On the controlling metal removal thickness in ECM process

*M.S. Hewidy**

Department of Production Engineering and Machine Design, Faculty of Engineering, Menoufia University, Shebin El-Kom – Egypt.

Abstract

Electrochemical machining [ECM], offers the unique advantage of a better accuracy and high surface integrity of hard machined components. A new technique has been developed to utilize a simultaneous moving and rotating electrode to remove a specific amount of material, from a pre-machined holes and rods of hardened steel specimens. One of the electrodes was provided with two simultaneous movements; traverse speed and rotational speed. The electrolyte was pumped into the gap between tool and workpiece, through a matrix of fine holes distributed along one of the electrode surfaces. A mathematical model has been proposed for accurately estimating the thickness of the removed workpiece layer under different working conditions. Experimental results revealed that this technique could lead to the removal of a surface layer thickness up to 200 microns, which consequently, classified this method as a super finishing process. Finally, the results of the experiments and the simulation are compared to each other. The obtained results are an endeavor to enhance the controllability of the ECM process.

1. Introduction

Electrochemical machining [ECM] is increasing being used in aircraft and aerospace industries due to its ability of producing complex shapes in very hard materials [1]. Finishing of the advanced hard materials poses many problems, particularly, those related to accuracy and surface integrity of the components. Recently, the ECM process has been recommended as the unique solution to get better accuracy and high surface integrity of the machined surfaces after the electrodischarge machining process [2-4]. On the other hand, it is felt that the capabilities of the ECM process on finishing of the pre-machined shapes have not been fully matured , due to the difficulties encountered in the supply and the distribution of the electrolyte in the interelectrode gap [5-6]. Electrochemical finishing of holes has been investigated by several researches [7-11]. Modification of tool shape [7], rotating of the tool [8-9] and electrochemical honing [10] were the main techniques which have been adopted to improve the electrolyte distribution in the ECM process. However, it has been reported that electrolyte pressure drop is usually associated during these methods. Furthermore, the chance of changing the electrolyte conductivity was associated with the electrolyte circulation in the machining gap [12] . This result decreases the control of the dimensional accuracy and sometimes leads to poor surface quality [13]. Furthermore, it has been observed that there is a deviation of the flatness of the machined workpieces at the place where the electrolyte enters and leaves [13] .

In the present work, an attempt has been submitted to finish holes and rods through the ECM process using a simultaneously moving and rotating motions to remove a specific amount of material from the hole or rod surface. The

Manuscript received from Dr. M.S Hewidy on : 4 /12/1999
Accepted on : 21/12/1999
Engineering Research Bulletin, Vol 23,No 1, 2000 Minufiya University, Faculty of Engineering , Shebien El-Kom , Egypt, ISSN 1110-1180

electrolyte was pumped into the gap between tool and workpiece, through a matrix of fine holes distributed along one of the electrodes [Fig. 1].

2- Theoretical model

For an accurate modeling of the ECM process, the successive removal thickness of the workpiece surface can be calculated considering the effect of each tool element length. Figure 1 shows the tool and workpiece geometry at side gap equals Y_{si}. During the ECM process the initial side gap value will increase according to the forward motion of the electrode [tool]. Each element of the tool electrode [Δb] causes an increase in the workpiece radius equal to ΔY_{si}. Depending on the tool length [B] and the other working conditions of the ECM process, the workpiece diameter [D_{wi}] could be determined according to the present relationship:

$$D_{wi} = D_t + 2Y_{si} \qquad (1)$$

The electrolytic area cross – section [A], at instantaneous workpiece diameter, equal to D_{wi} and can be calculated as follows:

$$A = \tfrac{1}{4}\,\pi\,[D_{wi}^2 - D_t^2] \qquad (2)$$

The electrolyte velocity in the side gab [V_{si}] can be computed from the following equations:

$$V_{si} = Q/A_i \qquad (3)$$

where Q is the electrolyte flow rate [mm^3/min]

The electrolyte velocity varies according to the change in the cross – sectional area of the flow.

The metal removal thickness along the side gap can be computed as follows [13]:

$$\Delta Y_{si} = Z.\, J_{si}.\, \Delta t \qquad (4)$$

Where, Z is the effective metal removal rate [A. mm^3/min] and can be computed as follows:

$$Z = \varepsilon / \rho_w .\, F \qquad (5)$$

Where ε is the chemical equivalent, ρ_w is the workpiece density [g/cm^3] and F is the Faraday's constant.

