Manufacturing of axial slots by electrochemical machining process

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Abstract

Axial slots are usually required for generator rotors, journal bearing and sliding bearing. Machining and finishing of these slots usually achieved through milling techniques. However, it has been found that there is difficulty in achieving adequate surface finish and acceptable dimensional accuracy of the resultant slot shape. Recently, electrochemical machining (ECM) has been suggested as a promising technique valid to produce these slots under high surface quality and min. machining costs. The previous attempts have been carried out through successive ECM processes, first to machine the hole, and then to create the slots. In the present work, an attempt has been submitted to get both of the hole and slots in one pass as a final process. A special ECM test rig has been designed for this aim. The main affecting parameters on the resultant slot shape were, tool geometry, applied voltage and feed rate. The results obtained in this work enable the manufacturing engineer to select the required shape dimensions through different combinations of ECM parameters.

Introduction

Axial slots are one of the common shapes in the manufacturing processes. It is usually required for generators, journal bearing and sliding bearing. Conventional wheel cutters are generally used for slotting the material encompassed by the slot opening (Fromson and Mancusa 1995). Finishing of machined slots is produced by end mill or broaching, in which multiple passes are employed to obtain the required slot geometry. The previous conventional techniques have a great restriction when it needs to deal with high strength materials (Balazinski and Songmene 1995).

To overcome the problem of the extra hardness of these materials like titanium and inconel, non traditional machining methods have been recommended to machine it (McGeough 1988) and (Rajurkar 1993).

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Electrochemical machining (ECM) process offers the unique advantages of better accuracy and high surface integrity of machined components (Amalnik and McGeough 1996). The progress of ECM process and its wider acceptance is hampered by its inability to produce complex shapes under acceptable dimensional accuracy and adequate surface integrity (Kozak , 1998).

Some investigations have been studied the manufacturing of slots by ECM processes. (Kargin 1975) and (Streenia 1975) studied the producing of the external slots through different tool shapes; straight, curved and spiral. They have used a tubular cathode to get the required slots shape. Internal slots have also been obtained by ECM process (Goyer and Moehring 1988). In their work, they have reported that there is a difficulty in producing the interior slot through milling techniques because it tend to nick the edges of the slot, and could lead to the scarp of the part. They have got the slot shape for a pre-machined hole.

In the present work, an attempt has been made to simultaneously produce both hole and slot by ECM process in one pass, without a need to a pre-machined hole or any successive finishing processes. It is believe that this advantage will enhance the productivity of ECM process and deal with it as a mass production technique more suitable for small and medium enterprises. From economical point of view, the production rates will greatly increased because the hole and the slots could be cut simultaneously. A special test rig was completely designed for this aim.

Experimental work

In order to study the characteristics of the electrochemical drilling, coupled with axial slots, a special test rig has been designed to comply with the features of this process. Special tools have been designed to simultaneously perform both slotting and drilling processes in one pass. The tools were brass, with internal radius (r_o) equal to 1.75 mm and external radius (r_t) as 4mm (Fig. 1). The electrolyte was pumped into the interelectrode gap through a central hole in the tool. The tools have been insulated using epoxy resin material with different layer thickness (Fig. 2). The insulated layer thickness (t) were ranged from 1 to 2.5 mm. The accurate layer thickness has been obtained through a fine turning process for the dried epoxy resin material. Four negative slots have been created in the tool surface through a fine removing process for the insulating material. The width of each side land (x) was 2 mm. The height of the land (y) was ranged from 4 To 16 mm. To initiate the electrochemical cutting process, the tool has been provided with a bared frontal area, and constant tool land (b) equal to 1.5 mm.

All the experiments were carried out using NaCL electrolyte at concentration of 20% w/v. The electrolyte pressure was fed into the closed machining cell at 4 kg/cm^2 and the outlet pressure was 0.25 kg/cm^2. Figure 3-a represents a block diagram of the constructed ECM cell. Figure 3-b shows the closed cell, which has been employed to carry out the present investigation. The consumed current was measured each 30 s. The final workpiece geometry has been measured at different sections, 2 mm apart between each others, using an optical microscope (Carlzeiss Jena 5668) with an accuracy of 0.01 mm.

Table 1: Summarizes the experimental conditions, which have been adopted during the present investigation. The specimens were mild steel, with an outer diameter equal to 25 mm, and 15 as a thick.

