The Analysis of the related performance during MICRO-EDM

Liu shuyang, Han Zhihong

Jingdezhen Ceramic Institute, Jingdezhen 333403, China
Corresponding author: Dr. Liu shuyang ,Tel:+86-187-97883058;
e-mai: Hanliuyang@163.com

Abstract—In this paper, the energy on workpiece surface in electrical discharge machining (short in EDM) process were modeled and its related parameters were analysized, based on electron sputtering and the resistance heat reaction of current flow when the tool electrode is negative. The study shows that: when the steady-state discharge current is constant, workpiece surface of power energy concentration is higher.The proportion of resistance heat reaction on workpiece surface in total power energy η_c^+ decreases with the increase of the equivalent radius ratio of real discharging area to the area of workpiece end surface λ, and when λ is constant , η_c^+ increases with the increase of J_{t3}. The experimental phenomena and results verify the rationality and effectiveness of the proposed model.

Keywords-Resistance heat reaction;Electron spilling work; Electron sputtering work

I. INTRODUCTION

As a kind of special machining technology, EDM has already been indispensable in processing ultra hard materials and heat sensitive materials[1-3]. However electrical discharge phenomena in EDM make both observation and theoretical analysis extremely difficult. Therefore, some questions are still remained. First, the material removal mechanisms are not yet well understood. Second, what are the relationships between the energy distribution and working efficiency? Third, how the EDM process results in the energy distribution [4]? It shows that further research work is necessary for a better understanding of the nature of the phenomena involved in the EDM process.

Many scholars' research and related experiments have already shown that particles in the discharge channel were mainly on electric streams ejected from cathode, and the effects of positive ions on the channel were very small[5]. Modern field-emission theories and thermal field emission theories, especially F-N equation descriptions, demonstrated that electrons escaping from surface needed to overcome surface barriers to work, which would translate into heat energy ,and gave the reactive functions of material[6-8]. Mao, C et al. conducted that with longer pulse-on time, the power available between the anode and cathode becomes greater, thus strengthening discharge energy [9]。 LIU et al. [10] derived electrodes complied with skin effect when flowing through the electrodes, which gave space boundary conditions for energy analysis of material removal.

In EDM discharge cycle, a variety of signs indicate that a large number polarity ion accumulation exists in interelectrode channel. Many scholars' research has shown that the most of the material removal was mainly caused by free electrons emitted from cathode. And the melting trace on the discharge surface in EDM show that heat effect was the main work mechanism of material removal, but the surface topography difference on anode and cathode surface further explained that work energy sources and methods were different. Modern field-emission theory about cold and heat electron emission introduced and perfected

In this paper, the energies on workpiece surface both in positive polarity polarity EDM process were modeled and its related parameters were analyzed, based on electron sputtering and the resistance heat reaction of current flow when the tool electrode is negative. A set of machining blind-hole experiments with pole electrodes were carried out and investigated, and the related parameters that affect the working efficiencies were discussed. The experimental phenomena and results verify the rationality and effectiveness of the proposed model.

II. THE SINGLE-HOLE EDM EXPERIMENT WITH POLE ELECTRODES

In order to analyses the mechanism and parameters of EDM processing, we designed single-hole EDM experiments with pole electrodes shown in Fig .1, where Sw_p represents the pulse switch and U_s is the voltage of discharging tube, R_{pp} and R_{np} are the resistances of tool electrode and workpiece electrode respectively, R_{pv} is the resistance of single discharging tube, and the amount of pulse tubes is n .
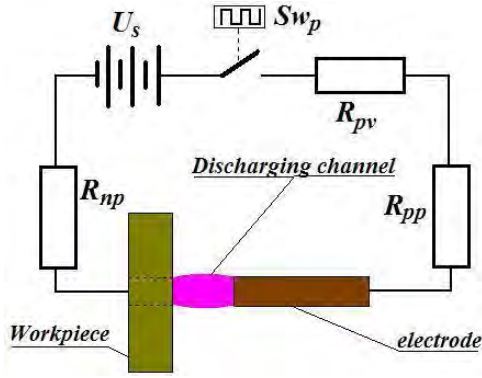
Figure 1.   Single-hole EDM experiment with pole electrode