The current density at the workpiece surface J_{si} at the initial side gap value Y_{si} is commonly expected as follows [13]:

$$J_{si} = [V - \Delta V].\, K_i / Y_{si} \qquad (6)$$

Where K_i is the electrolyte conductivity and Y_{si} is the side gap, V is the applied voltage ΔV is the over potential value [10].

The successive machining time interval Δt, can be estimated from the tool land interval Δb and the feed rate [f] according to the next equation:

$$\Delta t = \Delta b / f \qquad (7)$$

The width of the side gap at the end of Δb tool element length can be expressed as follows:

$$Y_{si+1} = Y_{si} + \Delta Y_{si} \qquad (8)$$

Where ΔY_{si} is the metal removal thickness for tool element length Δb at side gap Y_{si}.

The conductivity of the two-phase medium K_i can be determined as follows [10]:

$$K_i = K_o\,[1 + \alpha . \theta]\,[1 - \beta]^n \qquad (9)$$

Where K_o is the conductivity of the electrolyte in the tank, α is the temperature coefficient of the electrolyte conductivity at T_o, θ is temperature rise for each electrode interval, β is the void fraction of hydrogen. Both of θ and β can be calculated as mentioned in [10 & 14].

The temperature rise θ for tool element length can be represented by the following equation [10] :

$$\theta_i = K_i [V - \Delta V]^2 . \Delta b / [V_{si} . Y_{si}^2 . \rho_e . c_e] \qquad (10)$$

The void fraction of hydrogen can be calculated as follows [10] :

$$\beta_i = A_i . X^*_i / [1 + A_i] . X^*_1 \qquad (11)$$

Where:

$$X_i^* = [\Delta b . \varepsilon_a . J_{si} / \rho_e . V_{si} . Y_{si}] \qquad (12)$$

$$\rho_{gi} = P / R_g . \theta_i \qquad (13)$$

$$A_i = \rho_e . \varepsilon_g . / \sigma . \rho_{gi} . \varepsilon_a \qquad (14)$$

$$\sigma = V_g / V_{el}. \qquad (15)$$

Where:

ρ_{gi} is the hydrogen density for each interval [g/mm^3]

R_g is the gas constant

θ_i is the temperature for each interval [°C]

ρ_e is the electrolyte density [g/mm^3]

ε_g is the electrochemical equivalent of gas

ε_a is the electrochemical equivalent of electrolyte

Δb is the distance along the electrolyte flow direction [mm]

P is the electrolyte pressure [Mpa].

The major factor that contributes to temperature rise is the Joule heating effect [10]. However, in the present case, the temperature rise was low, since the process is a finishing and not a shaping. The pre-elementary tests of the present work revealed that the change of electrolyte temperature did not exceeded 1 °C, which has been attributed to the rotation of the electrolyte and the fast feed rate of the tool. So, the assumption of constant conductivity is reasonable [7].

$$K_i = K_o \qquad (16)$$

Substituting Eqs. 4,5,6, and 9 into Eq. 3 the equation can be rewrite as follow:

$$\Delta Y_{si} = (\varepsilon / \rho_w . F) . (V - \Delta V) . K_o / f) . (\Delta b / Y_{si}) \qquad (17)$$

Substituting Eq. 10 into Eq. 7, we get :

$$Y_{si+1} = Y_{si} + (\varepsilon / \rho_w . F) . (V - \Delta V) . K_o / f) . (\Delta b / Y_{si}) \qquad (18)$$

The final side gap can be estimated as follows:

$$Y_f = Y_{si} + (\varepsilon / \rho_w . F) . (V - \Delta V) . K_o / f) . \sum_{i=1}^{i=j} (\Delta b / Y_{si}) \qquad (19)$$

According to the previous equation, each tool element (Δb) enters the interelectrode gap at different side gap lengths (Y_{si}) and each element causes different and specific metal removal thickness (Δdg) of workpiece surface. The final workpiece diameter will be the summation of all the different metal removal thickness plus the initial diameter of the hole.

For steel material, and at $K_o = 0.02\ \Omega^{-1}\ mm^{-1}$, applied voltage V = 20v, ΔV = 2.3v [14], feed rate f = 20 mm/min, and initial side gap (Y_{si}) = 0.5mm

$$Y_f = 0.5 + 0.04 \sum_{i=1}^{i=j} (\Delta b / Y_{si}) \quad (20)$$

For rod finishing [Fig. 1-B] ECM process, the same technique is also valid with a little change to predict the accurate value of the final rod (anode) diameter [D_{tf}] :

$$D_{tf} = D_{tj} - 2dg \quad (21)$$

Where, D_{tj} is the initial rod diameter and dg is the final metal removal thickness of the rod and can be expressed as follows:

$$dg = (\varepsilon / \rho_w.F). (V - \Delta V). K_o / f). (\Delta L / Y_{si}) \quad (22)$$

Length value(ΔL) is the cathode interval.