Results and discussions

Figure 4 shows the effect of applied voltage on the depth (w) of the resultant slot dimensions at different feed rate values. It has been observed that as the applied voltage increases, the depth of slot increases. This result is due to the increase of the consumed current and density at the higher values of the applied voltages, which has led to higher metal removal rate. For all the experiments consumed the currents were not exceeded 25 A. The great drop of the current consumption is due to the insulation of most of the tool surfaces. This advantage facilitates the construction of ECM equipment with low power supply, which logically reflects on the equipment price and machining costs. It was also been cleared that as the feed rate increases, the width of the slot decreases. This result has been attributed to the reduction of the time of the electrochemical action at the higher feed rate values, which consequently led to a lower metal removal rate at the side area. The wide rang of the resultant depth of the slot, from 1.1 mm to 6 mm, reflects the reliability of the combinations of the EC parameters to achieve the required slot depth.

Figure 5 shows the effect of length of the side tool land on the depth of the slot. It has been observed that, as the length of the side land increases, the depth of the slot increases. This result is due to the increase of the time of the ECM action on the workpiece wall at the side area, which causes successive metal removal rate on the slot surfaces. The effect of feed rate on the width of the slot was similar to that obtained in Fig. 4. Furthermore, the increase of the feed rate value leads to more current consumption, which increases the electrolyte temperature and sometimes generates hydrogen bubbles, which evolve in the side gap area and decreases, the electrolyte conductivity. The reduction of the electrolyte conductivity decreases the current density and consequently, decreases the metal removal rate.

Figure 6 represents the relation between feed rate and the ratio x_m/x_o, which is the ratio between maximum and minimum width of the resultant slot shape. It has been observed that, as the feed rate increases, this ratio decreases, which improves the conicity of the slot wall. According to the trend of the curves, it is expected that the increase of feed rate value could lead to more straightness of the slot wall. However, the increase in the feed rate value needs more pumping pressure of the electrolyte, which has not been available during this work.

Figure 7 shows the effect of the insulating layer thickness on the ratio x_m/x_o at different applied voltages. It has been anticipated that as the thickness of the insulating layer increases, the ratio x_m/x_o decrease and consequently, the straightness of the slot wall improves. This result has been attributed to the distribution of the current line in the interelectrode gap (Hewidy and Jain 1987). Furthermore, it shows that the stray cutting decreases as the insulating layer thickness increases. The increase of the layer thickness enhances the presence of the electrolyte in the interelectrode gap, which acts as a dam to the electrolyte.

Figures 8-9 show computer presentation for the slot profile at different working parameters. Figure 10 shows a sample of ECM products for the slot shape.

Conclusions

The present work proposes the electrochemical slotting, as a shaping technique, particularly valid for the hard materials.

The results proved the adequacy of this technique as a simple method for both slot machining and finishing with the advantages of simple tool design, low power consumption and better dimensional accuracy.

Low voltage, thick insulating layer, high feed rates and short tool side land could lead to higher dimensional accuracy of the resultant slot shape. On the other hand, high voltage, low feed rate, thin insulating layer and long tool side land could use to get different shaping shapes by ECM process

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Table 1. List of experimental conditions

Electrolyte:	NaCl, 20% w/v
Inlet pressure:	4 kg / cm^2
Outlet pressure:	0.25 kg/cm^2
Tool material:	Brass
Tool geometry:	Fig. 1
Workpiece material:	Mild steel
Workpiece diameter:	25 mm
Workpiece thickness:	15 mm
Length of tool land (b):	1.5 mm
Width of each side land (x):	2 mm
Length of side land (y) (Fig.2):	4,6,8,10 and 12 mm
Thickness of insulating layer (t):	1,1.5,2 and 2,5 mm
Applied voltage:	8,12,16,20 and 24 v
Feed rate:	0.5, 0.75, 1, 1.25 and 1.5 mm/min

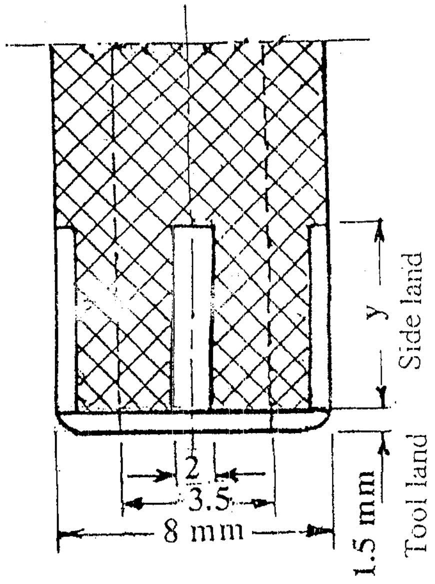

Fig. 1. Compound tool geometry.

