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IMPROVING ACCURACY OF ELECTROCHEMICAL MACHINING PROCESSES

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ABSTRACT

The main difficulties regarding producing non-equal sided shapes such as parallelogram slots, airofoil grooves, elliptical holes, etc.are due to non equal gap distribution allover the machined surface. Such difficulty can restrict ECM industrial applications on a large scale. The scope of the present paper comprises an analytical and experimental model for studying various probabilities to overcome such difficulty and presents suitable recommondations for such practical situation.
Experimental and theoretical results revealed that there is a significant improvement in both dimensional accuracy and power consumption obtained by the use of the proposed model. It has been found that in the present case, improving in accuracy and power consumption of about 21 % and 28% respectively was obtained.

INTRODUCTION

ECM is one of the main non conventional machining techniques. Many articles were published for the practical ECM applications. Jain et al. (1) summarized most of these applications. Over the years, the practical applications of ECM processes have been developed and extended to new operations such as wire cutting, single pointed tool and broaching processes. Electrochemical broaching (ECB) operation is considered as a new technique of ECM (2,3). It can be utilized with much advantages in forming complex shape components (4). The main advantage of ECB is the ability to use higher feed rates than with other ECM processes (5) like drilling, sinking boring, etc.
Some authors studied the characteristics and performance of broaching process. Kremer et al. (5) studied the broaching of square and hexagonal holes regarding their accuracy. Ghabrial et al.(6) were concerned with defining the progressive shape formation for certain arbitrary tool design in the course of broaching triangular and square holes. A comperative study between electrochemical broaching and stationary ECM was performed by Sinbel(7) regarding sizing, rate of metal removal, power consumption and surface quality for circular holes.

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In spite of the fact that ECB proved to be adequate for finding high attainable degree of accuracy, it is still faced with certain problems. Some of the main problems that may arise with ECB are:

1. Stray Attack

Regardless of the broaching tool end shape, it has tapered configuaration(8). Therefore, stray attack is linked to the high relatively tool lengths. Such stray cause deterioration in front and rear faces of the workpiece. Moreover, in the case of NaCl electrolyte dissolution will occur even at very wide gaps resulting in considerable stray machining. Also a passivating film is not generated and the dimensional control is poor, i.e., there is a considerable amount of stray current attack. Lower current density caused by stray current machining may lead to etching, striations, dull spots and pitting in stray machining zones.

2. Non Uniform Gap Distribution

One of the main difficulties regarding producing non-equal sided shapes such as parallelogram slots, airofoil grooves, elliptical holes, etc. is the non equal gap distribution(4) allover the machined surfaces as shown in Fig. 1. This is due to the great differences in current flow lines, electrolyte flow stream and metal removal rate in both directions. It should be mentioned that along the tool center lines accumulative side cutting with considerable zero feed rate causes concavity defect on the machined surface(9).

While the previous works(3-7) were mainly devoted to study the effect of various parameters controlling ECB process, the need was felt to analyse the problems which restrict its wide applications for producing complex shape components.
The scope of the present paper comprises an analytical and experimental investigation for studying various probabilities to overcome such difficult situations.

ANALYSIS

There are certain area of potential improvement which may lead to more economic utilization of ECB, and improving the process accuracy.
Regarding deterioration in front and rear workpiece faces, dummy pieces can be used to avoid such stray attack. Such dummy pieces must take the same initial workpiece configuration and made from the same machined alloys for avoiding the change in potential for different materials. In spite of the high costs of such machined alloys, it is still the main way for avoiding such situation.
Regarding non uniform gap distribution along the whole circumference of the machined surface, it is possible to use a modified tool shape, for example, segmented tools, tools with slanting slots and tools with intermediate or open recesses. The proposed model is concerns with the use of segmented recessed and insulated tools as indicated in Fig. 4.

Proposed Model

During the course of the tests, the processed shapes vary with time and for each time interval the boundary condition varies. Thus, the processed profile always depends upon the new boundaries.

