International Journal of Production Engineering
Vol. 1: Issue 2
www.journalspub.com

# Mathematical Modeling of Process Parameters in EDM (Spark Erosion) of p20 Material Using Response Surface – Methodology

*R. Aravind Babu*, C. Poornima, P. Pradeep, K.K. Deepaknallasamy*
Industrial Engineering, Department of Mechanical Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India

***Abstract***

*The surface quality is an important phenomenon in any metal cutting processes. This paper experimentally investigates and discusses EDM machining of P20 die steel using copper electrode. The process parameters (discharge current, pulse on and off time) which influences the surface roughness was determined. Response surface methodology is used to develop a mathematical model the effect of input parameters on Surface roughness. The developed mathematical model is a second order equation of input parameters.*

**Keywords:** spark erosion electric discharge machine, mathematical modelling, central composite design of experiments, response surface methodology, surface roughness

**Corresponding Author*
*E-mail: ttaravindbabu@gmail.com*

## INTRODUCTION

The surface quality of the machined surface is very important for the product to maintain its reliability and longevity. It is important to consider the surface quality while machining a component. Among the advanced non-traditional machining techniques, EDM is considered to be the best in machining high strength, non-corrosive and hardened material. [1]

An experiment is designed and conducted to identify the effect of process parameters of EDM machine on surface roughness of the workpiece. In spark erosion EDM machining process, Metal removal takes place as a result of the generation of extremely high temperatures generated by the high intensity discharges that melt and evaporate the two electrodes. A series of voltage pulses of magnitude about 20 to 120 V and frequency on the order of 5 kHz is applied between two metal parts which are separated by a small gap in a pool of electrolyte. The application of voltage pulses causes electrical breakdown. The breakdown arises from the acceleration toward the anode of both electrons emitted from the cathode by the applied field and stray electrons present in the gap. These electrons collide with the neutrons of dielectric, thereby creating positive ions and further electrons, which in turn are accelerated respectively toward the cathode and anode, respectively. When the electrons and the positive ions reach the anode and cathode, they give up their kinetic energy in the form of heat. Temperatures of about 8000 to 12,000°C and heat fluxes up to 1017 W/m2 are attained. With a very short duration spark of typically between 0.1 to 2000 µs the temperature of the electrodes can be raised locally to more than their normal boiling points.[2] Owing to the evaporation of the dielectric, the pressure on the plasma channel rises rapidly to values as high as 200 atmospheres. Such great pressures prevent the evaporation of the superheated metal. At the end of the pulse, the pressure drops suddenly and the superheated metal evaporates explosively. Metal is thus removed from the electrodes. Fresh dielectric fluid rushes in, flushing the debris away and quenching the surface of the workpiece. Unabsorbed molten metal solidifies to form what is known as the recast layer. The expelled metal solidifies into tiny spheres dispersed in the dielectric liquid along with bits from the electrode. The remaining vapor rises to the surface.[3]

Several factors need to be considered during electric discharge machining. This includes factors such as the duty cycle, voltage applied, type of di-electric medium used, pulse generator, gap control, material removal rate, surface roughness, over cut, flushing mechanism, type and size of electrode used. In addition to the above aspects, there are some application-specific factors such as environmental conditions, electrode wear, surface and sub-surface damage, and creation of thin and brittle heat affected zone. EDM eliminates the effect of vibration, residual stresses since it does not involve direct of materials. [4]

Previous research has focused primarily on mechanisms of surface roughness and the effects of Input variables on surface roughness. The behavior of SR when the standard input variables (like discharge current, pulse OFF time and pulse ON time) are carefully controlled, has not been extensively explored. Exploration of this controlled-condition situation is important because of its prevalence in the production environments.

## LITERATURE SURVEY

M. Kunieda et al discussed the transformation between solid, liquid and gases and the science behind the EDM process. Singh et al. 2011 studied the transformation of energy during EDM process using mathematical models.