The previous equations are simplified from the main radial gap configuration. The equations are based on a plane-parallel gap configuration which proved its adequacy in similar cases [7] .

The mathematical models obtained earlier were plotted to study the influence of process parameters on metal removal thickness. In order to analyze the metal removal thickness of the workpiece in the ECM process and to predict it, a computer simulation (Fig. 2) has been performed using the theoretical models developed in the previous section. The parameters used in the simulation of the metal removal thickness are collected from experimental results and listed in Table 1.

Figure 3 shows the effect of the applied voltage on the resultant workpiece diameter at different feed rates. Figure 4 shows the significant effect of feed rate on the resultant hole diameter at different conditions of the initial side gap values. It has been revealed that as the initial gap value increases, metal removal thickness decreases. This result is due to the decrease of the current density value at the higher values of the side gap.

Based on the present theoretical analysis, Fig. 5 reveals that as the number of tool strokes increases, accumulated metal removal thickness increases. This result was expected, however, it has been submitted to emphasize the possibility of this technique to achieve the required metal removal thickness through the increase of tool strokes instead of the increase of the tool length, which sometimes leads to poor controllability of the ECM process.

3. Experimental work

A special test-rig has been designed to confine with the features of the ECM process. Figure 6 shows the machining cell that has been used for hole and rod finishing. The cell has been adapted to work on a radial drilling machine to get the advantages of the controlled feed rate, and the rotational motion of the tool. The electrolyte was sodium chloride [200 g/1] and has been supplied into the cell through a centrifugal pump drawing from a plastic tank [1 m^3].

The specimens [holes and rods] were made of hardened steel with a circular cross-section as shown in Fig.1. The pre-machined holes of the workpiece were machined through a fine turning process to get different initial side gap values between tool and workpiece surface. A matrix of fine holes [2.5 mm diameter] were arranged on the tool surface to supply the electrolyte into the interelectrode gap. The outer frame of the machining cell was made from a tube of transparent Perspex. Table 1 summarizes the working conditions used during the present work .

To adapt the cell to be valid for rod finishing (outer surfaces), some modifications have been introduced on its construction to confine with the features of this process, especially that for the tool fixture. However, the present results were only concerning with hole finishing. Surface roughness of the specimens has been tested using Talysrf 10.

μm.

Table 1.

ECM Working Conditions.

Parameter	value
Workpiece material	St.45
Workpiece outer diameter	20 mm.
Workpiece height	20mm
Tool material	Brass
Tool diameter	9 mm to 12 mm
Tool rotational speed	10 r.p.m
Electrolyte type	NaCl
Electrolyte conductivity	0.02 Ω^{-1} mm^{-1}
Electrolyte pressure	1 Kg/cm^2
Applied voltage	12-24 v
Feed rate	10-30 mm/min
Machining time	40s to 1 min.

4- Results and discussions

The accuracy and the productivity of the ECM process with a rotating electrode is influenced not only by the average electrolyte flow rate, but also by the entire cross-section of the interelectrode gap. For hole finishing, the investigations have been carried out using fine perforated electrodes with the objective of achieving optimum machining performance in terms of high surface quality and minimal metal removal thickness. Experimental results revealed that in order to keep the machining process without sparking, it was necessary to provide an electrolyte flow rate of more than 3 liters per minute. It was observed that using electrodes with closely packed perforations caused tendency to sparking.

Figure 6 shows the effect of the applied voltage on the metal removal thickness. It has been observed that as the applied voltage increases, the final metal removal thickness also increases. This result has been attributed to the increase of the current density as the applied voltage increases. Figure 7 shows the significant effect of the feed rate on the metal removal thickness at different working conditions of the initial side gap values. It has been observed that as the initial gap value increases, metal removal thickness decreases. This result is due to the drop of the current density value at the higher values of the initial side gap. Figure 8 shows the effect of the number of strokes on the metal removal thickness. It has been found that the surface roughness was ranging from 2 μm up to 0.62 μm according to the current density value [25A/cm^2 up to 86 A/cm2]. It has also been found that as the metal removal thickness increases, surface roughness improves.

5. Conclusions

- The present technique proved its adequacy to finish outer and inner surfaces under high surface quality and low-cost operation.
- In the present work , the possibility of increasing feed rates, has been achieved which could lead to remove wall thickness up to 0 • 2 mm. This result enhances the controllability of the ECM process.
- Theoretical model and computer simulations facilitate the prediction of metal removal thickness through different combinations of ECM parameters.
- The proposed technique of electrolyte supply can be extended to deal with complex shapes of moulds and dies.

