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# OPTIMIZATION OF MACHINING CONDITIONS IN ELECTRO JET DRILLING USING GENETIC ALGORITHM

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**Abstract:** *Producing accurate sub-millimetre size holes in parts for use in aerospace, electronic, computer and medical industries necessitate the use of non-conventional machining methods. The electro jet drilling (EJD) is one of the non-traditional hole drilling techniques which have the necessary potential to meet the stringent requirements of small hole drilling.*
*This paper presents an attempt at modelling the process through response surface methodology and genetic algorithm. Experiments have been conducted on SUPERNI 263 material. Applied voltage, electrolyte concentration and feed rate are selected as independent process variables. The responses have been modelled using a rotatable experimental design. Genetic algorithm has been used to optimize the process parameters subjected to a set of constraints on input variables, radial overcut and hole taper with the objective of maximizing the removal rate. Results of confirmation experiments indicate close agreement with simulated results.*

Keywords: *Electro jet drilling, genetic algorithm, response surface methodology. constrained optimization.*

**Nomenclature**

| | |
|---|---|
| V | Applied voltage [Volts] |
| C | Electrolyte concentration [ % by volume] |
| F | Feed rate [mm/min] |
| MRR | Material removal rate [mg/min] |
| $R_{oc}$ | Radial overcut [mm] |
| $(R_{oc})max$ | Maximum radial overcut [mm] |
| $T_a$ | Hole taper [degrees] |
| $(T_a)max$ | Maximum hole taper [degrees] |
| $d_{entry}$ | Hole entry diameter [mm] |
| $d_{exit}$ | Hole exit diameter [mm] |
| $d_{glassnozzle}$ | Outside diameter of glass nozzle [mm] |
| t | Workpiece thickness [mm] |
| $X_I$ | Process variables |
| $x_i^l$ | Lower bound on process variables $X_i$ |
| $x_i^u$ | Upper bound on process variables $X_i$ |
| $f(x)$ | Fitness function |
| $\phi(x)$ | Objective function |
| $N_{con}$ | Number of constraints |
| $P_i(x)$ | Penalty function |
| $g_i(x)$ | Constraint function |
| $R$ | Penalty coefficient |

## 1. INTRODUCTION

Recent progress made in the field of aviation (cooling holes in jet turbine blades), space, automobile, electronics and computer (printed circuit boards, inkjet printer head), medical (surgical implants), optics, miniature manufacturing and others has created a need for small and micro size holes with high aspect ratio in extremely hard and brittle materials (Kojak et al. 1996; Ahmed & Duffield, 1990; Bellows, 1988). Producing macro or micro holes of high aspect ratio in super alloys is beyond the capabilities of conventional machining processes. High tool wear and excessive heat generation have rendered the twist drilling unsuitable. The complexity of shapes and degree of precision required on the components used in these industries need such holes to be straight, accurate and exactly positioned and at a faster rate of machining. As the trend towards miniaturization continues, the nontraditional micro hole drilling techniques are receiving greater attention because of the specific advantages which can be exploited during the micro hole machining operations. For such cases non-conventional processes are preferred for economical hole making (Shan*). Electro jet drilling (EJD) is one such non-conventional process, which possesses all the requisite capabilities in meeting the modern day demands of drilling small and micro holes.

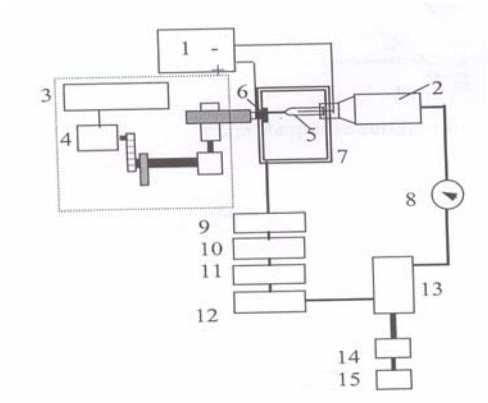
EJD is a non-conventional machining process in which a negatively charged stream of acid electrolyte is impinged on the workpiece to form a hole. The acid electrolyte (10-25% concentration) is passed under pressure (0.3-1.0 $N/mm^2$) through a finely drawn glass tube nozzle. The electrolyte jet gets charged when a platinum wire, inserted into the glass tube is connected to the negative terminal of DC power supply. The workpiece acts as anode. When a suitable electric potential is applied across the two electrodes, the material removal takes place through electrolytic dissolution as the charged electrolyte stream strikes the workpiece. The metal ions thus removed from the work surface are carried away with the flow of the electrolyte. A much longer and thinner electrolyte flow path requires much higher voltage (150-750V) so as to effect sufficient current flow (Shan*).