Paramashivan et al. 2010 [5] developed a mathematical model for the environmental emissions of EDM process while machining steel work piece with copper electrode. It was observed that a major portion of emission was condensed back to dielectic medium due to high convective coefficient of dielectric medium. They revealed that emission increases with the increase in peak current. [6]

Hasçalýk et al. 2004 [7] investigated the machining characteristics of AISI D5 tool steel in Electric Discharge Machining process. During experiments, parameters such as open circuit voltage, pulse duration and di-electric fluid pressure were changed to explore their effect on surface roughness and metallurgical structure. Optical and Scanning Electron Microscopy surface roughness and micro hardness tests were used to study the characteristics of machined specimens. It was found that the intensity of the process affect the amount of recast and surface roughness.

Vineet Srivastava et al. 2012 observed the effect of discharge current, pulse ON time, duty cycle, gap voltage on material removal rate, electrode wear rate and surface roughness using Ultrasonic Assisted Cryogenically Cooled copper electrode during machining of M2 grade high speed steel. A feature on UACED Med surfaces is the abundance of cracks. The density of cracks increases with the increase in discharge current. Increased pulse ON time increases the induced stresses, which tends to promote crack formation. The high frequency pumping action creates more turbulence and cavitation giving a better ejection of the melted metal, this increases the removal rate and also lets less liquid material recast on the surface.

## EXPERIMENTAL SETUP

The experiments are conducted on P20 die steel, which is identified as most commonly used materials in the manufacturing of injection molding dies and thus selected for the experiments.

Prior to electric discharge machining, the surface grinding operation is carried out on the work piece.

### Process Parameters

The process parameters selected for the present work are shown in Table 1.

***Table 1.*** *Machining Parameters and Their Levels.*

| Process parameters | Low | High |
|---|---|---|
| Discharge current (A) | 1.1 | 6.5 |
| Pulse-on time (µs) | 2.6 | 10.5 |
| Pulse-off time (µs) | 4.9 | 7.1 |


***Fig. 1.*** *Spark Erosion EDM Machine.*

### Work Material

The work material selected for the study was P20 die steel which is used extensively in manufacturing Injection molding and die casting dies. The chemical composition of this material is Carbon- 0.4%, Manganese-1.5%, Silicon-0.4%, Chromium-1.9%, Molybdenum-0.2%.P20 die steels are nitrated and carburized.

### Experimental Setup

The experimental setup was carried out at Tool and Die center, PSG Industrial Institute, Coimbatore on a Mitsubishi EA-8 EDM Machine as shown in Figure 1. P20 die steel (Length: 70 mm, Width: 85 mm, Height: 65 mm) is used for the experimentation.

### Machining Performance Evaluating Factors

The machining performance is evaluated by surface roughness (SR). Surface roughness was measured using Mitutoyo surface roughness tester.

## RESPONSE SURFACE METHODOLOGY

Response surface methodology is a collection of mathematical and statistical technique that is useful for modeling and analysis of problems in which a response of interest is influence by several variables and the objective is to optimize the response. The experiment designs that are capable of resolving curvature in the response associated with each design variable are called response-surface designs or designs for quadratic models. If we consider an experiment with just one independent quantitative variable *x1*, then a model that includes curvature will take the form:

$$y(x_1) = b_0+b_1x_1+b_{11}x_1^2$$

In our study three levels of three variables are incorporated into an appropriate experiment design such that curvature due to each variable can be quantified, the general form of the model is:

$$Y= b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2$$

Where $Y$ is the response and $x_1$,$x_2$ and $x_3$ are the quantitative variables. $b_1$, $b_2$ and $b_3$ represent the linear effect of $x_1$, $x_2$, and $x_3$ respectively. $b_{11}$, $b_{22}$ and $b_{33}$ represent the quadratic effect of $x_1$, $x_2$ and $x_3$, whereas $b_{12}$, $b_{13}$ and $b_{23}$ represents the linear by linear interaction between $x_1$ and $x_2$, $x_1$ and $x_3$, $x_2$ and $x_3$ respectively.