Acknowledgments

The author would like to express his thanks to Prof. S.J. Ebeid Ain-Shams University, Prof. A.M. Abdel Maaboud and Dr. M.F. Safti Menoufia University for their helpful suggestions during this research .

References

1- M.S. Amalnik, J.A. McGeough, Intelligent concurrent manufacturability evaluation of design for electrochemical machining, J. of Materials Proc. Tech. 61 (1996). p130

2- T. Masuzauwa, S. Sakai, Quick finishing of WEDM products by using a mate electrode, Annals of CIRP, 35 (1987), p.123.

3- J.A. McGeough, EDM-ECM finishing hybrid technology , EDM digest, (1988), p.8

4- S.M. Zybura, A. Novak, Investigations on the process of electrochemical smoothing surfaces after rough electrodischarge machining surfaces, Proc. of the 10 th Int. Symposium of ISEM, (1992), p.568.

5- B.Wei, K.P.Rajurkar, Accuracy and dynamics of 3-dimensional numerical control electrochemical machining [NE-ECM], Proc. of Modeling and Machine tools: Accuracy, Dynamics, and Control, (1990), p.33.

6- M.S. Hewidy, S.J. Ebeid, K.P. Rajurkar, M.F. El-Safti, Electrochemical machining performance under orbital motion, Int. Conf. On Advances in Prod. Engineering, 2 (1998), p. 2361

7- M.S. Hewidy, K.P.Rajurkar, G. Royo, M. Fattouh, Theoretical and experimental investigation of electrochemical ballizing, int. J. of Prod. Research (1989), p. 1335.

8- F. Zawistowski, New system of electrochemical form machining using universal rotating tools, Int. J. of Mach. Tools Manufac., 30 (1990), p 475.

9- S.I. Instrument, Stabilization of electrolyte flow in electrochemical machining with rotating electrode, Machines and Tooling, 50 (1979), p.29.

10- J.A. McGeough, Principle of electrochemical machining, Chapman and Hall, London, (1974).

11- K.G.Asthane, P.C. Pandey, Effect of electrolyte velocity on ECM, Proc. of 5 th ISEM Conf. On Mech. Engineering, (1983), p.121.

12- M.S. Hewidy, V.K. Jain, On the production of elliptical holes by ECM, Int. J. of Prod. Research, 25 (1987) p. 433.

13- J. Kozak, K.P. Rajurkar, B. Wei, Modeling and analysis of pulse electrochemical machining , Trans. of ASME, J. of Engineering for Industry, 116 (1994), p. 316

14- K.P. Rajurkar, M.S. Hewidy, W.H. liu, Modeling and simulation of the dimensional accuracy in the ECM process, Engineering Research bulletin of Menoufia Unives. Shebin El-Kom, Egypt, 21 (1998) p.83.