For the sake of modelling of the process, the tool is supposed to be consisting of taper elements entering the workpiece in sequence as indicated in Fig. 2. The electrolyte resistance in the interelectrode gap is given by

$$R_e = \int_{h_1}^{h_2} \frac{1}{2\pi k\, b \cos\alpha} \frac{dR}{R} = \frac{\ln h_2 / h_1}{2\pi\ k\ b\ \cos\ \alpha} \quad \ldots \quad \ldots \quad \ldots (1)$$

Current density at the workpiece surface is defined by

$$J = \frac{I}{2\pi\ R_2 b} = \frac{k(V-\Delta V)}{h_2\ \ln h_2/h_1} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots (2)$$

The rate of change of the workpiece radius w.r.t. time

$$\frac{dh_2}{dt} = \frac{\varepsilon J}{F\rho_m} = \frac{\varepsilon\ k(V-\Delta V)}{F\rho_m\ h_2\ \ln h_2/h_1} \quad \ldots \quad \ldots \quad \ldots \quad \ldots (3)$$

$$\frac{dh_2}{dt} = \frac{C}{h_2\ \ln h_2/h_1} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots (4)$$

Where,

$$C = \frac{\varepsilon\ k(V - \Delta V)}{F\ \rho_m}$$

By integrating equation (4) we get

$$Ct = [\frac{h_2^2}{2} \ln \frac{h_2}{h_1} - \frac{h_2^2}{4}] - [\frac{h_{2o}^2}{2} \ln \frac{h_{2o}^2}{h_1} - \frac{h_{2o}^2}{4}] \quad \ldots (5)$$

OR

$$4Ct\cos^2\alpha = [2R_2^2 \ln \frac{R_2}{R_1} \ln \frac{R_2}{R_1} - R_2^2] - [2R_{2o}^2 \ln \frac{R_{2o}}{R_1} - R_{2o}^2]$$

The workpiece radius is given by

$$R_2 = R_1 + \Delta R \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots (6)$$

Employing equations (5) and (6), we can get

$$4\ Ct\ \cos^2\alpha = [\frac{\Delta R^3}{R_1} + 2\Delta R^2] - [\frac{\Delta R_o^3}{R_1} + 2\Delta R_o^2] \quad \ldots \quad \ldots (7)$$

Furthermore, to study the effect of the main working parameters such as gap voltage and tool feed rate on surface integrity equation (7) can be developed to be

$$4 \frac{\varepsilon kb}{F\rho_m} \cos^2\alpha \frac{U}{FR} = [\frac{\Delta R^3}{R_1} + 2\Delta R^2] - [\frac{\Delta R_o^3}{R_1} + 2\Delta R_o^2] \quad \ldots \quad \ldots (8)$$

Thus, by using equations (1-8) difficulties regarding the variation of boundary conditions could be eliminated and effective power consumption, current density and anodic profile can be obtained.

EXPERIMENTAL PROGRAM

ECM tests were conducted on an ECM set-up shown in Fig. 3. A special pressurized test cell was constructed. Test cell was accompained with necessary accessories required for attaining high degree of accuracy and machining conditions. NaCl electrolyte solution was utilized. Test specimens were made of mild steel and provided with a predrilled hole of 13 mm. Three types of brass conical tools having cone angle of 45° and final diameter of 16 mm. were designed as indicated in Fig. 4. The first one was provided with equal insulated grooves. While the second was provided with equal spaced Vee grooves, the third one was used without any modifications. A special tool holder was designed through which coaxial alignment was realized. The coated material used was BONDO EPOX-STEEL from DYNATRON-BONDO CORP. U.S.A. Preliminary tests were tried in order to achieve feed rate higher than 4 mm/min. However, difficulties regarding the limited size of driving system available outlet pressure of centrifugal pump and power supply capacity.