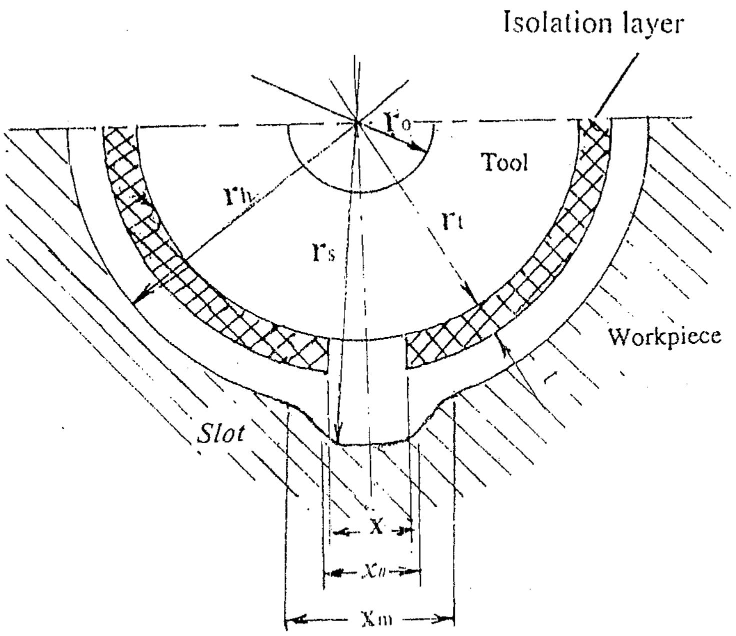

Fig.2. Tool and workpiece configuration.

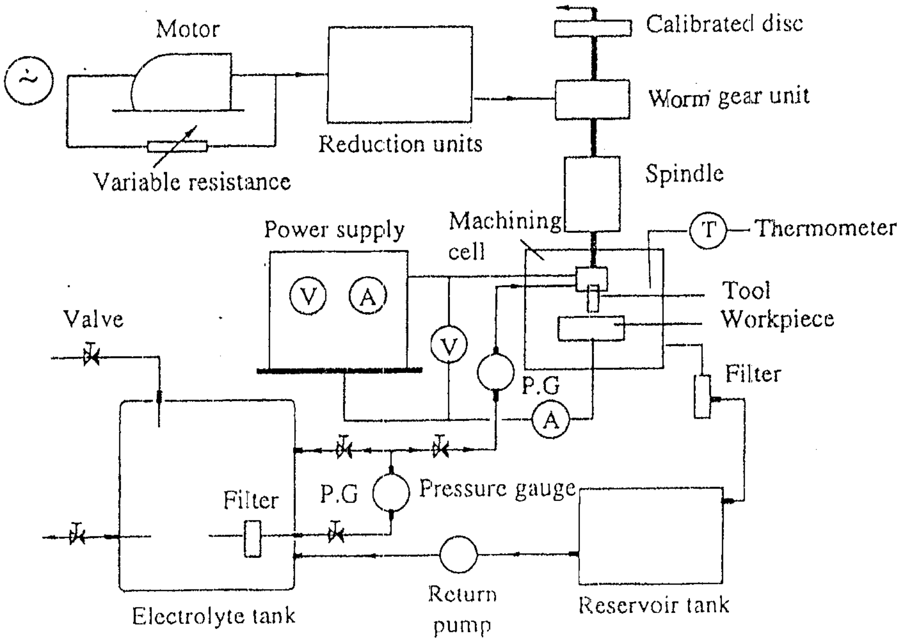

Fig. 3-a. Block diagram of electrochemical machining cell.

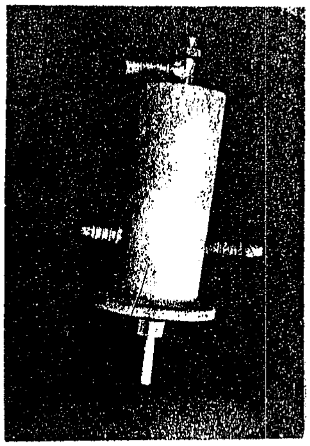

Fig.3-b. ECM closed cell.

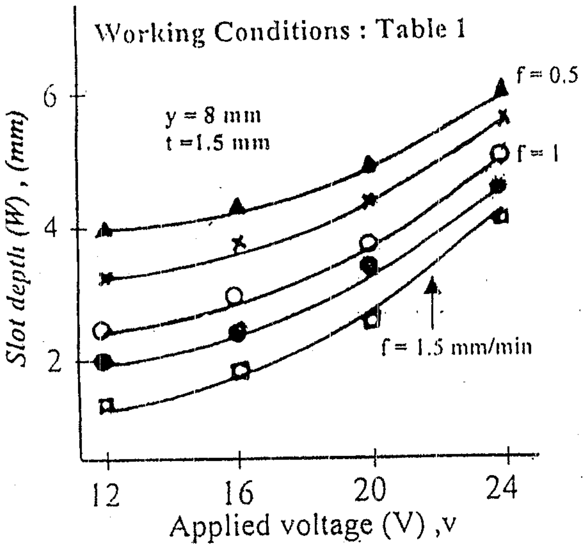

Fig 4. Effect of applied voltage on slot depth.