TABLE.1 TECHNICAL DETAILS OF THE SINGLE-HOLE EDM EXPERIMENTS

NO.	Polarity	Material		Discharge parameters			Lift-put cycle		n	R-rpm (r/min)	Safe gap(mm)	EDM time	mean time
		work	tool	Ton(μs)	Toff(μs)	Lgap(mm)	Tkp(s)	Tkl(s)					
1				10	5.6	0.08	0.8	0.6	7	0	0.18	472h53'	
2		45#	45#	10	5.6	0.08	0.8	0.6	7	0	0.18	562h05'	523h31'
3	–			10	5.6	0.08	0.8	0.6	7	0	0.18	535h34'	

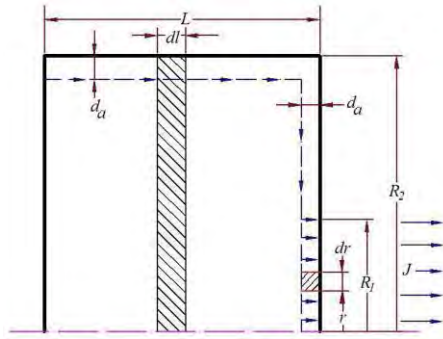III.   HE WORK ENERGY ANALYSIS ON THE WORKPIECE SURFACE OF NEGATIVE EDM PROCESS

Figure 2.   the movement of electron current in workpiece electrode

The foregoing experiments indicated that during the negative EDM process, the work energy on the workpiece surface also has two origins, one is the sputtering energy Q_h produced by the high-speed field-emission electrons, and the other is the uniform resistance heat Q_s generated by electrons current flowing through the limited workpiece surface.

According to the Skin Effect of electric charge, the electron current channel performs a shape as a concentric tube with two diameters $2\pi(R_2 - d_a) \times L$ and $\pi(R_2^{\,2} - r^2) \times d_a$ respectively, shown in Fig .2. Where, A_1 is equal to the end area of interelectrode discharging channel, A_2 is the superficial area of workpiece, J_t is the density of the electron current at the t moment, d_a is nearly equal to the mean diameter of atoms of workpiece material, R_1 is the radius of area A_1 which is equal to the equivalent radius of the discharging channel, and R_2 is the equivalent radius of area because the discharging channel between electrode pairs are vacuum during the steady discharging stage, so it was considered that there is no energy loss for the field-emission electrons when they are high-speed moving in the interelectrode channel, and all kinetic energy carried by them is completely acted on the machining surface. Supposing the initial speed of field-emission electrons away from the surface of tool electrode is zero and according to the law of conservation of energy, the Q_h should be equal to the potential energy of field-emission electrons at the moment when they just break through the surface barriers of tool electrode, id est. the sputtering energy during a micro period dt of steady discharging stage can be expressed as.

$$dQ_h^{A_1^+} = dE_e = U \cdot J_{t3} \cdot A_1 \cdot dt \quad （1）$$

By integral, thus the sputtering energy during the steady discharging stage of a discharging pulse can be obtained,

$$Q_h^{A_1^+} = U \cdot \pi R_1^2 \cdot J_{t3} \cdot (T_{on} - t_3) \quad （2）$$

Same to the expression of the Eq. (12), the total resistance heat on A_1^+ area during a single discharging pulse can be calculated as,

$$Q_s^{(A_1^+)} = Q_s^{(A_1^-)} = \frac{2\rho_w}{3\pi \cdot d_a} \cdot \left(\frac{R_2}{R_1} - \frac{R_1^2}{R_2^2} + \frac{3}{4}\right) \cdot (T_{on} - t_3)$$