RESULTS AND DISCUSSION

Fig. 5 shows the variation of power consumption with time for each proposed tool model, for different machining conditions. The curves also show that the power consumption increases as the time increase due to the tool advances throughout the workpiece. Experimental tests were conducted to compare anode profile and power consumption obtained by using proposed tooling system. A significant improvement in terms of the conformity of the machined surface profile was obtained when using segmented insulated tool as shown in Fig. 6.
An improvement in the dimensional accuracy of 21% and 13% were realized by using insulated and recessed tools respectively. Moreover, insulated tools reduced the power consumption by about 28.8% when compared with non modified tool (No. 1), in spite of increasing power consumption and improving accuracy at high feed rate as shown in Fig. 6.

Experimental results have revealed some problems related to both recessed and insulated tools.
Regarding the recessed tool, the main problem is the disturbance of the electrolyte mainstream over the cathode surface . As indicated in Fig.7. the flow over an irregular cathode could be quite different. Around the hills the flow streams adheres to metal surface and the metal dissolved smoothly. In the valleys the flow separates from the cathode surface causing a rotating eddies in the region between mainstream of electrolyte and cathode surface, leading to cavitation. Thus, a matt etched surface resulted.

Regarding segmented insulated tool, insulation breakdown is the main problem arising due to the simultaneous effect of heat and electrolyte pressure. Also failure of insulation can cause component scrape and serious tool damage. Thus, no analytical work was devoted to 2nd. proposed tool.

Fig.8 shows anodic profile and current density obtained theoretically. It is evident by comparison between Fig. 8.A and Fig. 8.B that significant improvement in both dimensional and power consumption can be obtained. Table 1. shows theoretical values of the improvements.

It should further be mentioned that by controlling the insulated and non insulated lengths, different values of process accuracy can be obtained. Theoretical radial gap calculated from equation (8) is plotted in Fig.9. Experimental results agree well with the theoretical curve.This is attributed to the fact that the proposed model takes into account the variation of boundary conditions during machining in the estimating processed profile. However, experimental results for power consumption deviate from the theoretical. Obviously ; theoretical calculations have not included the amount of stray machining as shown in Fig. 8,

Results of such study could be of a practical value for predicting, the processed profile when using a tool of specified geometry. Further, the proposed trends would serve as a guideline for estimating the modification which is to be made in the tool profile to produce a workpiece of specified geometrical shape.

CONCLUSIONS

The experimental work reported in this paper leads to the following conclusions.

1. Comparison between experimental and theoretical results proved the usefulness of the proposed model for predicting the processed profile and power consumtpion.

2. Segmental insulated tools were found to yield much less over cut and power consumption than other proposed tools. They improve accuracy and power consumption by about 21.66% and 28.8% respectively.

3. This tudy would serve as a guideline for estimating the modification to be made in the tool profile to produce a workpiece of uniform gap distribution.

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NOMENCLATURE

b	tool width (mm).
d	tool diameter (mm).
R_e	electolyte resistance (Ω).
ΔR	interelectrode gap (mm).
FR	feed rate (mm/min).
V	applied voltage (volt).
I	consumed current (A).
ΔV	overpotential (volt).
J	current density (A/mm^2).
K	electrolyte conductivity $(\Omega mm)^{-1}$.

SUBSCRIPTS

0	initial condition.
2	workpiece.
1	tool.