The available literature mainly deals with the qualitative description of the process and its applications (Kojak et al. 1996; Baker 1991; Ahmed & Duffield, 1990). The relationship among the process influencing parameters and their effect on the process performance are not completely known. No effort seems to have been made towards modeling and optimization of the process. Sustained research is required to transform the process into a robust process for its wide scale commercial use in industries.

In the present study a central composite design (CCD) and response surface method (RSM) have been used to analyse the effect of the three process parameters of EJD on the material removal rate, radial overcut and hole taper. The modeling phase was followed by maximization of MRR in the EJD process by genetic algorithm subject to a criteria set of constraints on radial overcut, hole taper and the input variables. For this purpose MATLAB release 12 was used.

## 2. EJD EXPERIMENTATION AND ANALYSIS

Fig.1 illustrates the schematic of EJD experimental set-up used for drilling small through holes in SUPERNI 263A sheets. Each work specimen of 25mm × 25mm × 2mm thickness was soldered on the face of an 8mm diameter stainless steel rod, which could be rigidly held in desired position. Through holes were drilled in all experiments and each experiment was repeated three times. The mean values of the three response measurements were used as output at each set of parameters. The experiments were conducted in random order so as to negate the effects of any setup conditions or environmental factors, which were not included in the experiments, and which may change with time and affect the responses (Sen & Shan 2003).




1: DC Power supply; 2: Nozzle manifold; 3: Microprocessor; 4: Stepper motor; 5: Glass tube nozzle; 6: Workpiece; 7:Perspex enclosure; 8: Pressure gauge; 9: Electrolyte tank; 10: Pump; 11: Filter; 12: Electrolyte tank; 13: Screw pump; 14: Speed variator; 15:Pump motor.

Fig.1 Schematic of experimental setup for electro jet drilling

For each particular run, the specified input parameters were set and through hole were machined. Completion of hole was marked by the exit of the jet through the workpiece. The time taken for machining a through hole was recorded by an electronic timer. An electronic balance (Metler, LC: 0.1mg) was used to weigh the workpiece before and after drilling. The rate of machining was determined using equation (1). The hole size measurements were taken using Toolmakers microscope. A total of three diameter measurements were made at hole orientations $60^0$ apart and averaged values were used in calculations. The radial overcut was determined using equation (2). Based on the entry side hole diameter and exit side hole diameter measurements, the hole taper was calculated using the equation (3).

$$\text{MRR} = \frac{\text{Initial weight} - \text{Final weight}}{\text{machining time}} \quad (1)$$

$$\text{overcut} = \frac{d_{\text{entry}} - d_{\text{glasstube·nozzle}}}{2} \quad (2)$$

$$\text{taper}(\theta) = \tan^{-1}\left[\left(\frac{d_{\text{entry}} - d_{\text{exit}}}{2t}\right)\right] \quad (3)$$

## 3. METHODOLOGY

Response surface methodology was used to obtain predictive expression for the response parameters. The model has been optimized using Genetic Algorithmic (GA) approach. The modeling of the EJD process can be regarded as a problem of correlating the input parameters of the process with its output parameters. In general the relationship between the response and the independent variables is unknown. For a system which exhibits non linear relation, a second order polynomial model is usually employed. In the present work, RSM has been applied for developing mathematical model in the form of multiple regression equations for the hole quality characteristics. In applying the RSM, the dependent variable is viewed as a surface to which a mathematical model is fitted (Montgomery 2001).

