OPTIMAL WORKING CONDITIONS IN ECM
PART I : CIRCULAR HOLES

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ABSTRACT

The present paper reports the results of an experimental program to study the influence of process parameters on the side gap value in the electrochemical drilling (ECD).

Twenty-Seven tests were performed on an experimental test rig using mild steel workpieces. A 3^3 factorial design is used to study the influence of feed rate, applied voltage and tool land on the side gap width.

An empirical equation for the calculation of the side gap was presented which allows computing of the gap width within a tolerance of .05 mm. to 0.15 mm. Furthermore, this experimental technique will contribute towards the selection of optimum process conditions in the electrochemical drilling processes.

INTRODUCTION

Electrochemical drilling (ECD) has become one of the main fields of the non-traditional processes. It has been applied successfully to several practical applications in industry to get circular and non-circular holes.

Circular holes, as a common process have attracted many authors [1-11] to study the relationship between tool shape and resultant workpiece profile. All the previous papers were carried out using the classical techniques of the experimentation

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design (vary one factor at time, hold everything else constant). The final result of these techniques was relatively limited because it has missed the plan of the experimentation work.

Many equations have been presented for estimating the tool overcut in ECD [1-8] . All these techniques have inserted a side gap correcting factor to suit their experimental results. This factor was varying from 1 [2] to 1.7[11].

The object of this work is to design a plan of work having the capability of including all the possible combinations between the working parameters is the ECD. The experimental tests were made also to derive empirically equations from the results. This was thought to be the best way, as all theoretically drerived equations would have the disadvantage that they could not contain the exact way of current lines along which the metal removal takes place (Fig. 1).

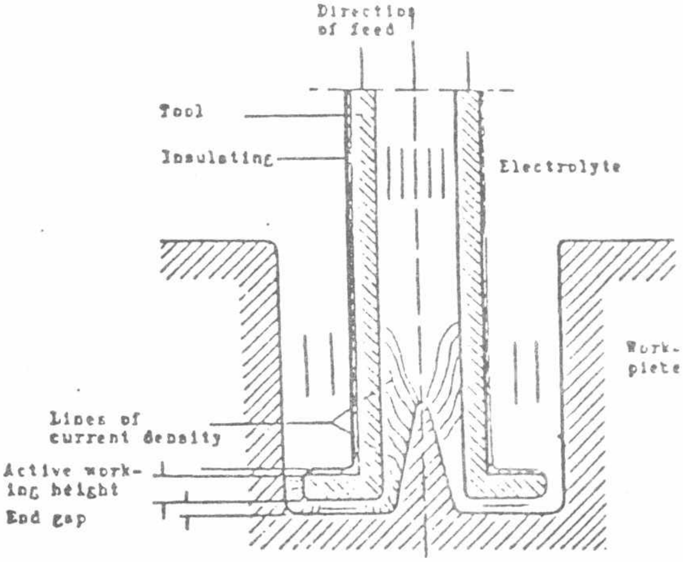


Fig.1 Boring a hole by means of electrochemical machining

after Dietz et al., [8]

Applied voltage, tool land, and feed rate were considered the main factors affecting the ECM process. Side gap has been considered the significant measurement that can differentiate between the various working parameters during the (ECD) operation.

Three levels of applied voltages, tool lands and feed rates have been applied in these investigations using a 3^3 factorial of design technique. The selection of these parameters and their levels has been based on some practical considerations to achieve high tool life, minimum power consumption and maximum machining productivity. Furthermore, this work is an endeavour to present an elaborate study about (ECD) to enable the tool designer in the ECM to estimate the side gap using realistic and practical equations.