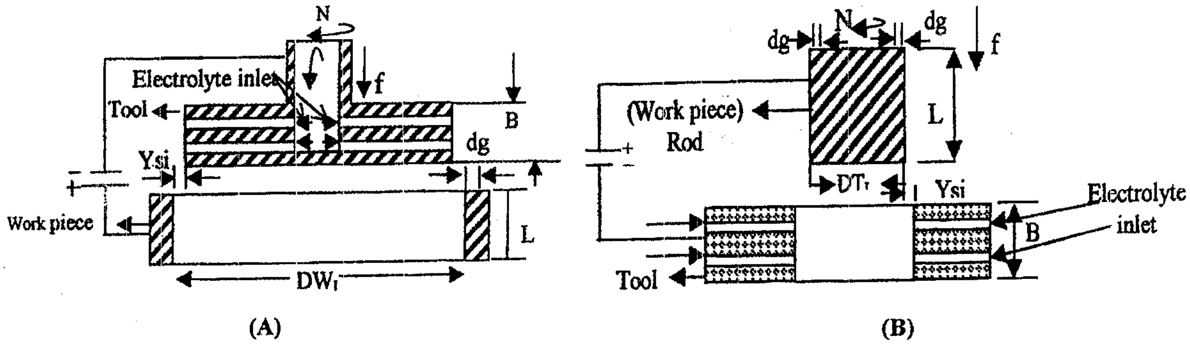


Fig . 1 Hole and rod finishing by ECM process

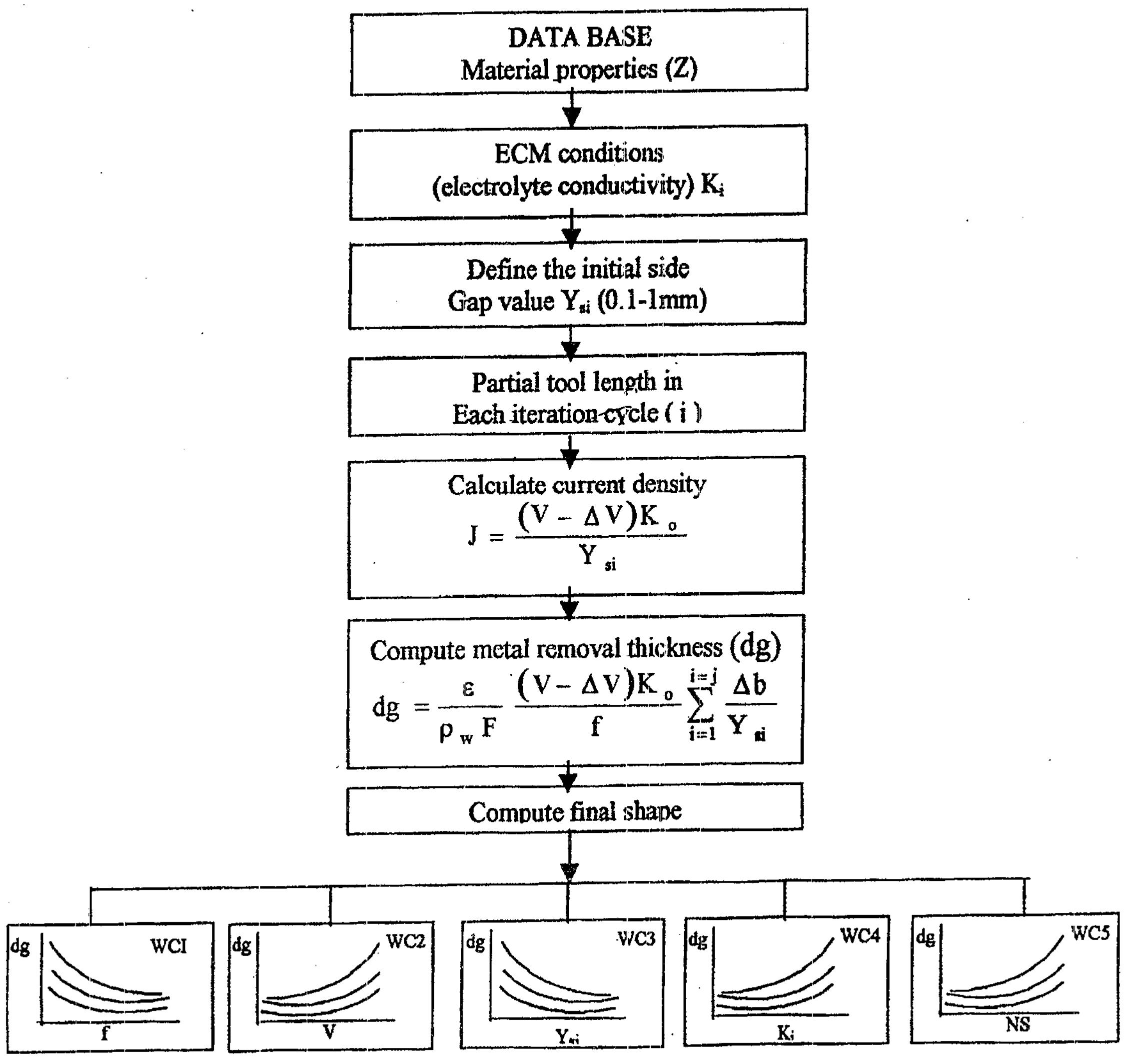


Fig. 2 Calculation of metal removal thickness

