SOME ECONOMICAL ASPECTS OF ECM PROCESSES

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ABSTRACT

The main drawback of the ECM process, despite its suitability in performing special types of workpieces, lies not only in the difficulty of knowing how to use it effectivly, but also how to justify its initial costs. Consequently, it is extremely important to carefully estimate the economic merit of the ECM process before utilizing it in manufacuring processes. In this work, an attempt is made to apply the electrochemical to certain applications that are considered to be impossible to be performed by conventional means, such as drilling of fine deep holes or cutting hard and / or brittle materials. An analysis of the factors affecting electrochemical machining costs is made. However, no generalization is possible since each application has to be considered on its own merits. Power consumption, machining time, electrolyte and labor costs are the main factors that have been taken as controlling factors.

Experimental results revealed that amperage values are extremely affected by any change in either tool geometry of volumetric metal removal rate. Minimizing the costs of tooling system is achieved successfuly in this work by using simple manufacturing tools. Furthermore, the results provide production engineers with realistic information to reach an economical power consumption and a minimum operation cost when using ECM processes.

INTRODUCTION

The main problem in introducing ECM in industry is believed to be the high purchase price of the machine. The economic success of introducing these type of machines depends dramatically on the nature of their application. For instance, the high capital cost of an ECM plant cannot be justified if the operation is a simple one, or if the material is easy to machine. The objective of this work is to set out the basic principles for selecting the suitable electrochemical machine that will be confined with the local production requirements for a company. Moreover, this work aims at providing production engineers with some necessary information about estimating power consumption, machining time, and babor cost. The proposed method is

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adapted to be applied in a special process; where using a tubular cathode in cutting of hard materials.

EC MACHINE

Electro-chemical machine is usually used in producing special products that have specific geomatries. Factors such as tool shape, feed direction and electrolyte circulation are the most common features that characterize the design of each machine. Furthermore, proper tooling and fixturing must be provided for each operation. The power supply for an EC machine is considered to be the most expensive single item of the installation and may be accounted for a substantial part of the total cost of the complete machine. Generally, the power of any EC machine is referring to the maximum output current produced from the power supply. A question is usually arises : what is the orthodox method for a production engineer to define the power and the specifications of the required machine that is needed to implement a limited process. The suitable selection of an EC machine gives the facility of avoiding some sophisticated or burden costs. The relationship between some of more important parameters involved in an EC machine power is proposed and shown in Fig. (1) . Since unnecessary higher power will increase the cost, it is important to keep in mind that the selected EC power should be within the required process [1].

PREVIOUS WORK

Kargin [2] used a tubular cathode with an external diameter of 5 mm and wall thickness in the range from (0.5 - 1) mm to cut hard and brittle materials (semi-finish machining). To supply the electrolyte into the inter-electrode gap, he provided the tubes with three longitudinal holes in their walls. Streeniya [3] has used the above technique successfully in cutting blocks of hard metal.

Mathematical models have been proposed by Ghabrial et al. [4] to find some important features when using cylindrical tools in electrochemical machining. The equilibrium gap, anode area, consumed current, current density, width of cut and volumetric metal removal rate can be given in following equations, respectively;

$$Y_e = \frac{(V - \Delta V) \cdot K \cdot \epsilon}{F \cdot FF \cdot \rho_m} \tag{1}$$

$$A_{an} = (4.04\ r + 2.56\ Y_e)\ L \tag{2}$$

$$I = K(V - \Delta V)\left(\frac{2.04\ r + 2.56\ Y_e}{1.13\ Y_e} + \frac{2\ r}{\sqrt{Y_e\ (3\ Y_e + 2\ r)}}\right) L \tag{3}$$

