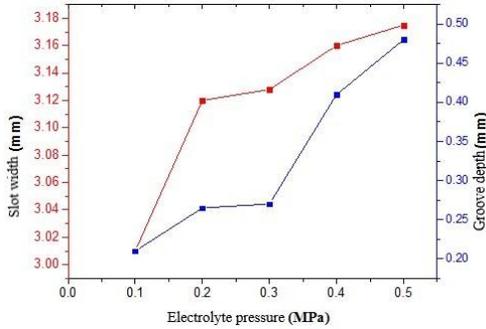


Figure 10. Effect of different inlet pressure on workpiece forming

It can be seen from Figures 9 and 10 that as the inlet pressure of the electrolyte increases, the material removal rate MRR, the width and depth of the ring groove first increase and then remain unchanged, and finally increase rapidly, and the overall trend keeps increasing. According to the calculation formula of the material removal rate, on the one hand, when the inlet pressure increases, the renewal speed of the electrolyte increases, and the effective current density increases, the material removal rate, the groove depth and the groove width increase; on the other hand, when the electrolysis is performed When the hydraulic pressure is greater than the bonding force of the surface material of the workpiece, the material removal rate and the ring groove size are inevitably increased. According to the distribution law of the electric double layer voltage, in the electrolytic processing process, as the electrolyte inlet pressure increases, the electrolyte renewal speed increases, and the electrolyte resistance decreases, the voltage distributed in the electric double layer capacitor increases. That is, the increase in energy of electrolytic processing inevitably leads to an increase in material removal rate, groove depth, and groove width.

## V. CONCLUSION

In order to study the forming law of the inner wall structure of electrolytic processing, based on the research of electrochemical machining theory, the influence of single factor on the forming rule of electrolytic wall structure is studied experimentally. The research shows: pulse voltage, duty cycle, pulse frequency The inlet pressure and the material removal rate and the forming size of the electrolytic processing are promoted. The main conclusions are as follows:

- It is feasible to realize the processing of the inner wall ring groove of 1J116 soft magnetic alloy material by electrochemical machining, which can realize the processing of the surface without deformation, residual stress and micro crack.

- The effects of pulse voltage, duty cycle, pulse frequency, and inlet pressure on material removal rate are positively correlated.
- The groove width and groove depth of the inner wall ring groove increase with the increase of the process parameters. In order to achieve higher machining accuracy, a reasonable range of process parameters should be selected.

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