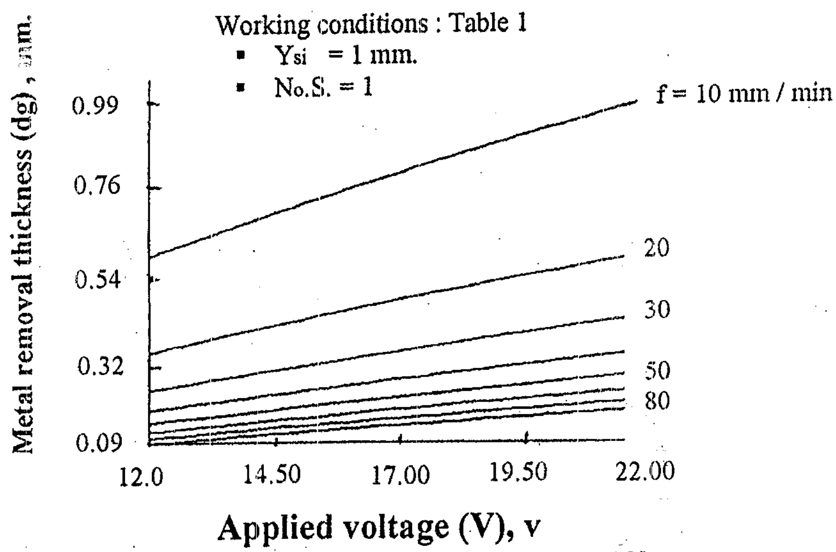


Fig. 3 Effect of applied voltage on dg at different feed rates .

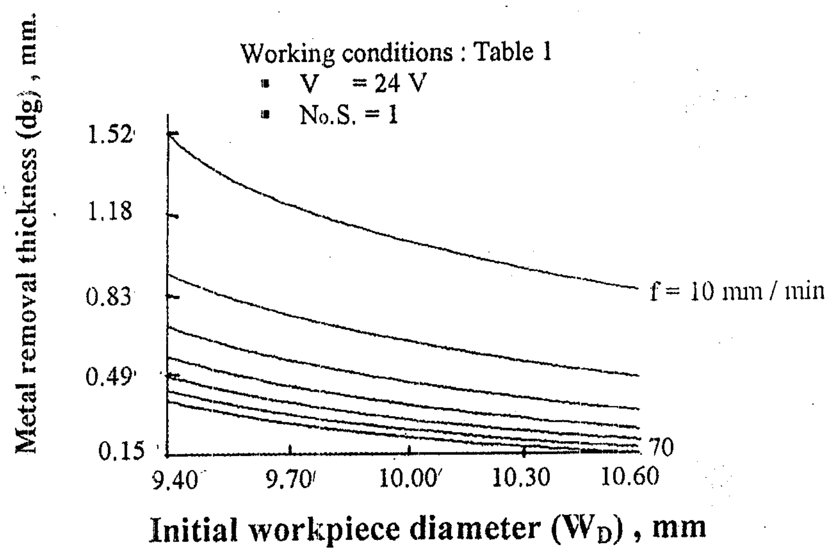


Fig. 4 Effect of initial side gap on dg at different feed rates .