$$J = \frac{I}{A_{an}} \tag{4}$$

$$W = 2\sqrt{Y_e\ (3\ Y_e + d) + d} \tag{5}$$

$$VMRR = W \cdot L \cdot FF \tag{6}$$

EXPERIMENTAL WORK

In the experimental work, the above technique has been applied using both

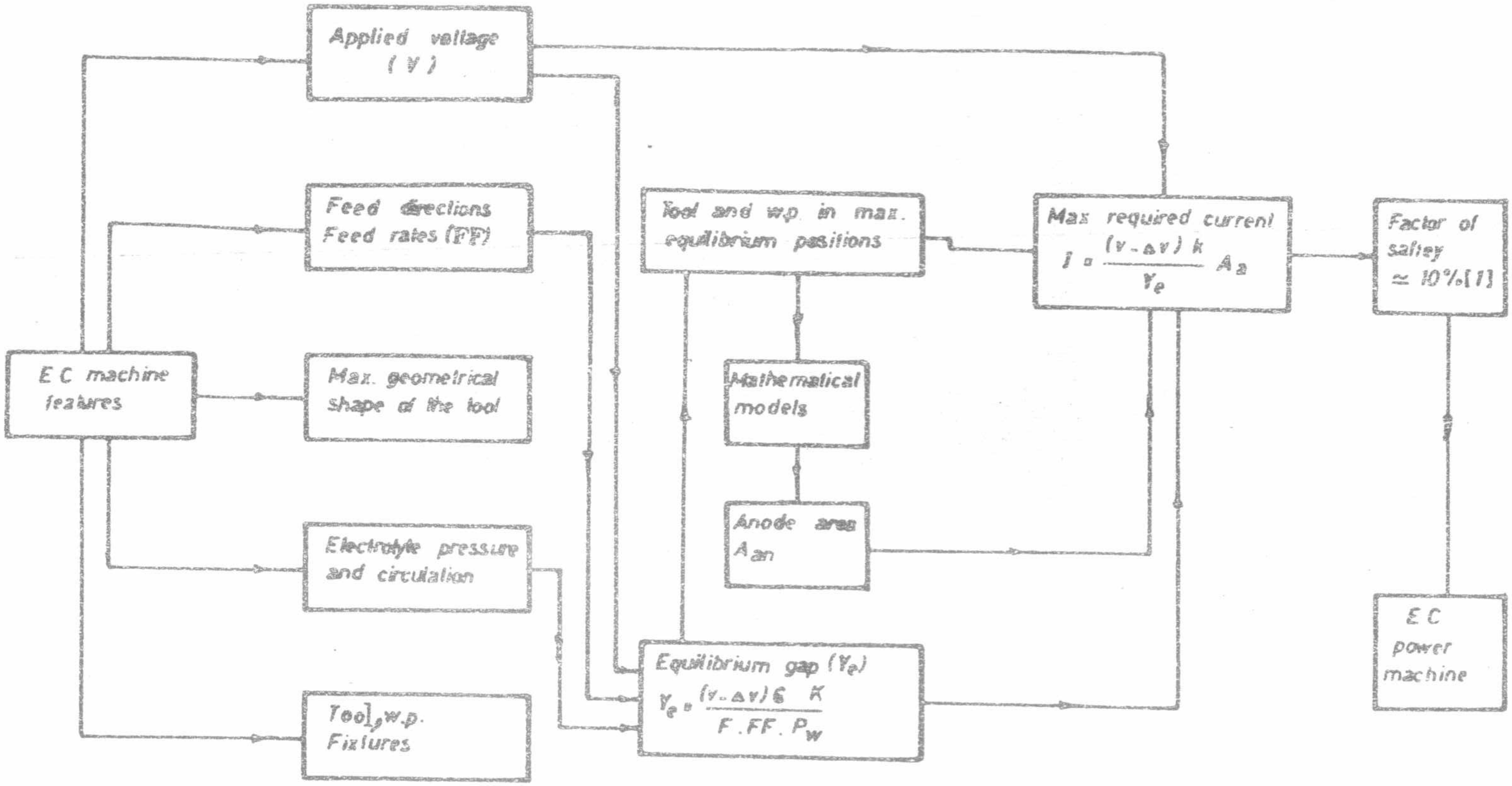

Fig.1 Proposed simplified scheme for estimating E C machine power

straight and curved tubes. A special test rig was designed, with the local limitations, to perform the process. A tubular cathode, made of copper, with an external diameter of 5 mm and having three longitudenal holes in its wall, for providing the electrolyte into the interelctrode gap, was used. The specimens made of St. 37 having dimensions of 25 x 20 x 10 mm were used. The expriments were conducted under the extreme cutting conditions. These conditions were achieved by employing feed rate in range from 3 to 4 mm/min, applied voltage 22 volt and Sodium Chloride having conductivity of $0.02\ \Omega^{-1}\ \text{mm}^{-1}$ as an electrolyte. Plate I shows a sample that has been cut by both straight and curved cathodes. Figures (2 and 3) show the cathode used in the investigations.