### 3.1 RSM FORMULATION

The following empirical model equations were derived using Design Expert (Version 6.0.8).

$$\text{MRR} = -0.42097 + 7.9167\times10^{-3}V + 5.017\times10^{-3}C + 0.6835F + 3.185\times10^{-3}C^2 - 2.462\times10^{-4}VC \quad (4)$$

$$R_{oc} = +0.0086 + 0.00021V + 0.0132C - 0.0956F + 0.111F^2 - 1.09\times10^{-5}VC \quad (5)$$

$$T_a = +5.536 + 0.01712V + 0.01793C - 2.382F + 2.367\times10^{-5}V^2 + 0.0148C^2 - 1.294\times10^{-3}VC \quad (6)$$

## 4. OPTIMIZATION USING GENETIC ALGORITHM

GAs are computerized search and optimization algorithms based on the mechanics of natural genetics and natural selection. Since their inception GAs have been subjects of growing interest as an optimization technique in nearly all kinds of engineering applications. GAs mimics the survival of the fittest principle of nature to make a search process. GAs use what is termed as a fitness function in order to select the fittest string that will be used to create new, and conceivably better, population of strings. GAs are different from traditional optimization in the following ways (Goldberg, 1989).

1. GAs work with a coding of the parameter set not the parameters themselves.
2. GAs search from a population of points and not a single point.
3. GAs use information of a fitness function, not derivatives or other auxiliary knowledge.
4. GAs use probabilistic transition rules, not deterministic rules.
5. GA solution in most likelihood is a global solution.

In order to use GAs to solve any problem, the variables $x_i$'s are first coded in binary strings having 1's and 0's which represent a possible solution to the given problem. GAs begin with a population of strings created at random. Fitness of each individual is evaluated with respect to the given objective function. The computations are carried out in three stages to get result in one generation or iteration. There are three basic operators found in every genetic algorithm: reproduction, crossover and mutation.

A simple genetic algorithm code was developed in the present study. The steps involved in the optimization using GA process are given (Deb, 1996) below:

Step1: Choose a coding to represent process parameters, a selection operator, a crossover operator, and a mutation operator. Choose population size *n*, crossover probability $p_c$, and mutation probability $p_m$. Initialize a random population of strings of size *l*. Choose a maximum allowable generation number $t_{max}$, and set $t=0$.
Step 2: Evaluate each string in the population.
Step 3: If $t > t_{max}$ or other termination criteria is satisfied, terminate.
Step 4: Perform reproduction on the population.
Step 5: Perform crossover on pairs of strings selected randomly.
Step 6: Perform mutation on strings with probability $p_m$.
Step 7: Evaluate strings in the new population. Set t = t + 1 and go to step 3.

The problem of optimization of EJD process can be described as maximizing MRR subject to a set of constraints on input variables, radial overcut and hole taper. In order to use GA the constrained optimization problem is stated as follows:

Maximize MRR

s.t.

$R_{oc} \le (R_{oc})max$
$T_a \le (T_a)max$

$$\text{and} \quad x_i^l \le x_i \le x_i^u \tag{7}$$

with consideration to the present experimental setup and the workpiece used, the limits on the input variables V, C, and F are as follows:

$$100 \le V \le 550$$
$$10 \le C \le 25$$
$$0.0 \le F \le 1.0 \tag{8}$$

The following parameters were specified to get optimal solutions with low computational effort:

- Number of generations : 100
- Population size : 100
- Crossover probability : 0.8
- Mutation probability : 0.01
- String length : 15

Since it is a constrained optimization problem, penalty terms corresponding to constrained violation are added to the objective function and fitness is obtained.