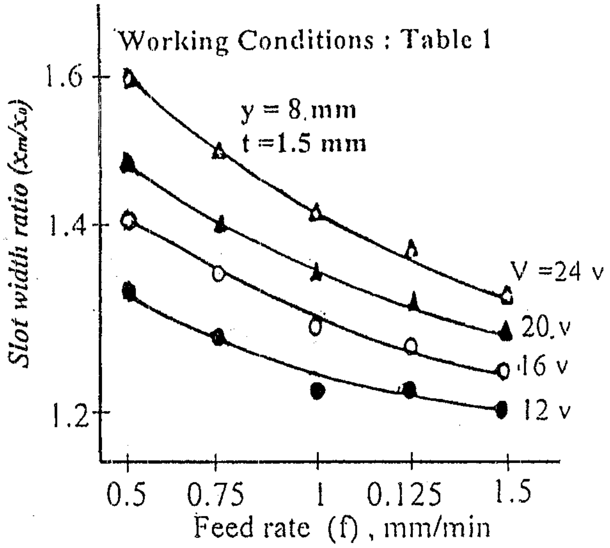

Fig. 6. Effect of tool feed rate on slot depth ratio.

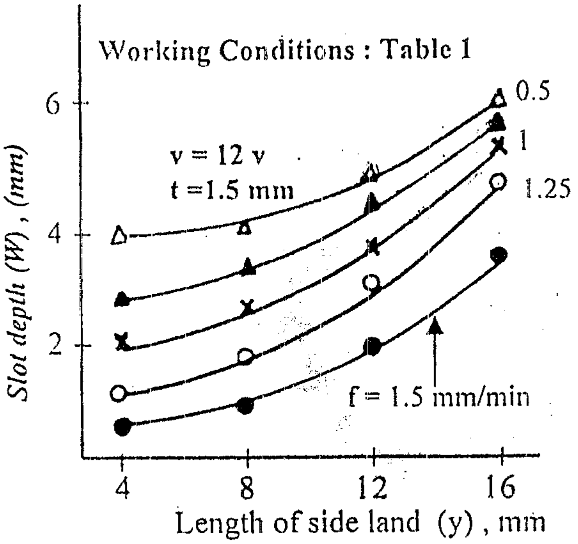

Fig.5. Effect of side land length on slot depth.

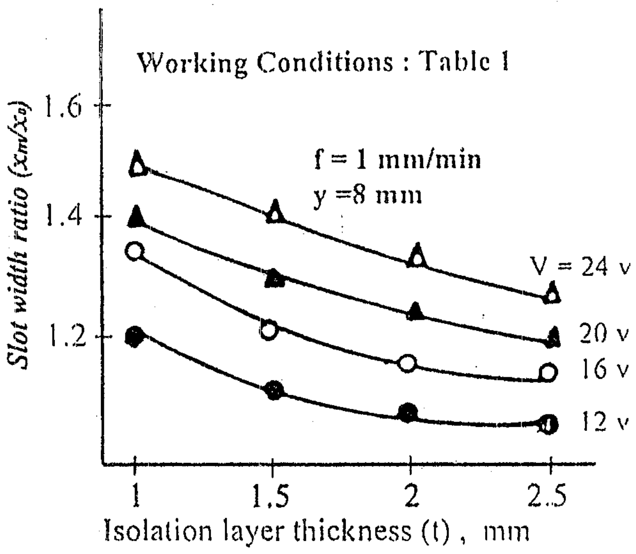

Fig.7. Effect of isolation layer thickness on slot width ratio.