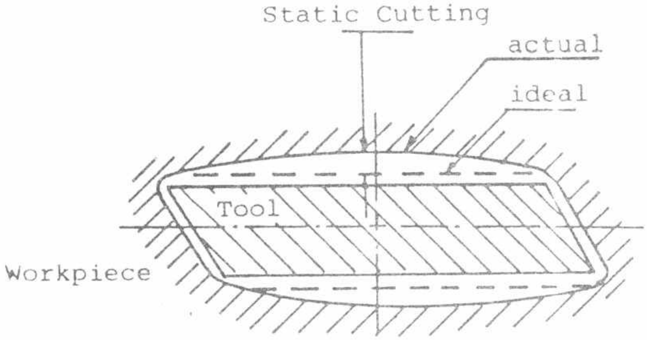
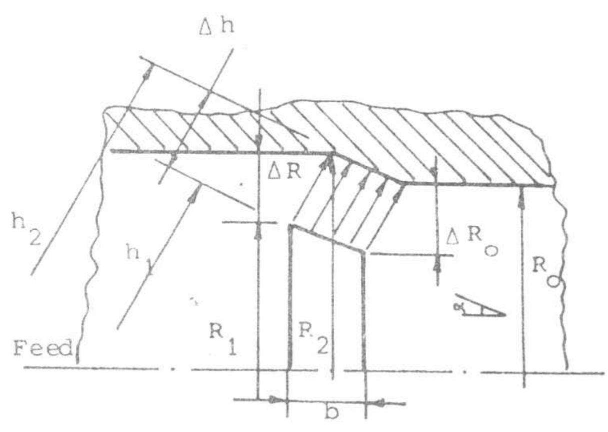


Fig. (1): Effect of Static Cutting on final Shape (4).

Fig. (2): Elemental tapered tool.



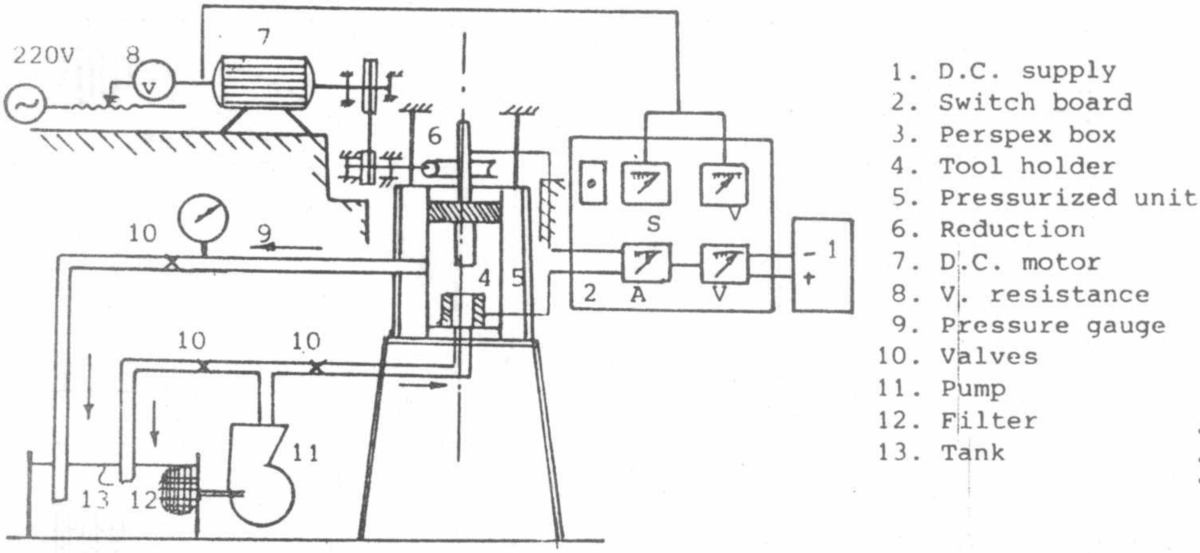
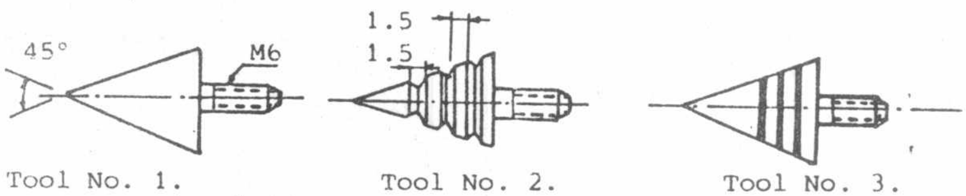


Fig. (3): Schematic layout of ECM set-up.



