

Conceptual Study of Parameter Optimization in Machining Process

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Abstract:

Optimization of parameters is important in every machining process because the response or result is affected by each parameter. The parameter which has highest impact if optimized and controlled tightly then the response of the process is not deviated to the large extent. For optimization purpose Electrochemical Machining process is considered. Electrochemical Machining Process (ECM) is non- conventional, non-mechanical machining process in which material removal from the workpiece is done by means of Principle of Electrolysis. As in electrolysis in electrochemical machining two electrodes are used of which one is positive (Anode) and other is negative (Cathode). The material removal rate in electrochemical machining is determined by Faraday's Laws of Electrolysis and is affected by number of the parameters controllable and non-controllable. Each and every parameter is having its own effect on material removal process. Among all the parameters any one is having highest impact on the response or material removal rate and other is having less impact than the first and so on. In this paper conceptual study has been done for optimization of parameters by Taguchi Methodology in case of Electrochemical machining process to get high material removal rate or good response.

Keywords: Optimization, Electrochemical machining process, material removal rate, Taguchi method,

Introduction:

Optimization of parameters is important in every machining process because the response or result is affected by each parameter. The parameter which has highest impact if optimized and controlled tightly then the response of the process is not deviated to the large extent. Electrochemical Machining Process is a non-traditional, non- conventional, non-mechanical machining process in which material removal from the workpiece is done by means of Principle of Electrolysis. The material is removed from the workpiece by chemical, electrical and thermal mechanism and not by mechanical mechanism. Principle of electrolysis is shown in figure 1. In electrochemical machining process the voltage is supplied through positive and negative poles. The positive pole is connected to the workpiece (Anode) and negative pole is connected to the tool (Cathode). When current is supplied in between the electrodes due to gap between the tool and workpiece current is not flowing from tool to workpiece.

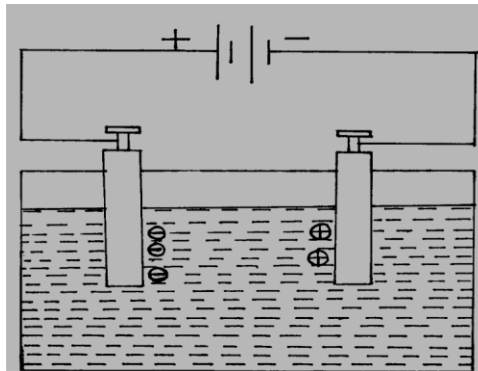


Figure 1. Electrolysis

For completion of the circuit electrolyte which is normally aqueous salt solution flowed through the gap (Inter electrode Gap). Principle of electrochemical machining process is shown in figure 2. Electrochemical machining process is used for machining complicated shapes or contours and hard materials which are difficult to machine by mechanical machining methods. The material removal rate (MRR) is affected by various parameters which are controllable as well as non-controllable. The MRR is computed theoretically by Faraday's laws.

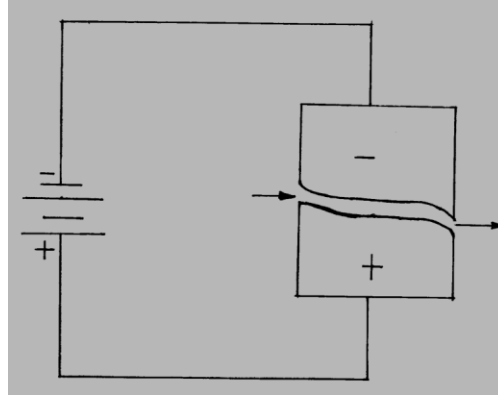


Figure 2. Principle of Electrochemical Machining

Material Removal Rate:

Faraday's laws state that: 1] The amount of chemical change produced by an electric current i.e. the amount of any material dissolved or deposited is proportional to the quantity of electricity passed. 2] The amount of different substances dissolved or deposited by the same quantity of electricity are proportional to their chemical equivalent weights.