$$f(x) = \phi(x) + \sum_{i=1}^{N_{con}} P_i(x) \tag{9}$$

$P_i(x) = 0$ if $g_i(x) \le 0$
else

$$P_i(x) = R\langle g_i(x)\rangle^2 \tag{10}$$

| Constraints | | Optimal inputs | | |
|---|---|---|---|---|
| $(R_{oc})$ max | $(T_a)$max | V | C | F |
| 0.16 | 10 | 323.88 | 10.02 | 0.68 |
| 0.17 | 10 | 349.26 | 10.42 | 0.68 |
| 0.18 | 10 | 363.04 | 10.00 | 0.86 |
| 0.19 | 10 | 373.77 | 10.81 | 0.86 |
| 0.20 | 10 | 378.32 | 11.02 | 0.86 |
| 0.21 | 10 | 393.72 | 10.92 | 0.98 |
| 0.22 | 10 | 398.56 | 12.56 | 0.95 |

Table 1 Optimization results

| Constraints | | Optimal outputs | | |
|---|---|---|---|---|
| $(R_{oc})$ max. | $(T_a)$max | MRR | $R_{oc}$ | $T_a$ |
| 0.16 | 10 | 2.18 | 0.159 | 9.40 |
| 0.17 | 10 | 2.31 | 0.166 | 9.85 |
| 0.18 | 10 | 2.51 | 0.177 | 9.77 |
| 0.19 | 10 | 2.55 | 0.185 | 9.87 |
| 0.20 | 10 | 2.58 | 0.188 | 9.93 |
| 0.21 | 10 | 2.74 | 0.202 | 9.98 |
| 0.22 | 10 | 2.71 | 0.216 | 9.87 |

Table 2 Optimal outputs from GA

## 5. CONFIRMATION EXPERIMENTS

The confirmation experiments have been carried out at the optimal input variables obtained from genetic algorithm (given in Table 1). The results of the response parameters were found within the range of ± 6.5% of the predicted results.

## 6. RESULTS AND DISCUSSION

The optimal input process variables such as applied voltage, electrolyte concentration and feed rate obtained from GA for the maximum material removal rate are given in Table 1. Table 2 shows the optimal values of the objective function and the constraint variables. The results of optimization obtained for maximizing the material removal rate at various constraints of radial overcut and hole taper using GA is shown in Fig.2. It can be seen that the MRR increases with the radial overcut for any taper

within the range considered. For the radial overcut constraint of 0.16 to 0.20mm increase in taper from 8 to 13 degrees increases MRR by about 1.25 times.
The maximizing function was written facilitating the user to set the constraints. The results predicted by GA show close agreement with the experimental results for the given range of operating conditions.

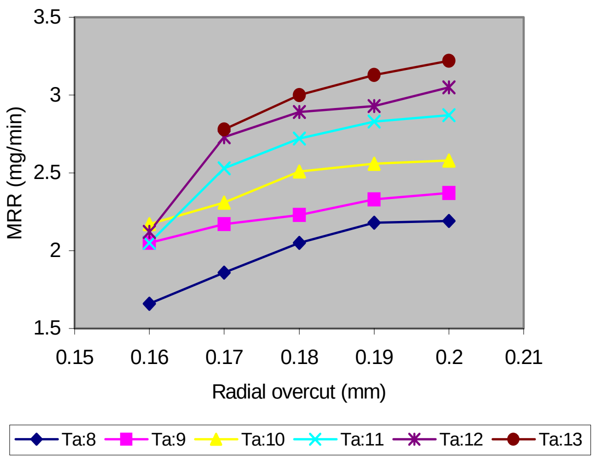



Fig.2 Results of optimization at various constraints of radial overcut and hole taper.

## 7. CONCLUSIONS

The proposed approach demonstrates the effectiveness of using GAs for the process modelling and optimization of EJD process. The approach presented in this work enables maximization of the material removal rate with the choice to the user to set the operating parameters within limits for the input variables. The optimization study reveals the significant relationship of radial overcut and hole taper with the material removal rate. The optimized model offers a solution for machining small holes at greater rate with better control over the radial overcut and hole taper. The simulated results obtained by GA are in close agreement with experimental results for the considered range of operating conditions.

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