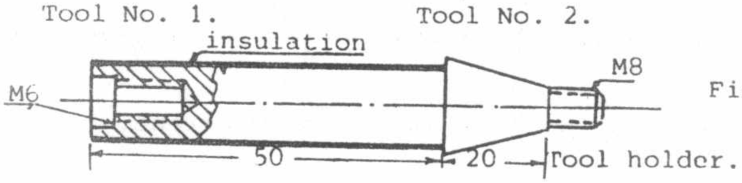


Fig (4): Tooling system and tool holder.

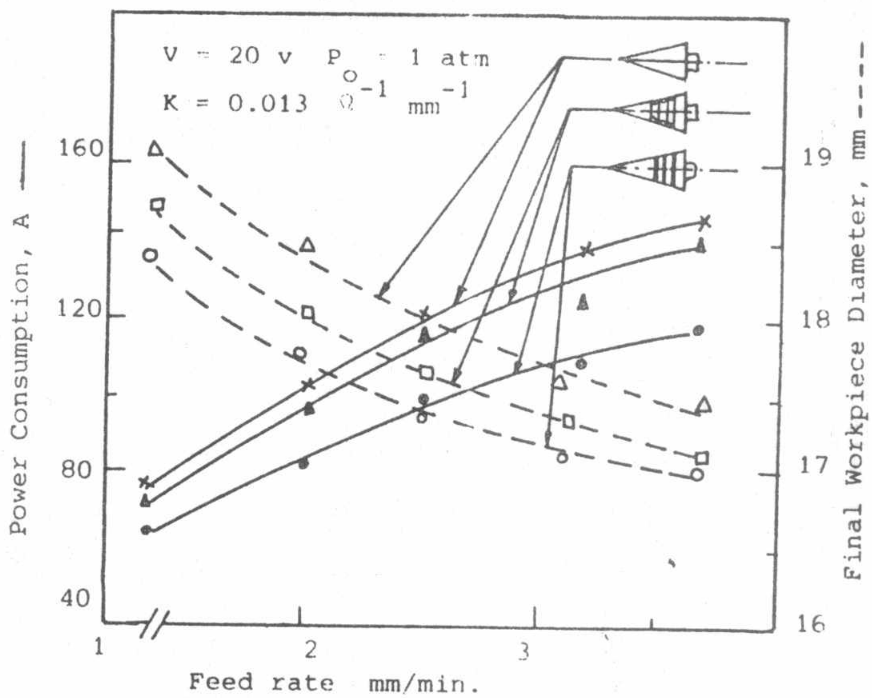


Fig. (6): Comparison between different tool shapes.