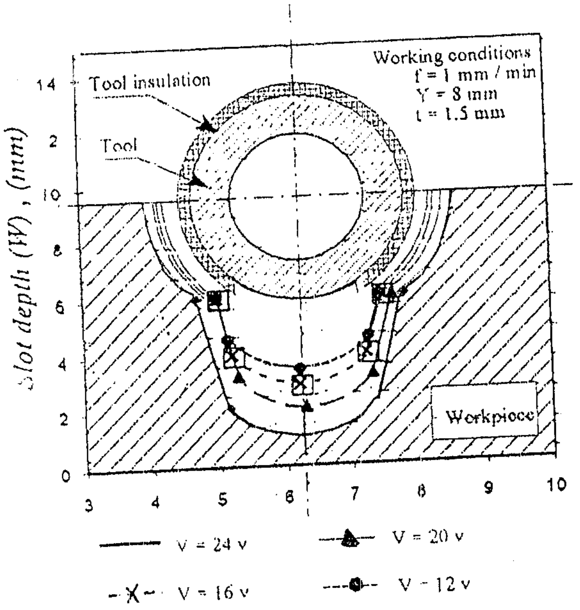

Fig. 8. Slot profiles at different voltage values.

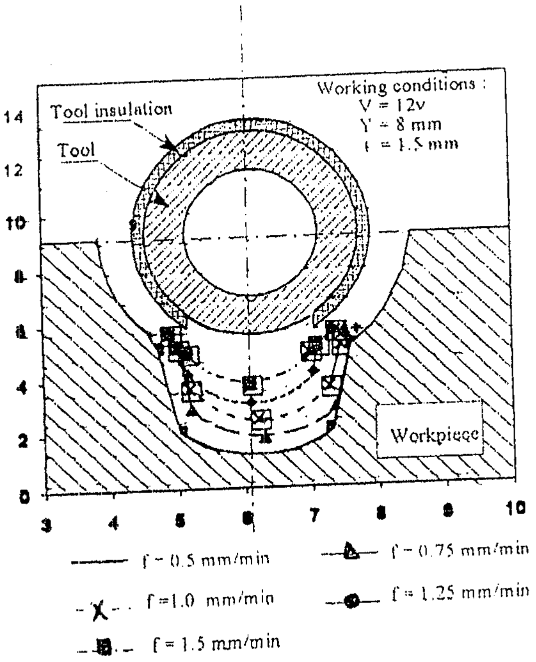

Fig.9. Slot profiles at different feed rate values.

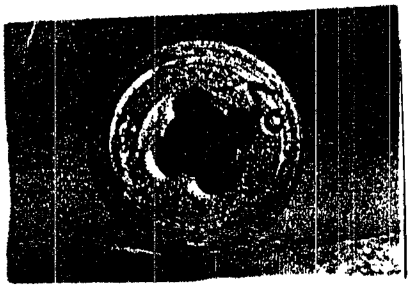

Fig.10. Slot shape by ECM process.

تصنيع المجارى المحورية بالتشغيل الكهروكيميائى

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الملخص

تعتبر المجارى المحورية من الأشكال شائعة الاستخدام فى مجال هندسة التشغيل مثل مجارى أعمدة المحركات الكهربائية والكراسى الإنزلاقية . وتكمن صعوبة تصنيع المجارى المحورية فى حالات زيادة صلادة المشغول حيث تؤدى أحيانا إلى تشوه الشكل المطلوب وتهدد بانهيار أداة القطع (end – mill) إضافة إلى أن طريقة الإنتاج نفسها تتطلب عمليات إعداد وتشطيب متتالية للوصول بالشكل إلى الدقة المطلوبة .

اقترحت مؤخرا عملية التشغيل الكهروكيميائى كتقنية جديدة تصلح لعمل المجارى المحورية الداخلية والخارجية ولقد تمت عملية الإنتاج على مرحلتين : مرحلة عمل الثقب الأولى ثم عمل تجويف المجرى مرة ثانية . والبحث الحالى يقدم نمطا جديدا لتشغيل المجارى المحورية الداخلية من خلال عملية واحدة تقوم فى آن واحد بعمل الثقب الداخلى وتجويف المجرى وذلك لزيادة إنتاجية عملية التشغيل الكهروكيميائى وتقليل التكلفة .

تم اعداد خلية معملية لذلك وتم تصميم عدة خاصة مخلق بداخلها شكل المجرى المطلوب إنتاجه فى المشغول وتم ذلك من خلال عمليات العزل بمادة الإبيوكسى وإزالتها بما يكون شكل المجرى المطلوب . أثبتت التجارب المعملية إمكانية عمل المجارى المحورية بالتشغيل الكهروكيميائى تحت ظروف الخلية المغلقة وتم قياس شكل المجرى الناتج تحت الظروف التشغيلية المختلفة وأهمها معدلات التغذية طول الجزء المعرض للمحلول من جسم عدة القطع - سمك العازل - الجهد الكهربى وقد بلورت النتائج فى شكل منحنيات تسهل التنبؤ بعمق المجرى الناتج وعرضه عند القمة والقاع لسهولة تقنين ظروف التشغيل المناسبة .