## DESIGN OF EXPERIMENTS

There are various families of design available in response surface methodology. Some of them are 2k designs with centers, 3k factorial designs, Box-behnken designs, Central composite method. Of three variable experiments, the 3k design with error degrees of freedom 17 is comparatively wasteful of resources. It has too many runs to justify its use over the other two designs. Box-behnken designs are comparatively more efficient than central composite designs. Box-behnken is a bit short on error degrees of freedom and has less runs. The design of experiments based on Box-Behnken design is shown in Table 2. [4, 5]

***Table 2.*** *Design of Experiments Using Box–Behnken Designs*.

| Expt. no | Discharge current (A) | Spark on time (μs) | Spark off time (μs) |
|---|---|---|---|
| 1 | 3.8 | 6.5 | 6 |
| 2 | 6.5 | 6.5 | 7.1 |
| 3 | 3.8 | 10.5 | 7.1 |
| 4 | 6.5 | 2.6 | 6 |
| 5 | 3.8 | 10.5 | 4.9 |
| 6 | 3.8 | 10.5 | 4.9 |
| 7 | 3.8 | 6.5 | 6.0 |
| 8 | 1.1 | 6.5 | 7.1 |
| 9 | 6.5 | 6.5 | 4.9 |
| 10 | 1.1 | 10.5 | 6.0 |
| 11 | 6.5 | 10.5 | 6.0 |
| 12 | 3.8 | 2.6 | 7.1 |
| 13 | 1.1 | 6.5 | 4.9 |
| 14 | 1.1 | 2.6 | 6.0 |
| 15 | 3.8 | 6.5 | 6.0 |

Response surface methodology deals with the effect of input parameters over the response variable. RSM is used to design the experiments and to determine optimal output value.

## EXPERIMENTAL ANALYSIS

The work piece is machined for each combination of input parameters based on the Design of Experiments and surface roughness were measured using Mitutoyo Surface roughness tester which is given in Table 3.

RSM is a hybrid mathematical and statistical method in which a response of interest is affected by several variables and the objective is to optimize this response.

In this study, a second-order polynomial was selected to develop empirical equations to represent responses (SR) in terms of controllable variables (IP, $T_{ON}$, $T_{OFF}$):

$$SR = 31.8618 + (0.974283\times IP) - (1.17379\times T_{ON}) - (8.73158\times T_{OFF}) - (0.00140647\times IP\times T_{ON}) - (0.0822811\times IP\times T_{OFF}) + (0.0852992\times T_{ON}\times T_{OFF}) - (0.0764460\times IP^2) + (0.0403915\times T_{ON}^2) + (0.693871\times T_{OFF}^2)$$

Where IP is the input discharge current, $T_{ON}$ is the Spark ON Time and $T_{OFF}$ is the Spark OFF Time.

***Table 3.*** *Surface Roughness for Each Combination.*

| Expt.no | Discharge current (A) | Spark on time (μs) | Spark off time (μs) | Surface finish(μn) |
|---|---|---|---|---|
| 1 | 3.8 | 6.5 | 6 | 4.0925 |
| 2 | 6.5 | 6.5 | 7.1 | 3.6475 |
| 3 | 3.8 | 10.5 | 7.1 | 3.305 |
| 4 | 6.5 | 2.6 | 6 | 3.5375 |
| 5 | 3.8 | 10.5 | 4.9 | 2.3875 |
| 6 | 3.8 | 10.5 | 4.9 | 1.7225 |
| 7 | 3.8 | 6.5 | 6.0 | 4.57 |
| 8 | 1.1 | 6.5 | 7.1 | 1.56 |
| 9 | 6.5 | 6.5 | 4.9 | 3.82 |
| 10 | 1.1 | 10.5 | 6.0 | 3.875 |
| 11 | 6.5 | 10.5 | 6.0 | 3.3725 |
| 12 | 3.8 | 2.6 | 7.1 | 2.21 |
| 13 | 1.1 | 6.5 | 4.9 | 1.3375 |
| 14 | 1.1 | 2.6 | 6.0 | 1.89 |
| 15 | 3.8 | 6.5 | 6.0 | 3.335 |

The surface finish obtained from electric discharge machining is a function of the discharge current. Normally, the surface roughness tends to increase as the discharge current decreases. The surface finish obtained also depends upon the flushing of the dielectric medium being used. Proper flushing and amount of discharge current provides a good surface finish. Though spark on time and spark off time are considered as parameters, surface roughness mainly depends upon the discharge current. The quadratic effect of combination of process parameters can be studied using counterplots shown in Figure 2.