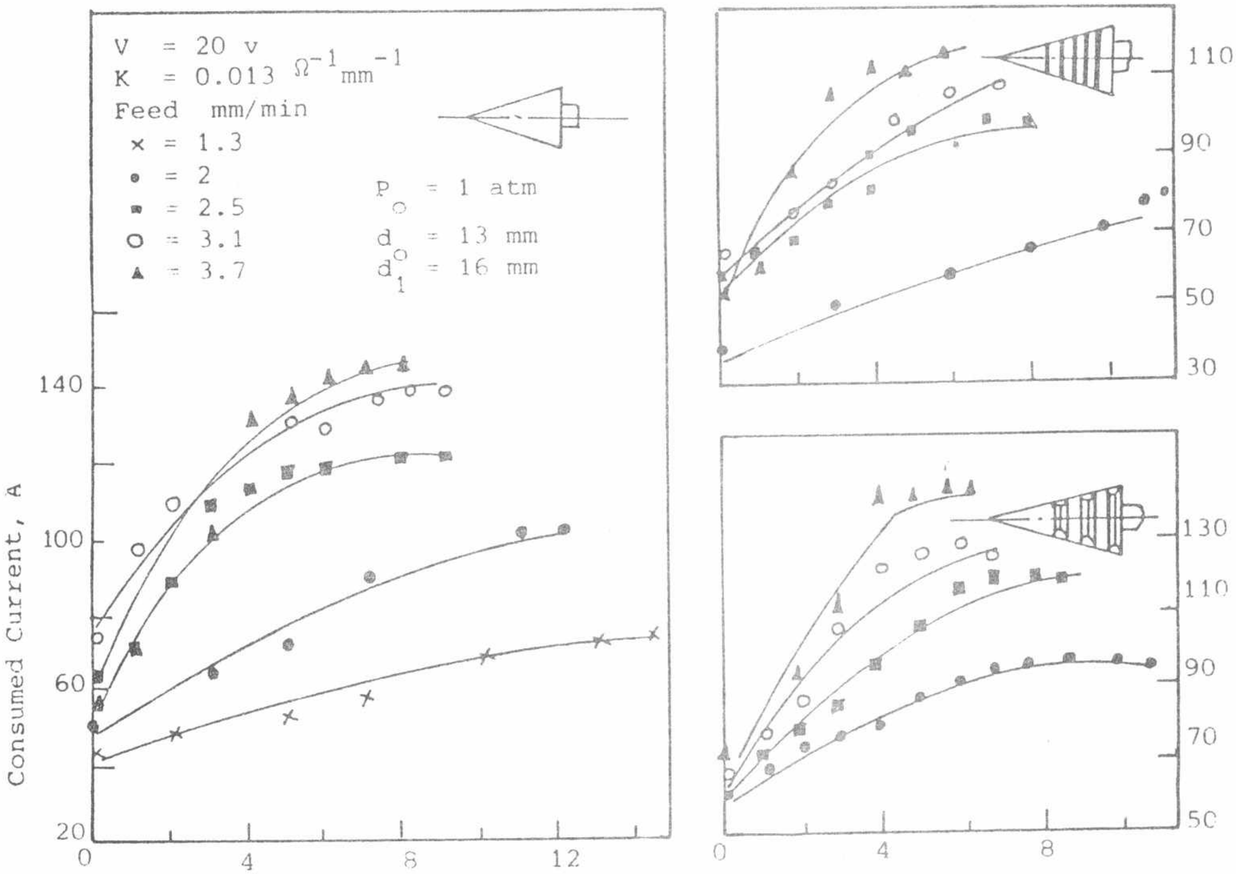


Fig. (5): Effect of machining time on consumed current.

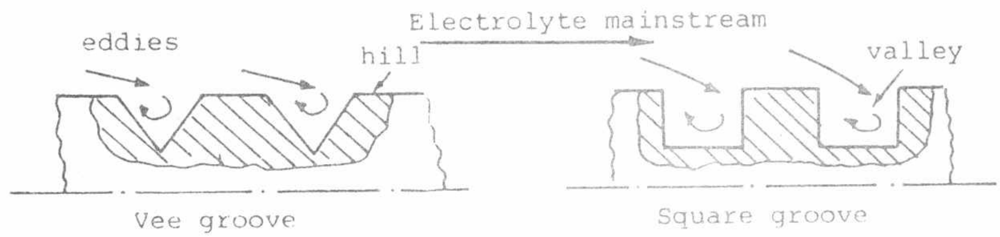


Fig. (7): Analysis of flow mainstream over recessed cathode.

U/FR V Min/mm	4.78	7.08	13.62
Modified tool (Insulated)	49.9	41.12	31.56
Tool without modification	54.14	46.55	35.74
Improving rate %	7.8	11.02	11.69

Effective current

4.78	7.08	13.62
17.1	17.42	18.3
18.2	18.6	19.4
5.5	6.34	5.67

Final workpiece diameter.

