Design and Modelling of ECM Rifling Tool

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Abstract: - Electrochemical machining is one of the most effective methods in machining of hard and complex shapes. As a result, it is a very good candidate for inside rifle machining. In this paper the principles and mathematical modelling, the results of computer simulation and experimental investigations of electrochemical rifling tool are presented. From this point of view, a rifling tool in electrochemical machining is modelled by finite element method. Then the tool based on this model is manufactured and tested. The basic non-linear differential equations are solved by Runch Kutta method. Some experimental tests are carried out and theoretical and experimental results are compared. The comparison between simulation modelling and experimental results shows a good agreement.

Key-Words: - Electrochemical Machining, Simulation, Machining Gap, Rifle

1 Introduction

Electrochemical machining (ECM) is one of the well-established non-traditional manufacturing processes nowadays. It is a good and effective method in machining of complex shapes [1]. ECM is based one shaping by controlled anodic dissolution with high current density. The process is carried out by passing an electric current through an electrolyte flowing within the inter electrode gap between the tool (cathode) and workpiece (anode)(Fig.1)[2].

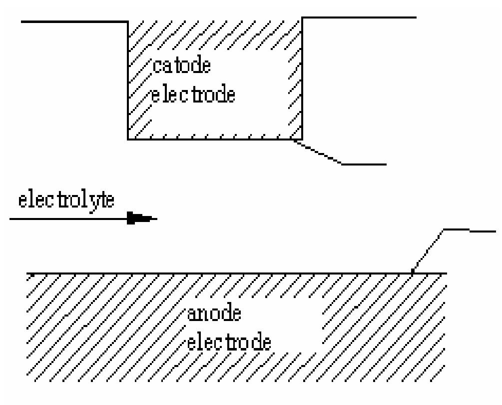


Fig. 1: Machining gap and its boundary condition

Since the machining is achieved by electrochemical reaction, hard and difficult-to-cut materials can be machined, and there is no residual stress in the workpiece.
The advantages of such machining method are that there is no wear on the tool electrode, therefore, the cost and time for tool replacement is saved [3]. In ECM process, a low voltage (8-30V) is normally applied between electrodes with a small gap size (usually 0.2-0.8 mm) producing high current density of the order of 10-400 A/cm^2 and a metal removal rate ranging from 0.1-10 $mm/\min$. Electrolyte (typically NaCl or $NaNo_3$ aqueous solutions) is supplied to flow through the gap with a velocity of 10-50 m/s to maintain the electrochemical dissolution with high rate and to flush away the reaction products (usually gases and hydroxide) and heat generated caused by the passage of current and electrochemical reaction [4].
Various variants of ECM like: electrochemical sinking, ECM with numerically controlled tool-electrode movement, ECM with orbiting tool-electrode, pulse ECM, electrochemical smoothing, electrochemical deburring are used in industrial practice. Another new electrochemical machining variant has been developed recently .In this variant, a universal tool electrode of simple shape moves along the workpiece surface and the final required shape is obtained by controlled envelope motion [5].
The use of ECM for production of dies, parts of turbine and high compression engines, medical implants, parts for electronic and military industries, etc. is well justified. Two major difficulties that are encountered during ECM process preparation involve tool-electrode design and the selection of input machining parameters [6].

2 Tool Design

ECM, as a non-mechanical machining method can successfully machine any conductive materials with high machining rate apart from its mechanical properties as hardness and brittleness. In this machining method, the optimization of output parameters and convenient selection of setup parameters in one hand, and designing with sufficient isolation of tool electrode on the other hand are of special importance [7]. On the way of tool designing and afterwards controlling dimensional accuracy of workpiece, decreasing in machining cost and also flexibility limitation of production systems are serious problems [8]. Therefore, first of all it is needed to design a suitable tool. In ECM, tool designing is based on cosine principles, so that the symmetrical form of machining shape is produced on tool surfaces and the machining will be done with this tool .In this research, the tool has corresponding rotational and linear motions based on the pitch of its helical slots that will be produced on the workpiece. There are numbers of helical slots on the cylindrical circumference of tool, so that, machining is done by the distance between these slots. To prevent machining operation from undesirable spots, the inner surfaces of these helical slots are isolated. The profile surface between these slots as the main machining surface depends on the number of inners slots.