EXPERIMENTAL WORK

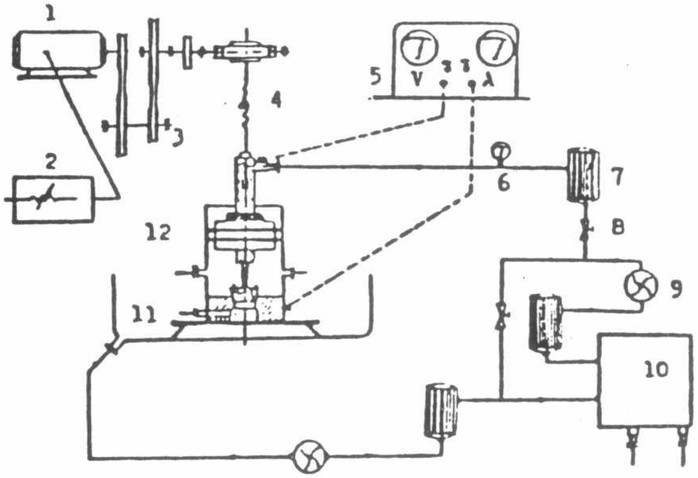
In order to carry out this work, a special test-rig has been designed and constructed to carry out these investigations (Fig. 2). Commercial sodium chloride (200 gm./L) was pumped through the interelectrode gap from a hole provided in the tool (Fig. 3). Large quantities of electrolyte were pumped [4] to ensure an adequate flow to prevent over-heating and boiling as a result of Joule heating.

The maximum available current of the power supply was about 550 Amp. The applied voltages were 10, 12, 14, 16, 18, 20, and 24 volts respectively. The available feed rates ranged from 0.1 to 8 mm./min.

To assure smooth flow of the electrolyte, the tools were provided with rounded corners about 1 mm. Brass was used as a tool material in these tests. All experimental tests were performed under the following constant conditions:

Electrolyte pressure.	1 Kg./cm^2.
Tool diameter.	12 mm.
Electrolyte conductivity.	0.02 Ω^{-1} mm^{-1}.

All these investigations have been realized in the range from volt/feed rate = 6 volts/mm/min. to 20 volts/mm/min. in order to avoid sparking and tool damage [9]. However, some experimental tests have been achieved at the ratio of 4.5 volts/mm/min.



1. Motor
2. Variable resistance
3. Reduction Unit
4. Feed system
5. D.C. power supply
6. Pressure gauge
7. Filter
8. Valve
9. Pump
10. Tank
11. Insulation
12. Machining cell.

Fig. 2: Schematic diagram of EC machine.

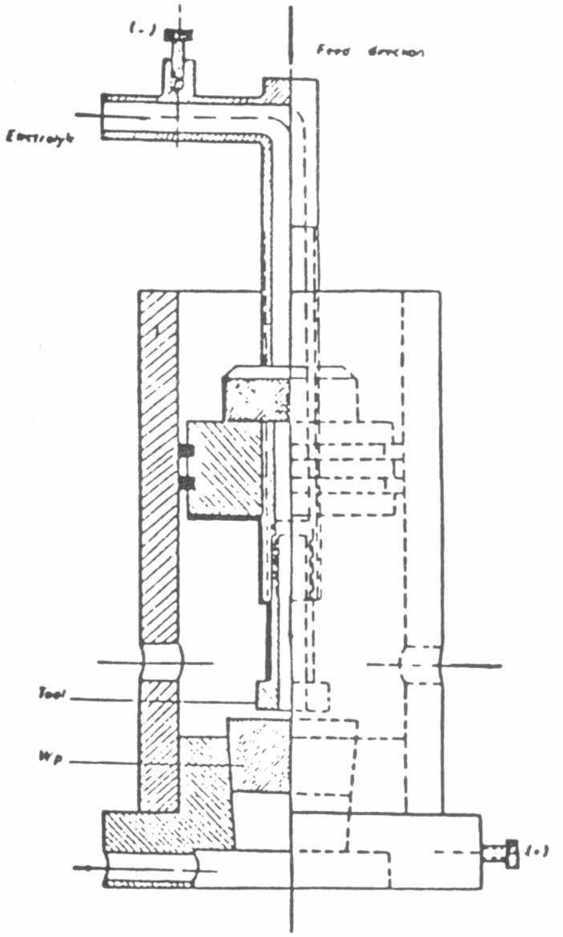


Fig. 3. Locally designed machining cell

EXPERIMENTAL STRATEGY

In this study, interest is focused on the degree to which the feed rate, applied voltage and tool land affect the (ECD) process.

A3-variable 3-level factorial design containing 27 running was tests performed. The choices of high, medium, and low levels for the variables are shown in Table 1.

Table (1)

Variable	Unit	Low	Medium	High
Feed rate (F)	mm./min.	1.0	2.0	3.0
Volt (V)	Volt	16.0	18.0	20.0
Tool land (L)	mm.	2.5	3.5	4.5

The values fall within practical limits of machining conditions, and provide a range which enables possible effects to be detected.