Table (1): Theoretical improvement ratio.

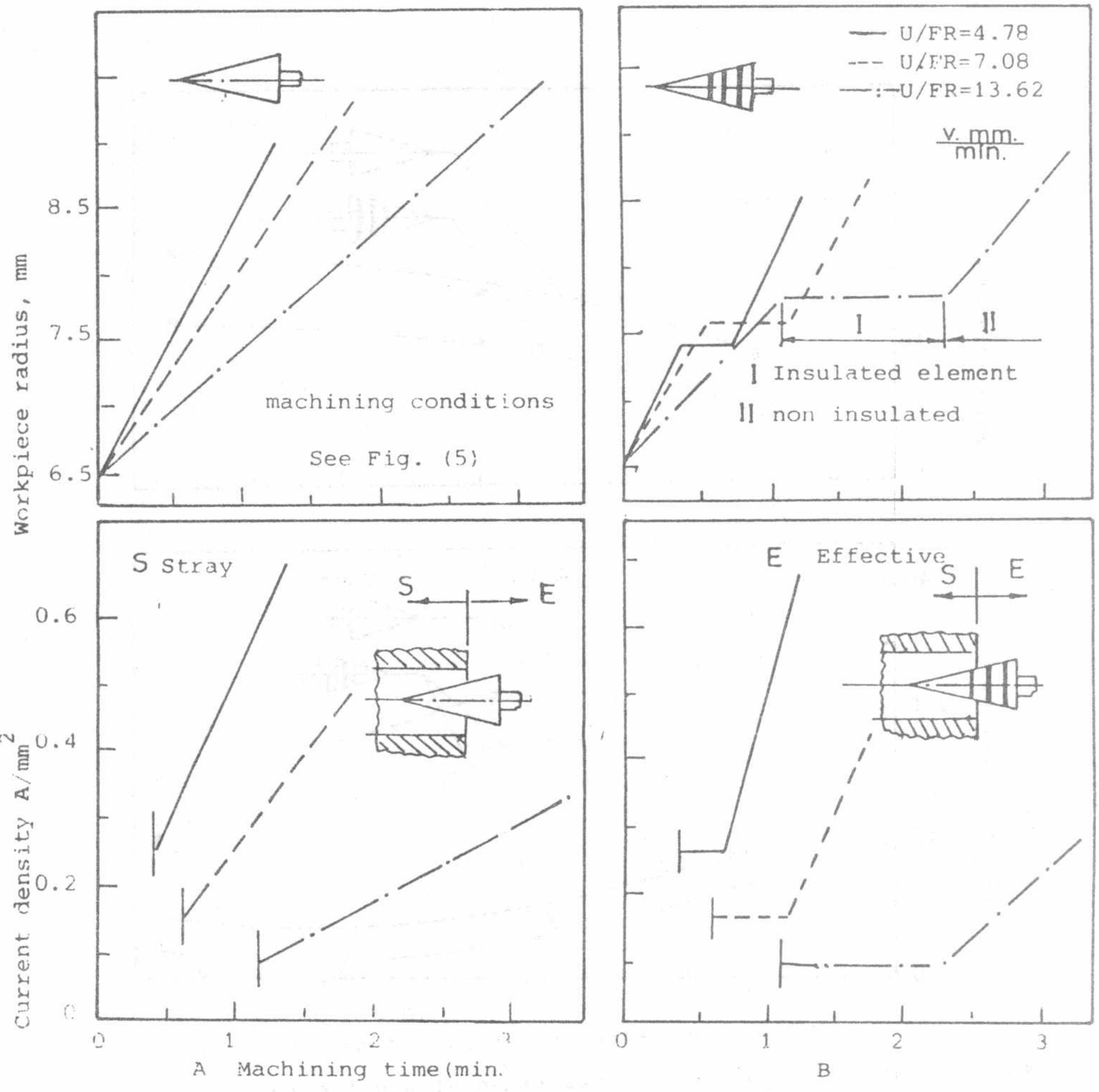


Fig. (8): Effect of machining time on process variables.