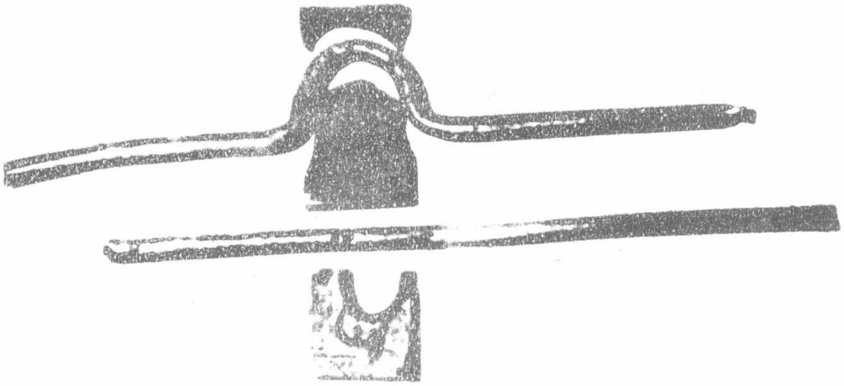

Plate I. Tubular cathode (straight and curved)

The experimental work has revealed excelent results which, in turn, implies the adequacy of its application widely in industry; where the problem is to select a suitable machine for producing a specific product and not vise versa. To find the maximum power of the required EC machine, for the practical products with actual dimensions in industry, the following parameters must be determined .

- maximum tube diameter,
- minimum equilibrium gab under different machining conditions (feed rate, applied voltage, and various electrolyte conductivity),
- anode area under the worst working conditions (maximum diameter and minimum equilibrium gap), and
- maximum required current for anodic dissolution.

To clarify the idea, an example may be presented. Assume a hundred of hardened steel blocks, each has dimensions of 250 x 100 x 100 mm, are needed to be cut along their length. By applying equations (1 through 6)

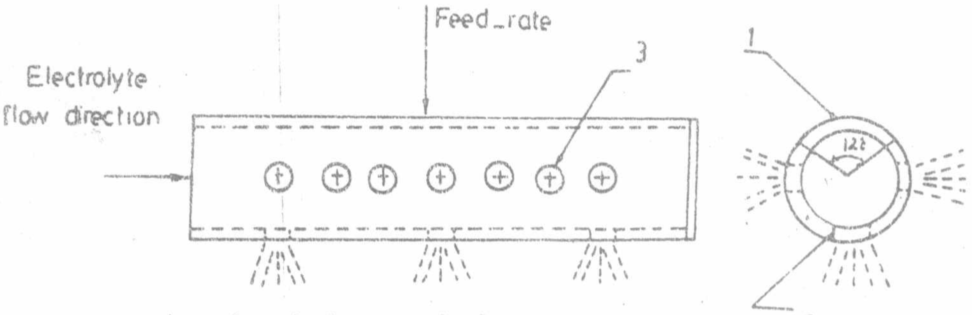

Fig. 2 Tubular cathode

1- insignificant cutting area (4) ,
2- Significant cutting area,
3- holes (for electrolyte supply).

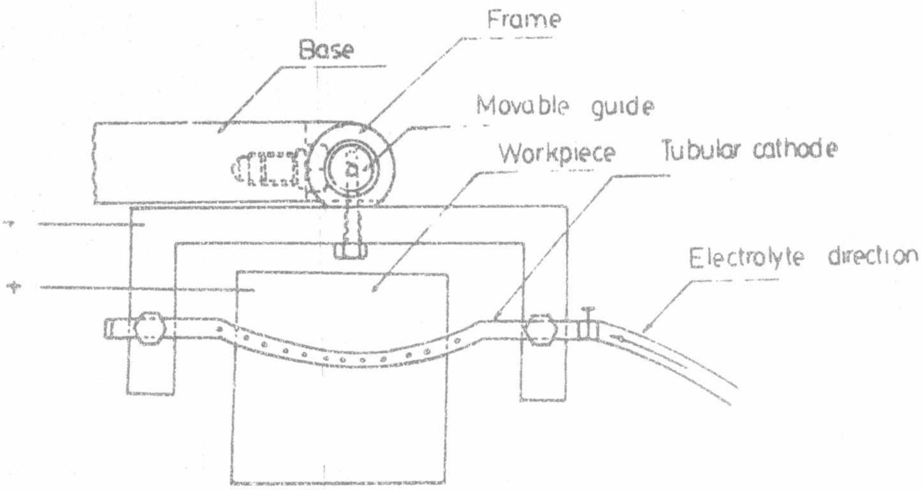

Fig. 3 Tubular cathode fixture and electrolyte supply system.

the following results were obtained : the equilibrium gap = 0.25 mm, anode area = 26.8 cm^2, consumed current = 4537 A, the current density = 168 A/cm^2, and metal removal rate = 7.4 cm^2/min. Consequently, a moderate machine (Vertical 5000 A, EC Machine) can be selected as a suitable one to perform this process. The estimated price of a such machine is in the range from 50 to 60 thousand dollars [5].

As a quick, rough estimation for any ECM process, it is generally necessary to provide the company with some industrial facts about this process. Current densities up to 230 A/cm^2 on the electrode surface is typical for the application of the process in industry [5]. In terms of metal removal, 1 cm^3/min can be removed by 600 A [5]. This convenient relationship is surprisingly accurate for most metals [5].