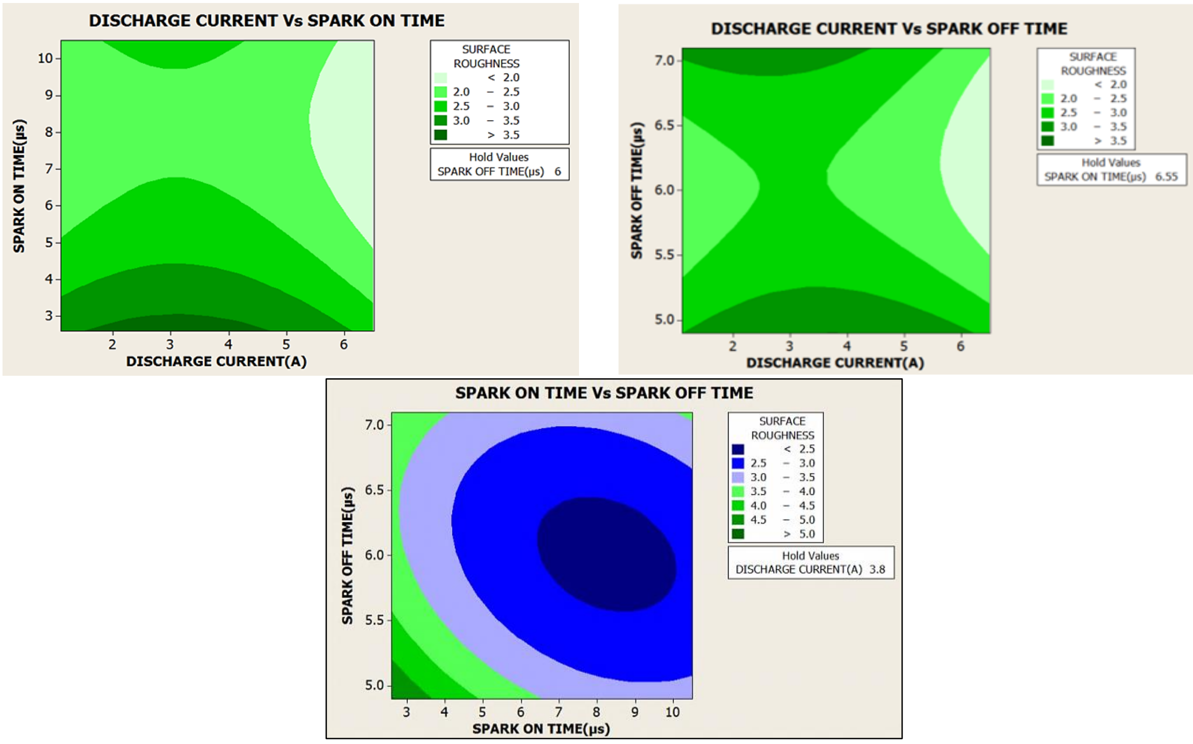


***Fig. 2.*** *Combined Effect of Process Parameters on Surface Roughness.*

More is the discharge current, less will be the surface finish. Considering all these factors and the experimental results obtained the empirical relationship between the independent variables and the surface roughness is established mathematically. Thus, desired surface roughness can be obtained. [7]

## CONCLUSION

In the present study, the Mathematical model for Surface Roughness was developed for most significant process parameters namely discharge current, pulse-on time and pulse-off time using response surface methodology in EDM process of P20 Die steel. Machining characteristics of the EDM process are primarily based on thermal conduction phenomenon, thermodynamic properties and physical properties of the tool and work. Hence the developed model for Surface Roughness is only valid for P20 Die steel with copper electrode. Based on the experimental results, the following conclusions are drawn.

- The input process parameters of electric discharge machining have been successfully modelled for the response variable surface roughness.
- Experimental values of surface roughness can satisfactorily be predicted from experimental diagrams of response surfaces and contour graphs. Results showed that central composite design is a powerful tool for providing experimental diagrams and statistical-mathematical models, to perform the experiments efficiently and economically.

The methodology developed in this study can be used to model any input parameters over the response variable and the optimum combination can be determined.

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