The samples are designated by:

S_{ijk}; i, j, k = 1, 2, 3, where i is for feed, j for volt and k for tool land.

For example S_{123} means the (ECD) process was performed with low feed rate, medium volt, and high tool land. Side gap was chosen to be the response variable for experiment. An average of three observations was taken as the final observation for the side gap.

Table 2 shows the experimental conditions and the observed value of the response (side gap).

Influence of machining conditions on the (ECD) Process:

The relationship between the response and the machining conditions employed is quantified by empirical equation. The influence of feed rate, volt and tool land on the side gap is determined through a 3^3 factorial design. A first order equation for practical purposes is developed.

Table (2)

Exp. No.	Exp. design-ation	Coded Variables X_1	X_2	X_3	Response parameter (side gap) mm	Consumed current
1	S_{111}	-1	-1	-1	1.94	40
2	S_{211}	0	-1	-1	1.43	61
3	S_{311}	0.585	-1	-1	1.14	69
4	S_{121}	-1	0	-1	2.48	85
5	S_{221}	0	0	-1	1.54	133
6	S_{321}	0.585	0	-1	1.16	161
7	S_{131}	-1	0.900	-1	2.47	99
8	S_{231}	0	0.900	-1	1.62	156
9	S_{331}	0.585	0.900	-1	1.29	209
10	S_{112}	-1	-1	0	2.28	93
11	S_{212}	0	-1	0	1.56	192
12	S_{312}	0.585	-1	0	1.25	242
13	S_{122}	-1	0	0	2.47	128
14	S_{222}	0	0	0	1.64	196
15	S_{322}	0.585	0	0	1.21	260
16	S_{132}	-1	0.900	0	2.19	133
17	S_{232}	0	0.900	0	1.85	210
18	S_{332}	0.585	0.900	0	1.49	271
19	S_{113}	-1	-1	0.750	2.28	131
20	S_{213}	0	-1	0.750	1.71	204
21	S_{313}	0.585	-1	0.750	1.33	240
22	S_{123}	-1	0	0.750	2.76	139
23	S_{223}	0	0	0.750	1.93	225
24	S_{323}	0.585	0	0.750	1.42	255
25	S_{133}	-1	0.900	0.750	2.94	156
26	S_{233}	0	0.900	0.750	2.06	237
27	S_{333}	0.585	0.900	0.750	1.66	280

Postulation of first order model:

A functional relationship between the response of side gap and the variables (volt, feed rate, and tool land) under investigation can be postulated by:

$$\text{Respnse } (Y_s) = C \cdot F^{\alpha} \cdot V^{\beta} \cdot L^{\gamma} \qquad (1)$$

Where;

Y_s = Side gap width mm.
C = a constant depending on electrolyte conductivity, w.p material
F = tool feed rate mm/min.
v = applied voltage volts.
L = length of tool land mm.

Equation (1) can be written as:

$$\text{Log } Y_s = \log C + \log F + \log V + \log L \qquad (2)$$

Which can be simplified to:

$$Y_s = C + X_1 + X_2 + X_3 \qquad (3)$$

To estimate the parameters of this first order equation, the method of least sqares is used with the following coding for the parameters.

	Coded Level Low	Medium	High
F	-1	0	0.585
V	-1	0	0.900
L	-1	0	0.750

The transforming equations are:

$$X_1 = \frac{\text{Log } F - \text{Log } 2}{\text{Log } 2 - \text{Log } 1} \qquad (4)$$

$$X_2 = \frac{\text{Log } V - \text{Log } 18}{\text{Log } 18 - \text{Log } 16} \qquad (5)$$

$$X_3 = \frac{\text{Log } L - \text{Log } 3.5}{\text{Log } 3.5 - \text{Log } 2.5} \qquad (6)$$

The estimation result of the response (Y_s) is as follows:

$$\text{Log } Y_s = 0.22 - 0.164\, X_1 + 0.019\, X_2 + 0.017\, X_3 \qquad (7)$$

Equation (7) was transformed as follows using the transformation equations 4, 5, and 6.

$$Y_s = 0.93 \cdot F^{-0.55} \cdot V^{0.4} \quad L^{0.12} \qquad (8)$$

From the above model, it can be seen that as the feed rate increases, the value of the side gap decreases. As the applied voltage increases, the value of the side gap increases.