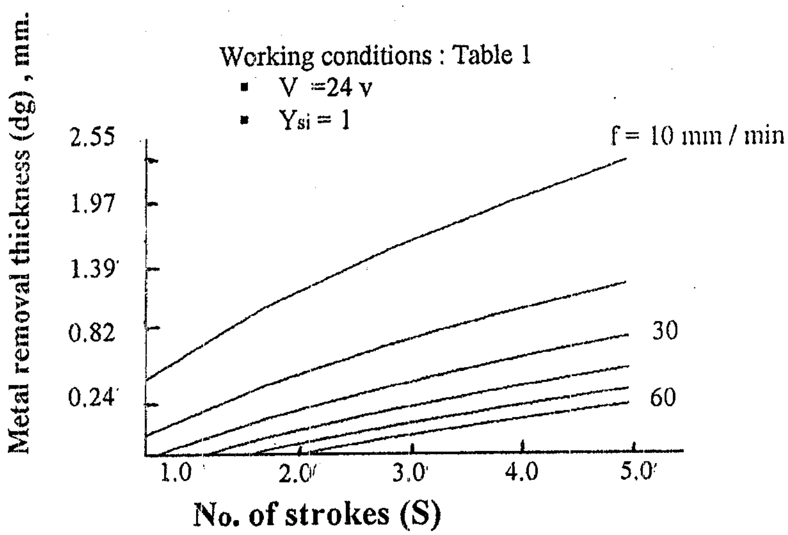
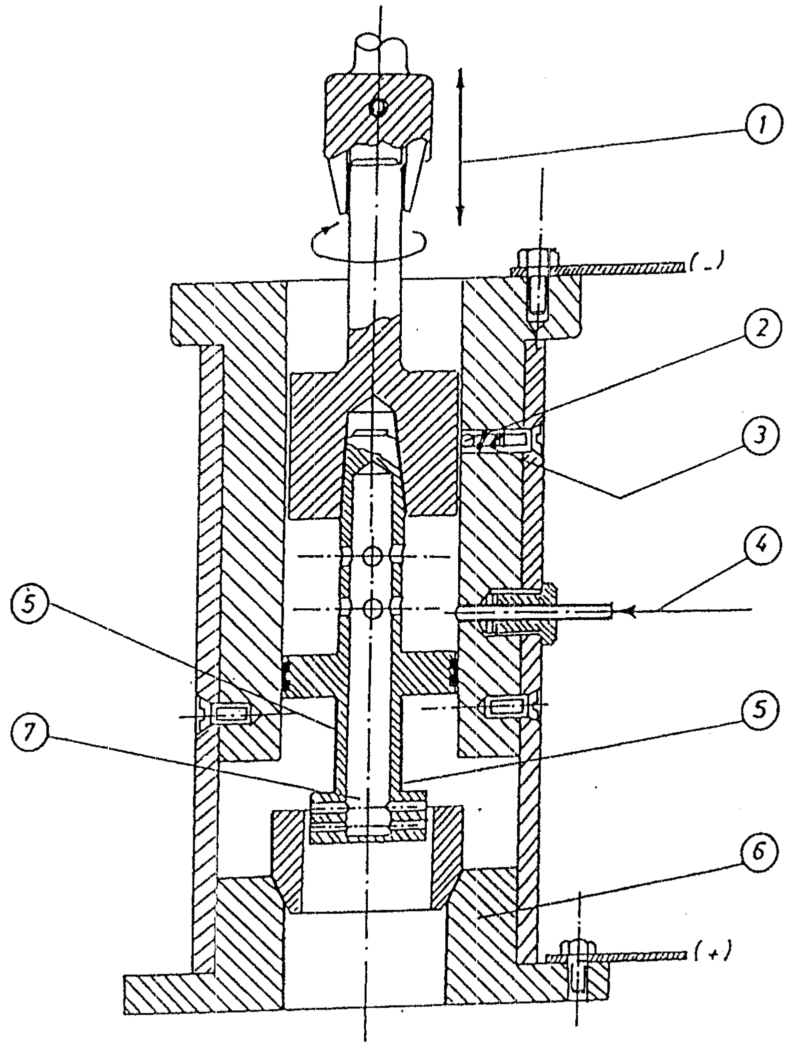


Fig. 5 Effect of machining strokes on dg at different feed rates .



1-Tool motion .
2-ball.
3-Spring.
4-Electrolyte inlet.
5-Insulation.
6-Workpiece fixture.

Fig. 6 : ***Electrochemical machining cell.***

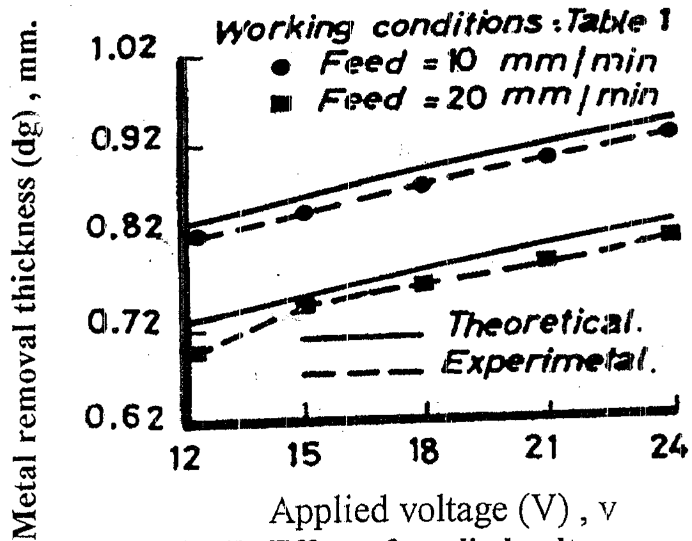


Fig. 7. Effect of applied voltage on metal removal thickness.

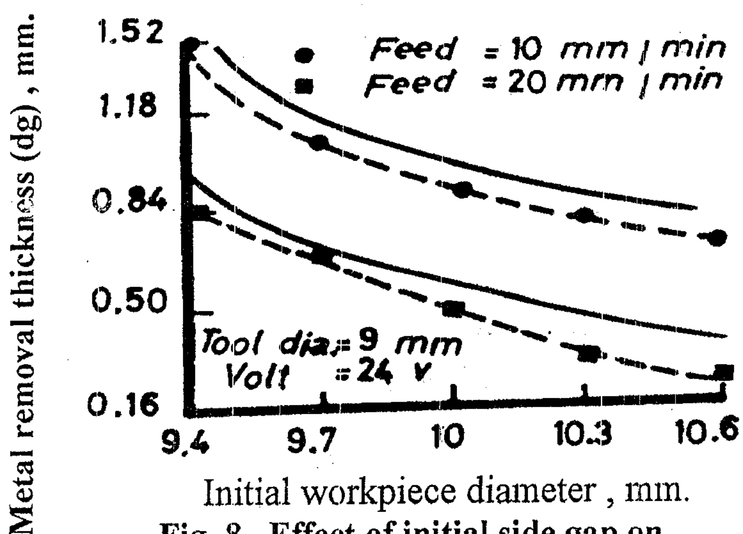


Fig. 8. Effect of initial side gap on metal removal thickness.