For the case under study, it is required about 4537 A to remove 7.4 cm^3/min. This value is approximately equal to the current that computed by the mathematical formulae. Actually, this method is valid, especially in case of the lack of the knowledgeable team in ECM.

TOOLING SYSTEM

There are two main problems in ECM; namely (i) the prediction of the resultant anode shape when the cathode shape is predicted and (ii) the design of the cathode shape to achieve a required anode shape. The second problem is by far the more difficult one and it can be regarded as the primary problem in ECM.

Many attempts [6 - 9] have been made to solve this problem by using numerical methods. Indeed, the lack of progress in solving this problem has meant that empirical methods are still widely used in practice [10]. Consequently, it is still necassary to make a considerable amount of adjustment of tool shape on an empirical (cut and try) basis. Actually, the cost can be quite high for the repetitive experiments that carried out to asses the relation between tool and workpiece to get the desired shape.

In the present work, the design of the tool and fixture was relatively low (about $ 200). This is due to the nature of the process as a semi-finish operation.

MACHINING TIME

The time required to produce a component using ECM is the sum of many items such as setting time, cutting time, inspection time for the first component (to check the tooling alignment), and maintenance time. Generally, cleaning and maintenance of ECM tooling and facility comprises about 15 percent of the available machining time [5]. The following equation can be used to estimate the time required to produce a component by using an ECM process;

$$T_{total} = (T_{position} + T_{cutting} + T_{stability} + T_{fixing\ \&\ dismount}) + \frac{1}{N}(T_{setting} + T_{w.p.washing} + T_{tool\ maintenance} + T_{inspection} + T_{machine\ washing})$$

For the present case, the total time was found from the above equation as:

$$T_t = (4 + 25 + 2 + 2) + \frac{1}{100}(15 + 1 + 20 + 30 + 20) \simeq 34 \text{ min.}$$

It is clear that setting and maintenance time comprises about 36 percent of the machining time.

POWER CONSUMPTION

At first, the electrical power that used in an ECM operation seems immense. A large portion of the supplied power is consumed in the dissolution of the atoms from the workpiece. The cost of metal removal in ECM can be expressed as the cost of the electricity that operates the machine. Consequently, in order to calculate the consumed power, it is necessary to sum up the power values for overcoming anodic dissolution, pumping system, and feeding system [11] . The equation that can be used is ;

$$E = (IV) + (1.73\ IV \cos\phi) + (IV \cos\phi)\ t \quad \text{KWhr}$$

For this investigation, the consumed power was found as :

$$\begin{aligned} E &= \left(92.4 + 15 + 3\right) .\ 41 \\ &= 45.26 \quad \text{KWhr} \end{aligned}$$

LABOR COST

The labor cost will depend on whether an operator controls one or more machine. If the actual cutting tine is long, then the operator may have time to load and initiate the machining cycle on additional machines. Highly skilled and qualified staff are normally required to perform ECM processes, so, the labor wage can be quite high [1]. Furthermore, the working in EC machines is considered a strenuous work.

In the present study, and in case of using one machine of ECM, the number of components that can be produced during one shift is calculated as follows ;

$$\text{No. of components} = \frac{\text{time of shift}}{\text{machining time}}$$

The machining time for the case under study was found to be 34 min. Considering an 8 hour shift basis, thus, the EC machine can perform about 14 components/shift.

CONCLUSIONS

- Although the economy of ECM is having a complexity and interacting nature, a simple analytical approach proved to be adequate and trustworthy to predict the power of EC machine in an endeavour to select the optimum machine from economical point of view.
- Anode area, power consumption, current density, and metal removal under the extreme machining conditions are the most factors that characterize the power and the features of EC machines.
- Setting and maintemance time in ECM comprise about 36 percent of the machining time.
- Power consumed in anodic dissolution is considered the vital portion of the total power consumption in ECM.

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NOMENCLATURE

A_{an}	Anode area	mm^2
d	Tubular cathode diameter	mm
FF	Frontal feed-rate	mm/min
F	Faraday's constant	A.min/gm
I	Electrolysing current	A
J	Current density on anode surface	A/mm^2
K	Electrolyte conductivity	1/ohm
L	Workpiece length	mm
r	Radius of tubular cathode	mm
T	Total machining time	min
t	Cutting time	min
V	Applied voltage	volt
ΔV	Over potential	volt
w	Width of cut	mm
Y_e	Equilibrium gap	mm
ϵ	Electrochemical equivalent of work material	
ρ_m	Density of workpiece material	gm/cm^3