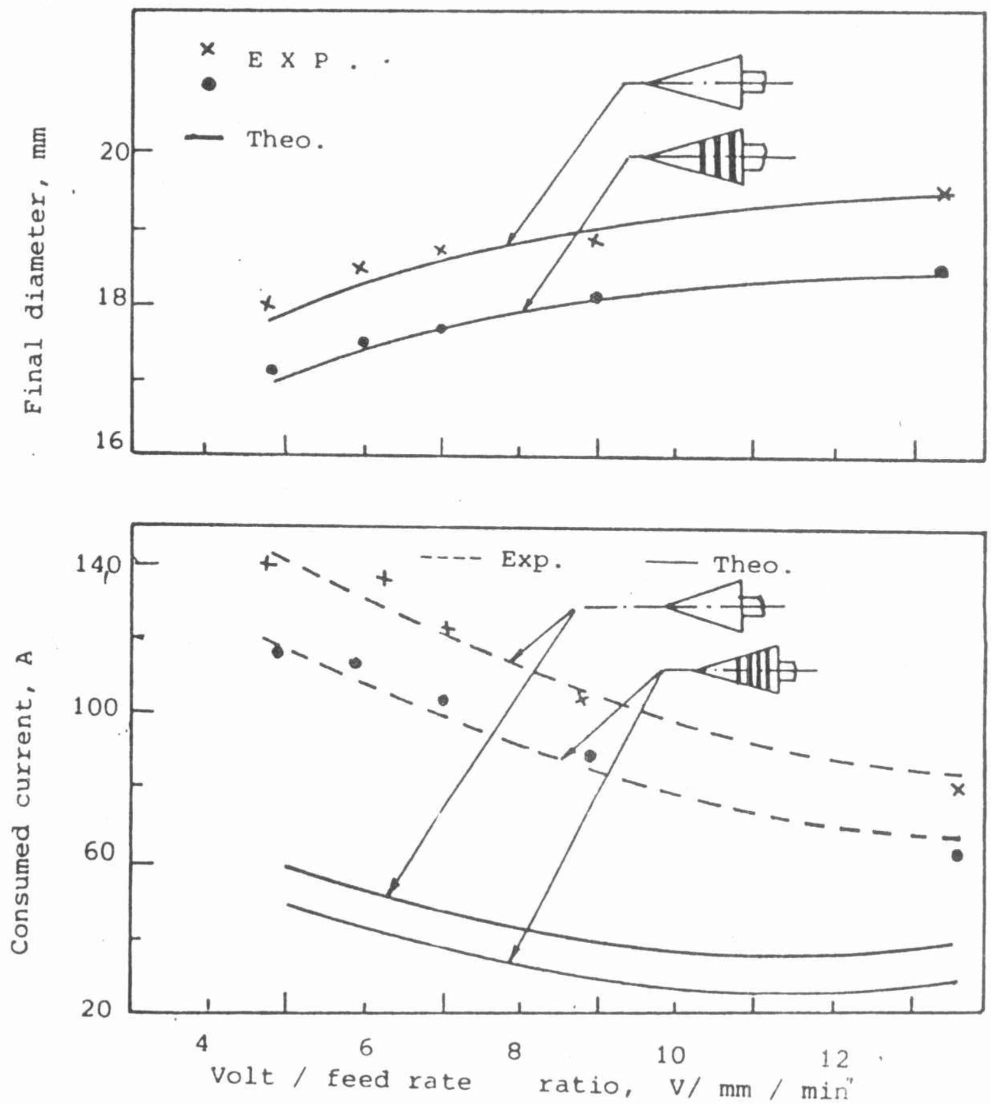


Fig. (9): Comparison between experimental and theoretical results.