The analysis of variance for the response parameter (Y_s) showed that the tool land is non-significant parameter. Therefore, the side gap is not a function of tool land for the range of tool land lengths (2.5, 3.5 and 4.5 mm).

RESULTS AND DISCUSSION

Experimental results as shown in Fig. 4, revealed that the response parameter in this work (side gap) can be achieved through many different combinations between applied voltages, tool lands, and feed rates.

For example, the side gap value of about 1.5 mm can be realized by the following combinations:

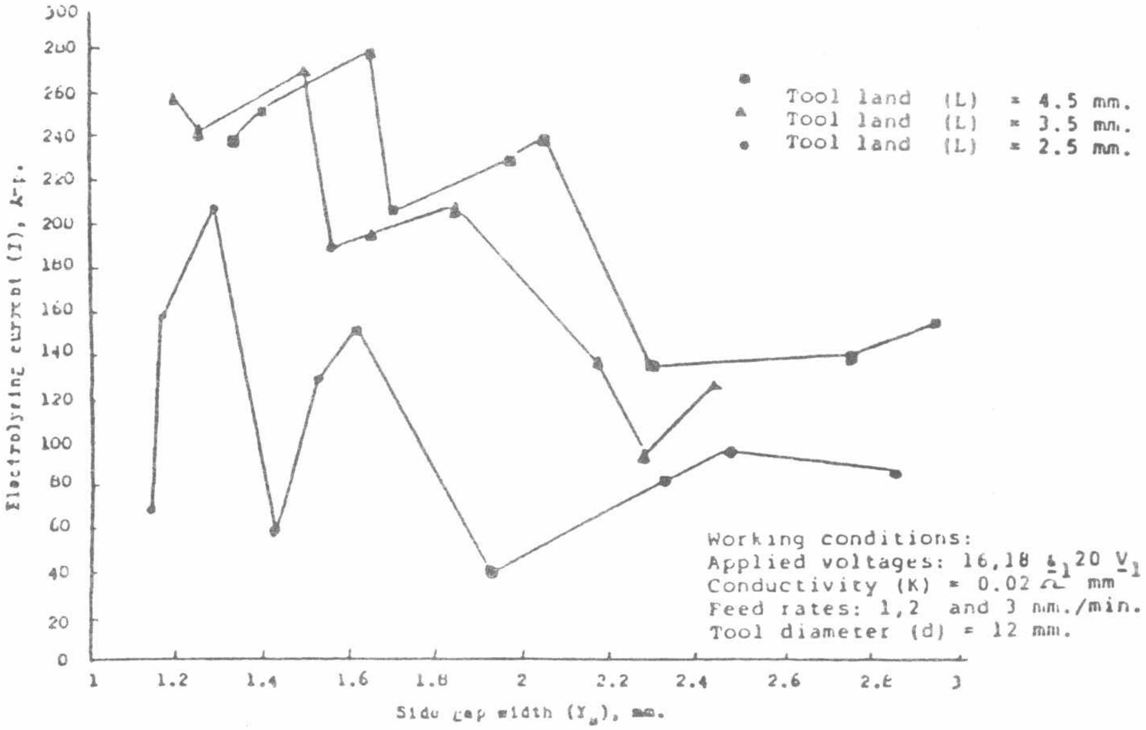


Fig. 4 Variations in the power consumption w.r.t. side gap width.

S_{211} (Feed rate = 2 mm./min.,volt=16v,tool land-2.5mm.,Y_s=1.43
S_{221} (Feed rate=2mm./min.,volt=18v,tool land=2.5mm.),Y_s=1.54
S_{212} (Feed rate=2mm./min.,volt=16v,tool land=3.5mm.),Y_s=1.56
S_{323} (Feed rate=3mm./min.,volt=18v,tool land=4.5mm.),Y_s=1.42

The consumed currents in the previous 4 possible combinations are as follows:

S_{211}	61	Amp.
S_{221}	133	Amp.
S_{212}	192	Amp.
S_{323}	255	Amp.

The variation in the power consumptions for the previous side gap is very significant especially from the economical point of view 10 . This technique will lead to the suitable slection of the working parameters in the (ECD) and consequently minimizing the value of the needed power supply of the EC machine.