（3）

So the total work energy on the area of A_1^+ during a single discharge pulse can be obtained,

$$Q^{(A_1^+)} = Q_h^{A_1^+} + Q_s^{(A_1^+)} = U \cdot \pi R_1^2 \cdot J_{t3} \cdot (T_{on} - t_3) + \frac{2\rho_w}{3\pi \cdot d_a} \cdot \left(\frac{R_2}{R_1} - \frac{R_1^2}{R_2^2} + \frac{3}{4}\right) \cdot J_{t3}^2 \cdot (T_{on} - t_3)$$

（4）

Ditto defining the ratio of the resistance heat to the total work energy on the area of A_1 as,

$$\eta_c^+ = \frac{Q_s^{(A_1^+)}}{Q^{A_1^+}}$$

Substituting the Esq. (3) and (4) in the equation above, then the ratio of the resistance heat to the total work energy during the steady discharging stage can be gotten as,

$$\eta_c^+ = \frac{\dfrac{2\rho_w}{3\pi \cdot d_a} \cdot \left(\dfrac{R_2}{R_1} - \dfrac{R_1^2}{R_2^2} + \dfrac{3}{4}\right) \cdot J_{t3}}{U \cdot \pi R_1^2 + \dfrac{2\rho_w}{3\pi \cdot d_a} \cdot \left(\dfrac{R_2}{R_1} - \dfrac{R_1^2}{R_2^2} + \dfrac{3}{4}\right) \cdot J_{t3}}$$

Defining $C_3 = U \cdot \pi$, then the equation above can be simplified by the substitution of C_1, C_2 C_3 and λ as,

$$\eta_c^+ = \frac{C_2 \cdot (4 - 4\lambda^3 + 3\lambda) \cdot J_{t3}}{C_3 \cdot \lambda^3 \cdot R_2^2 + C_2 \cdot (4 - 4\lambda^3 + 3\lambda) \cdot J_{t3}}$$

（5）

In our study, the pulse voltage of $AGIE\ CHARMILLES\ SE2$ machine is $U = 110(V)$, so, $C_3 = 345.575(V)$

Taking the data of the single-hole EDM experiment of negative polarity listed in table.1 as the example too, the varying tendency of η_c^+ about λ at different steady discharging current are shown in Fig .3. Obviously, η_c^+ is an increasing function about λ at certain J_{t3}, and

at some certain λ, η_c^+ gets higher with the increase of J_{t3}.
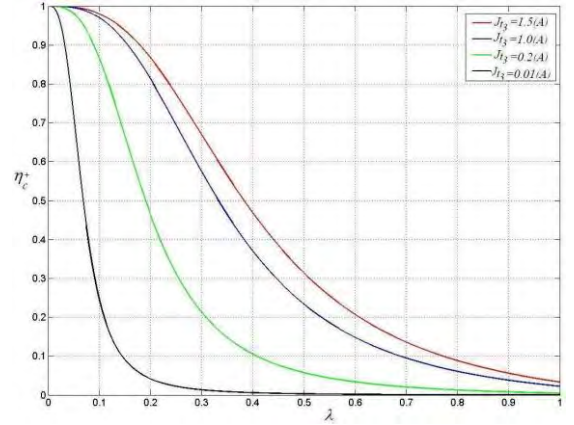
the varying curves of η_c^+ about λ at different J_{t3}

IV. CONCLUSIONS

(1) Based on electron sputtering and the resistance heat reaction of current flow , the work energy on the machined surface in negative polarity EDM process was studied, and the relevant equations were given。 The related parameters that affect the working efficiencies were discussed.

(2) The analysis of the combined machining method as well as experimental research has resulted in an empirical relation which highlights the influence of some of the analyzed work conditions。 It can be obtained that the ratio of the resistance heat to the total work energy η_c^+ increase with the decrease of the equivalent radius ratio of real discharging area and the area of workpiece end surface λ when J_{t3} is a constant .and η_c^+ would increase with the increase of the interelectrode discharging current when λ is a constant .

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