From faradays two laws,

$$\text{Material Removed/Dissolved (M)} \propto I \times t \times \epsilon \quad \text{----- (1)}$$

Where,

M – Mass of material dissolved, I – current, T – Time, ϵ - gram equivalent weight

$$M = \frac{I \times t \times A}{F} \quad \text{----- (2)}$$

Where, F – Faraday's constant.

The gram equivalent weight of the metal is given by $\epsilon = A/Z$ where A is atomic weight and Z is the valancy of the ions produced.

Therefore

$$M = \frac{I \times t \times A}{ZF} \quad \text{----- (3)}$$

Equation (3) contains constant and variable parameters in this current/voltage and valancy are variable and remaining all parameters are constant for single element. For calculating material removal rate for workpiece containing number of elements equation (4) is used.

$$MRR = \frac{I}{F \rho \sum_{i=1}^n \frac{X_i Z_i}{A_i}} \text{----- (4)}$$

Where,

I = current

F = faraday's constant (26.8 A) hr

ρ = density of material (Hastelloy C – 276)

= 8.89 g/cm³

A = atomic weight of element

Z = valancy of element

X = percentage composition of element

The material removal rate is calculated theoretically at different voltage/current and valancies from equation (4) for machining Hastelloy C-276, Ni-base Superalloy and is given in table 1.

Table 1. Material Removal Rate

Voltage	MRR	Valancy	MRR	Percentage	MRR
12	1.4519 x 10 ⁻⁶	Maximum	1.4519 x 10 ⁻⁶	Maximum	1.4519 x 10 ⁻⁶
14	1.6938 x 10 ⁻⁶	Intermediate	1.8225 x 10 ⁻⁶	Intermediate	1.6717 x 10 ⁻⁶
16	1.9359 x 10⁻⁶	Minimum	2.3490 x 10⁻⁶	Minimum	2.0219 x 10⁻⁶

From table1 it is concluded that: 1) as voltage increases material removal rate increases, 2) as valancy increases MRR decreases, 3) as percentage increases MRR decreases. The highest material removal rate is highlighted in table 1. From table it is not clear that by which parameter the MRR is affected more. While calculating material removal rate only one variable or parameter is changed maintaining all other parameters constant. In practice it is not possible to control number of variable parameters. When voltage is kept constant the material removal rate is changing due to change in valancy. In every material the percentage composition is given in the range and not fixed. Hence effect of percentage on MRR is considered as minimum, intermediate (any value in the given range) and maximum. The valancy of the atom is changing as temperature changes and each atom has multiple valancies. Hence the MRR is not correct or there is error in results to large or small extent. To minimize error optimization of parameters or proper combination of parameter values is important. Here the workpiece taken for calculation purpose is Hastelloy C-276. The percentage and valancy of each element is given in table 2.

Table 2. Chemical composition, Percentage and Valancy of each element of Hastelloy C-276

Sr. No.	Name of Element	Percentage	Valancy
1	Nickel	57	2,3
2	Molybdenum	15-17	3,4,6
3	Chromium	14.5-16.5	2,3,6
4	Carbon	0.01	1,2,4
5	Manganese	1.0	2,3,4,6,7
6	Silicon	0.08	2,3,4
7	Iron	4-7	2,3,
8	Tungsten	3-4.5	6,8
9	Cobalt	2.5	2,3,
10	Vanadium	0.35	3,5
11	Phosphorous	0.025	3,4
12	Sulphur	0.01	2,4,6

From table 2 it is clear that each element of the workpiece is having multiple valancies and valancy changes as temperature changes. Hence optimization of parameters to reduce error/noise in the result is important in high cost machining processes. Optimization of parameters is done by means of Taguchi method and the parameter combination for higher material removal rate or result or response is determined.

Optimization Methodology:

Optimization of parameters is done by means of Taguchi method. The first step in this method is to select the number of variables or parameters and their levels or values. The methodology for optimization is given below:

1. Selection of number of parameters and their levels.
2. Selection of Orthogonal Array.
3. Selection of Criteria (Higher-The- Better, Lower-The-Better, Nominal-the-Best).
4. Determination of Signal to Noise ratio (S/N ratio).
5. Selection of Best Combination of Parameters for maximum Material Removal Rate.