The next empirical equation can be used to estimate the power consumption for the ECD process:

$$I = 0.36\ (d+2\ Y_s)^2\ F + \frac{0.06\ (d+Y_s)\ L\ V}{\sqrt{2.25\ \frac{V^2}{F^2} + \frac{V}{F}\ L}}$$

Where;

I is the consumed current, Amp.
d is the tool diameter, mm.

The first term of this equation having the greater value of the power consumption which reflects the vitality of the feed rate parameter on the consumed current value.

Fig. 5 emphasizes the adequcy of the derived empirical equation to predict the side gap width in the ECD. The results show a better agreement with the experimental results than the other compared techniques.

CONCLUSION

The analysis and the combinations between the working parameters in the (ECD) are considered the optimum technique to achieve the required side gap using the minimum power consumption.

The simple empirical equations proved to be adequate to predict side gap and consumed current.

Feed rate is the significant parameter controlling the accuracy and the power consumption in the (ECD).

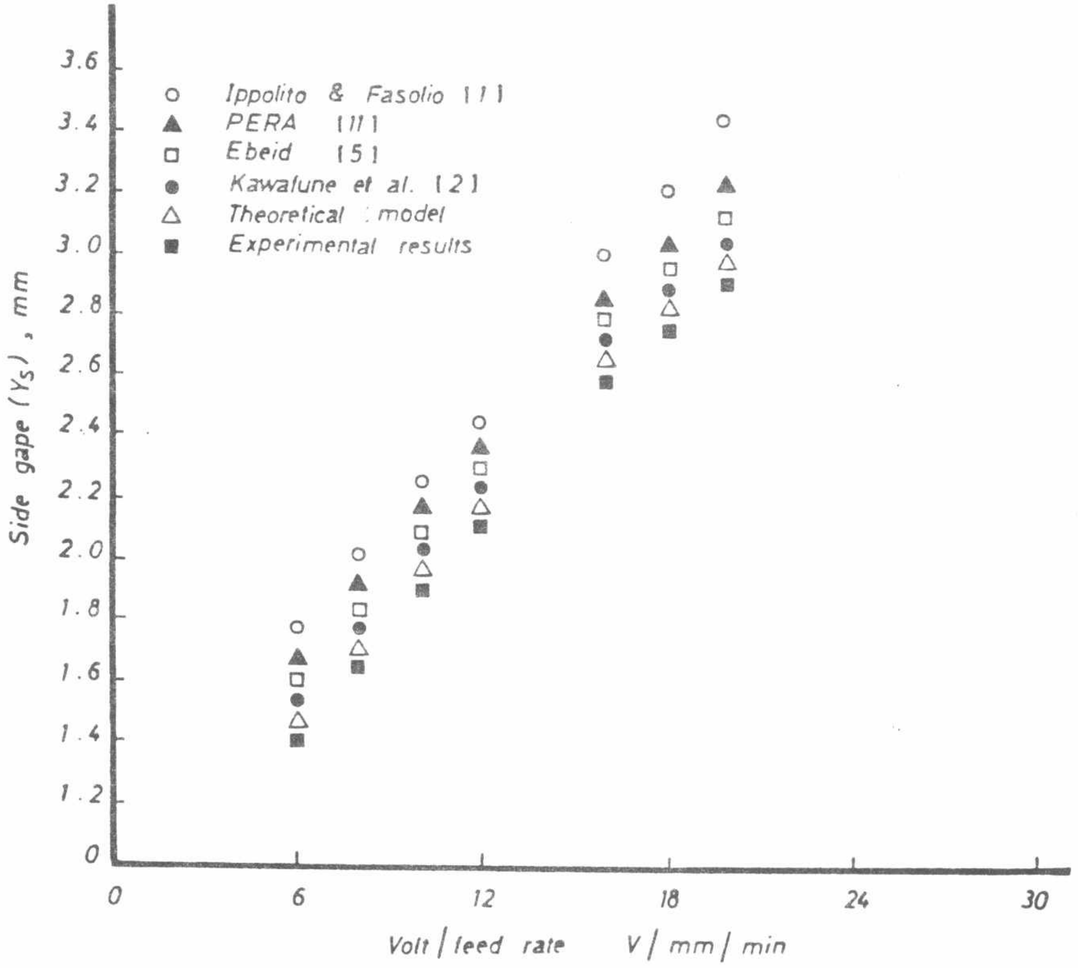


Fig.(5) Various techniques for estimation of the side gap width in ECD.

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