It is necessary to mention that the tool and workpiece have not relatively any lateral movement but the machining is done by rotational and linear motion of tool into the workpiece. The tool with the main mentioned structure and a tail for injection electrolyte is manufactured (see Fig.2).

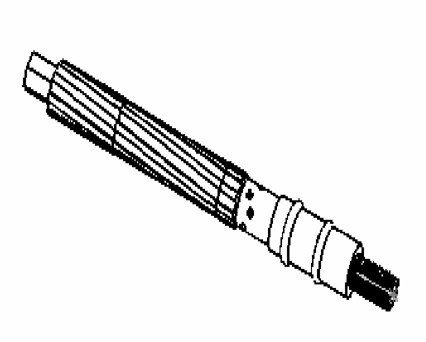


Fig. 2: Tool Electrode modelled

3 Modeling of Machining Process

There are a lot of parameters engaged in this machining method. Due to the small width and surfaces of machining tool which are separated by isolated materials from each others and the machining depth which is also small, the effects of hydrodynamic parameters, electrolyte temperature and gaseous products can be neglected. Voltage is one of the most important parameter that varies in all over the machining gap and its variation can be determined from following equation:

$$\nabla^2 u = 0 \quad \Rightarrow \quad div(gradu) = 0 \qquad (1)$$

This equation can be solved by using boundary conditions. These conditions are:

On cathode (tool): $u = U - E$, where U is the external voltage between electrodes (setup voltage) and $E = E_a - E_c$ in which E_a and E_c are electro negativity of anode and cathode respectively.

On anode: $U_{(t)} = 0$

The current density on the anode (workpiece) can be calculated after the determination of voltage calculation. The differential Ohm's law describes the current density:

$$j_A = -K_0 \left| gradu \right| A \qquad (2)$$

Where K_0 is the electrical conductivity coefficient of electrolyte.

The solution of this equation with transient boundary conditions in motion that is due to the tool positioning with respect to workpiece is complex, therefore, by making simplicity the current is considered to be linear across the gap [9]. Suppose the length of the normal gap is d, then, the current density on anode will be as follows:

$$j_A = \frac{U - E}{d} \qquad (3)$$

For simulation of the process, the machining path and also the type of co-ordinate system should be initially determined. Since the electrodes are cylindrical shapes, the cylindrical co-ordinate seems to be convenient. The normal gap can be defined as:

$$d = R - R_S \qquad (4)$$

Where R_s is the radius of tool electrode and R is the radius of a point on inner surface of the workpiece, which varies with time. The variation of R is as the following non-linear differential equation:

$$\frac{dR}{dt} = K_0 K_V \frac{U - E}{R - R_0} \left| gradR \right| \qquad (5)$$

In this equation, R_0 is the inner radius of rifle at t=0 which is constant for every point on the surface. The capability-machining coefficient K_v as workpiece characteristic is determined by weight percent and charge capacity of various elements in rifle's alloy. The initial condition for this equation is:

$$R = R_0 \; ; \; at \;\; t = 0 \qquad (6)$$

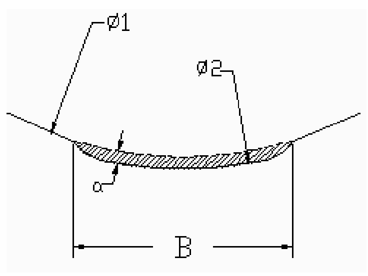
Due to the relative motion of electrodes, the equation has time dependent boundary conditions, which are determined regarding to the nature of process. These conditions are as follows:

$$Z_1 = \frac{\left| V_p.t - L \right| - \left| L - V_p.t \right|}{2} \qquad (7)$$

$$Z_2 = \frac{V_p.t + L - \left|V_p.t - L\right|}{2} \tag{8}$$

$$\theta_1 = \frac{W}{V_p}.Z - B \quad , \quad \theta_2 = \frac{W}{V_p}.Z + B \tag{9}$$

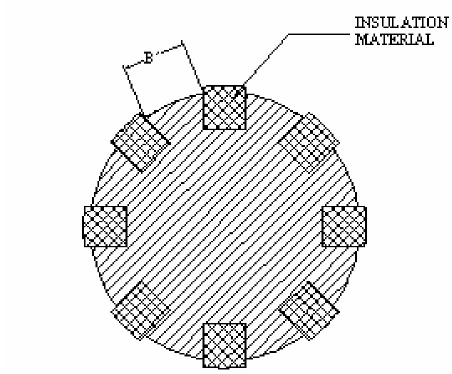
Where:
L: Tool's length
V_p: linear speed of tool
W: rotational speed of tool
B: rifle's width (see Fig.3).