1. Selection of number of parameters and their levels:

In electrochemical machining process the response or result is affected by number of parameters. The parameters may be variable (feed rate, flow rate, voltage current density etc.) or non variable (etc.). Optimization is done for variable as well as non variable parameters separately or combining both parameters. In actual practice effect of each parameter is difficult to determine. Each parameter is considered separately and experimentation is done by neglecting or avoiding or not taking into consideration effect of those parameters (e.g. if effect of voltage on MRR is taken into consideration, the effect of feed rate or any other component is not considered or that parameter is considered as constant). Therefore, Taguchi has designed Orthogonal Array combining number of parameters taking number of levels or values for obtaining better combination of parameters for obtaining highest MRR.

2. Selection of Orthogonal Array:

Orthogonal Array (OA) is determined by considering number of parameters and number of levels or values for which experiments to be run. In equation 4, three parameters i.e. voltage, percentage and valancy are variable and remaining i.e. Faraday constant, density and atomic weight etc. are constant. The values or levels of these variable parameters are given in table 3. Depending upon the parameters and their levels Orthogonal Array is selected. For optimization

purpose L9 Orthogonal Array is selected. The combination and values of parameters in this particular L9 orthogonal array are given in table 4.

Table 3. Parameters and coded levels

Voltage	Valancy	Percentage	Level
12	Maximum	Maximum	+1
14	Intermediate	Intermediate	0
16	Minimum	Minimum	-1

Table 4. Taguchi's Orthogonal Array

Sr. No.	Voltage	% Composition	Valancy
1	-1 [1]	-1 [1]	-1 [1]
2	-1 [1]	0 [2]	0 [2]
3	-1 [1]	1 [3]	1 [3]
4	0 [2]	-1 [1]	0 [2]
5	0 [2]	0 [2]	1 [3]
6	0 [2]	1 [3]	-1 [1]
7	1 [3]	-1 [1]	1 [3]
8	1 [3]	0 [2]	-1 [1]
9	1 [3]	1 [3]	0 [2]

Table 5. L9 Orthogonal Array with values

Sr. No.	Voltage (P1)	% Composition (P2)	Valancy (P3)
1	12	-1	-1
2	12	0	0
3	12	1	1
4	14	-1	0
5	14	0	1
6	14	1	-1
7	16	-1	1
8	16	0	-1
9	16	1	0

3. Selection of Criteria (Higher-The-Better, Lower-The-Better, Nominal-the-Best).

In case of the material removal rate the Higher-The-Better criteria is selected. For increasing productivity of the process the material removal will be more or high hence this criterion is selected.

4. Selection of S/N ratio:

S/N ratio for Higher-The-Better criterion is given as:

$$S/N = -10 \log \frac{1}{n} \left\{ \frac{1}{\sum_{i=1}^n Y_i^2} \right\} \text{-----} (5)$$

5. Selection of Best Combination of Parameters for maximum Material Removal Rate:

The calculated S/N ratios by means of equation (5) are given in Table 6. The S/N ratio having maximum value is taken as best combination of parameters for optimization. Thus the optimization of parameters is done.

Table 6. S/N ratio

Sr. No.	Voltage (P1)	% Composition (P2)	Valancy (P3)	S/N ratio
1	12	-1	-1	-109.5169
2	12	0	0	-110.4639
3	12	1	1	-110.7227
4	14	-1	0	-108.8932
5	14	0	1	-109.4588
6	14	1	-1	-108.4815
7	16	-1	1	-108.0488
8	16	0	-1	-107.3660
9	16	1	0	-107.9000

From these values the highest S/N ratio is taken as the best combination of parameters. Thus the parameters are optimized. Optimized condition of the parameters is 1) maximum voltage 2) intermediate percentage and 3) minimum valancy.

Conclusion:

In this case the best combination is high voltage at intermediate percentage and minimum valancy. This process is applicable for every machining process, to optimize parameters, in which number of parameters are variable and affect the response or create noise. Response/Result of each process is affected by number of parameters. The input parameters are termed as Signal and error in the response/result is termed as Noise. In this conceptual study for optimization of parameters is done and best combination of parameters is determined.

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