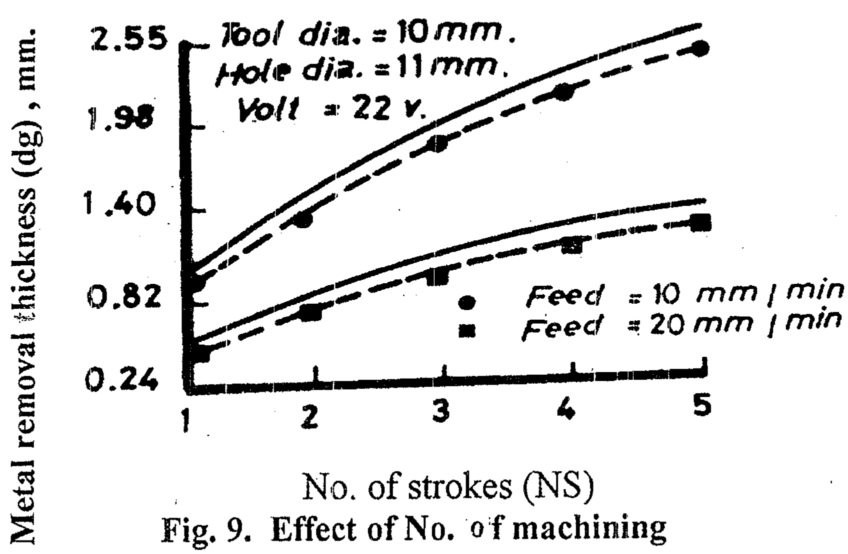


Fig. 9. Effect of No. of machining strokes on metal removal thickness.

التحكم فى السمك المعدنى المزال فى عمليات التشغيل الكهروكيميائية

محمود هويدى

قسم هندسة الإنتاج والتصميم الميكانيكى – كلية الهندسة جامعة المنوفية

الملخص

بالرغم من المزايا العديدة التى تقدمها عملية التشغيل الكهروكيميائى فى مجال تشغيل المعادن وخاصة المعادن الصلدة فإن عمليات تطور وانتشار هذه التقنية مازال مرتبطا ومقيداً بدقتها المنخفضة نسبياً إذا قورنت مثلاً بعملية التشغيل بالشرر الكهربى .

ومن ناحية أخرى تأتى عملية التشغيل الكهروكيميائى فى مقدمة طرق التشغيل الغير تقليدية من ناحية معدلات الإزالة المعدنية العالية وتكاملية السطح الناتج. أثبتت التجارب والأبحاث السابقة إن عملية التشغيل الكهروكيميائى ترتفع دقتها البعدية بشكل كبير فى حالة تشغيلها لفترات زمنية محدودة وهو ما جعلها تستخدم حديثاً كعملية تشطيب سريعة وتابعة لعمليات التشغيل بالشرر الكهربى Quick Finishing Process . انطلاقا من هذه الفكرة يقدم البحث عملية التشغيل الكهروكيميائى كتقنية يمكن رفع دقتها بدرجة عالية من خلال التحكم فى سمك المادة المزالة وذلك لتشطيب الأسطح الداخلية والخارجية .

أدخلت تحسينات على حركة العدة وهو استخدام حركة طولية ودورانية فى آن واحد لرفع درجة انتظامية وتوزيع المحلول الموصل كهربياً (ملح الطعام) فى منطقة التشغيل (الثغرة) ويقدم البحث أيضاً دراسة نظرية وتحليلية من خلال الحاسب الآلى لسهولة التنبؤ نظرياً بالسمك الناتج تحت ظروف التشغيل المختلفة مثل الجهد الكهربى – معدلات التغذية – مرات مرور العدة فى المشغول – الثغرة الجانبية الأولية – شكل العدة وارتفاعها وتم صياغة النتائج جميعها فى منحنيات تسهل عملية الحساب أمام مهندسى تصميم العدد والاسطمبات .