ϕ_1 : Inner diameter of gun pipe
ϕ_2 : Bottom diameter of rifle
B: rifle's width

Fig. 3 - The section of a rifling tool

It is necessary to mention that to solve these equations, the time is divided into domains, so that, the solving results in each domain are added to the amounts of previous domains. As the relevant situation of electrodes changes, therefore in each time domain according to tool's linear and rotational motion, only a portion of the workpiece surface is machined (Fig.4).



B: Machining width on the surface of tool

Fig.4 - The section of a linear slot of pipe gun

In above equations according to the time domain ($t = t_1, t_2, ...t_n$) a number of points are under consideration and the remained points are to be constant.

4 MathematicalModelling Simulation

Mathematical modelling can be simulated by various methods as: FDM, FEM, BEM and so on. Finite difference method (FDM) is used in this research, since the method is usually used in non-linear differential equations form. The results are according to conditions of Table 1. Figure 5 shows the schematic simulated model of rifle.

Table 1: Some setup parameters in machining process

Material	Description
Tool electrode	Cooper, 12.4 mm Dia, linear speed = 5mm/s,helical slot pitch = 38.1mm
Workpiece	Inner diameter = 12.9 mm,Hot working stainless still alloy, K_v = 0.0237 mm^3/A.S
Electrolyte	NaCl, Flow Rate=120 g/lit , K_0 = 0.0181 $(\Omega \cdot mm)^{-1}$
Gap Voltage	16V

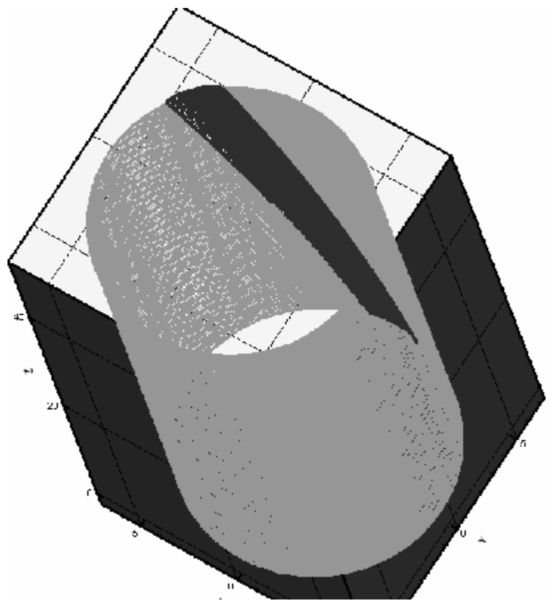


Fig.5: Schematic of simulated helically gun pipe's rifle slot

5 Testing Procedures

A number of tests have been carried out to analyze the computer simulation results. It is noticeable that the whole characteristics and properties of the tool electrode, workpiece material and electrolyte are the same as mentioned in simulation section. The tool electrode is produced by machining and isolated by Acrylic material with screw and pressing connection. The pressure of electrolyte is 24 bars with 30mm/sec input velocity. The results of these tests are shown in Tables2, 3. It is noteworthy that in experimental tests, the velocity of tool electrode (Table 1) and the voltage (Table2) are considered to be constant and equal to 5mm/sec and 10V respectively.

Table2: Experimental and simulated results of machining dept with tool's linear speed

Tool's Speed (mm/s)	2.3	3.05	3.633	4.366	4.966
Machining Dept (mm), Simulated	0.292	0.235	0.206	0.178	0.16
Machining Dept (mm), Experimental	0.3	0.245	0.23	0.195	0.175

Table 3: Experimental and simulated results of machining dept with gap voltage

Voltage (V)	8.5	9.25	10	11.5	14
Machining Dept (mm), Simulated	0.142	0.151	0.16	0.178	0.207
Machining Dept (mm), Experimental	0.13	0.17	0.175	0.18	0.209

6 Discussion

Rifle's tool electrode is modelled, simulated and manufactured. Some tests are carried out to show the effect of some parameters as voltage, tool electrode's linear motion and its effective length on machining dept.

The machining dept increases with gap voltage. Because, due to increasing in voltage, the current density increases and afterwards the machining dept and its rate will be increased (Fig.6).

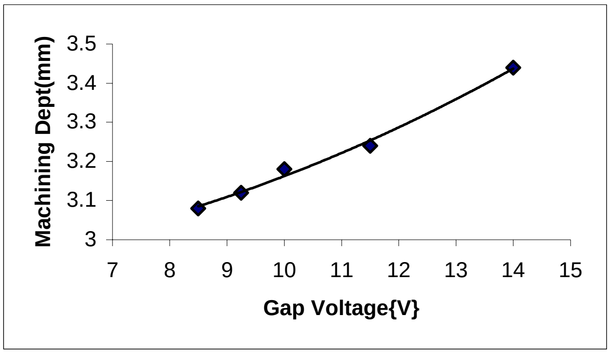


Fig.6: Variations of machining dept with gap voltage

Regarding to the Fig. 7, the machining dept decreases with linear motion of tool electrode, since the machining time decreases with this motion and as a result, the machining dept will be decreased.

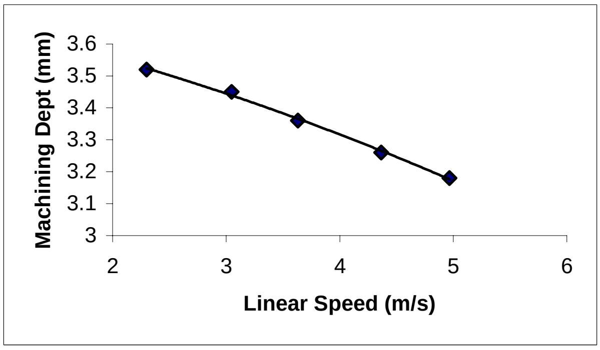


Fig.7: Variations of machining dept with tool's linear speed

The machining dept is also increased with the effective length of tool electrode.

Because with increasing in tool effective length, the machining surface of the workpiece in each time domain will be increased and afterwards; the machining dept will also increased. The difference between experimental and simulated values of process, which varies from 0.002 to 0.025 mm of machining dept, is very small and neglectable (Fig.8 and Tables2, 3).

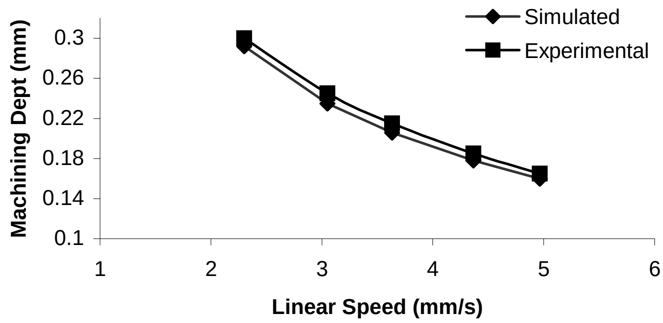


Fig. 8: Simulated and experimental results of machining dept variations with tool's speed

These variations do not obey a special trend, so that, they do not show a special change with increasing in voltage or velocity of tool electrode. The error resulted from simulated procedure is less than 15% in comparison with experimental results. This is mainly due to the poor capability of instruments in measuring of spherical slots.

7 Results

In this research a special ECM electrode is simulated by finite element method and a sample one of this tool electrode has been manufactured and tested. The comparison between simulated and experimental results shows a good agreement. This means that with determination of effective machining parameters, it is easily possible to simulate this machining process and determine various machining parameters like voltage, machining rate, electrolyte pressure and so on. Therefore, this simulation method can easily be replaced instead of high cost try and error method.

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