Optimization of Material Removal Rate in Electric Discharge Machining using Mild Steel

Gaurav Raghav, B.S. Kadam, Manjeet Kumar

Abstract: This paper aims at achieving the integrated approach to solve the optimization problem of EDM process. At any stage, the dominance factor of the input variables and output variables contained in the constraints and objective functions can be computed. This technique helps in getting the reliable multi-objective decisions under constrained penalties for the constrained optimization of such processes.

In the present work, relationships have been developed between the input decision variables and the desired goals by applying the statistical regression analysis of investigations obtained by Electro Discharge machining process for a considerable variation in the crisp sets of variables. The objectives functions were maximized or minimized by using the generalized Genetic Algorithms and the data are stored for a given set of objectives. The results are interpreted with respect to those obtained by using the bi-criterion approach. It is concluded that the results obtained by bi-criterion approach are approximately of the same order of accuracy as calculated experimentally but the computational simplicity of this method makes this methodology favorable to use to solve such mechanical engineering complex problems.

Key Words: EDM, Material removal Rate, Mild Steel, Optimization

I. INTRODUCTION

Optimization is a mathematical results and numerical methods for finding and identifying the best candidate from a collection of alternatives without having to explicitly enumerate and evaluate all possible alternatives. The process of optimization lies at the root of engineering, since the classical function of the engineering is to design new, better, more efficient and less expensive systems as well as to devise plans and procedures for the improved operation of existing systems [1]. The power of optimization methods to determine the best case without actually testing all possible cases come through the use of a modest level of mathematics and at the cost of performing iterative numerical calculations using clearly defined logical procedures or algorithms implanted on computing machines. The development of optimization methodology will therefore require some facility with basic vector-matrix manipulations, a bit of linear algebra and calculations, and some element of real analysis. We use mathematical concepts and constructions not simply to add rigor to the proceedings.

Manuscript received May, 2013.

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Some other work has been already done over the optimization techniques in production engineering. Joopelli, V [3] tried to optimize the moving trajectories of electrode of EDM. Gradient based methods have been used to optimize the single objective function variable. A moving frame reference has also been used to locate the tool electrode at any instant along its traversed trajectories.

Jain V. K. [4] analyzed the problem by using a simple optimization algorithm by keeping other objective functions unaffected and the results are concluded to give the suitable operating variable value selection on the basis of output obtained. The operating working voltage and the pulse interval plays an important role in obtaining the required surface finish. The flow movement of the dielectric fluid controls the homogeneous surface characteristics in the entire EDM controlled region. Kahng, C. H [5]

Kee. P. [6] specified an integrated approach for jointly solving process selection, machining parameter selection, and tolerance design problems to avoid inconsistent and infeasible decision. L.C. Lim, H.H. Lu [7] specified the basic thumb rules for the analysis of surface features of Electro discharge machining process

Madhu, P., Jain, V. K [8] developed the governing equations for the analysis of Electro Discharge machining process under a controlled environment. A computer program has also been developed in the form of subroutines for the calculation of electrode wear rate. Metal removal rate and dielectric material effect on the EDM process. The results obtained by the formulation used with the help of quadratic elements have shown a good convergence with those obtained by the commercial packages.

Masstoshi, S., and Ryo, Kubota [9] studied the imprecise or fuzzy nature of the data in real-world problems, job shop scheduling with fuzzy processing time and fuzzy due date is introduced. On the basis of the agreement index of fuzzy due date and fuzzy completion time, multi-objective fuzzy job shop scheduling problems are formulated as three-objective ones which not only maximize the minimum agreement index but also maximize the avg. agreement index and minimize the maximum fuzzy completion time.

Pandit, S. M [10] stated the critical factors affecting the performance of the Electro Discharge machining process when the work piece material is Cemented carbide. A suitable hard alloy material is selected as electrode tool material. And the dielectric fluid is given turbulent flow in and around the EDM region. The operating variables like Pulse duration, Discharge Current, Operating voltage, Pulse Interval time and heat dissipation rate differ in operating ranges considerably as compared to electro discharge machining of Steel alloys.

However, it has been claimed that consistency and repeatability of the machine towards maintaining the minimum deviation in the operating conditions helps a lot in the Machining accuracy in the process. Spedding, T.A. [11] used the concept of conformal transformation of the operating characteristic variables. The variables are parameterized and the parametric representation of the metal removal rate, surface roughness has been mapped onto parametric surface. The surface characteristics of the wire-Cut EDM process have been analyzed for the sensitivity of the operating variables. The dependencies of the decision variable on each other are represented and a computation algorithm has been proposed to evaluate the mapped point for specified surface characteristics onto parametric plane. Spedding, T.A. and Wang, Z.Q. [12] considered the theoretical aspects of the modeling of the wire-Cut EDM process. The interpretation of output variables variations has been carried out for the wire Cut EDM process and the suggested ranges of the input variables are given for a desired set of output variables in terms of metal removal rate and power consumption etc. Smyers, S., Guha, A. [13] stated a practical approach for Machining the Beryllium Copper alloys as work piece by Electro Discharge Machining process. Methods have been suggested for obtaining the desired level of surface characteristics by using this EDM method. Wang W.M. [14] stated that spark gap and the controlling parameters for a sensitive EDM process layout can be controlled in number of ways. A feedback system with real time stability analysis and process monitoring through digital modern sensors and transducers can give an efficient responding mechanism for the EDM process control. An artificial neural network was developed for EDM. The relationships between the operating intermediate processes along with decision variables have been framed. The performance Index evaluated by using this method helps in analyzing the adverse and positive gradient effects of the variation in the Metal removal rate, the surface roughness and the power consumption by the machine. Zhang, B. [15] calculated the effect of motion and turbulence level in the dielectric material during various stages of the electro-discharge machining process. The effect of the selection of dielectric fluid has also been analyzed for a given set of electrode tool and material combination.

II. ELECTRIC DISCHARGE MACHINING

Electrical Discharge Machining (EDM) is a controlled metal-removal process that is used to remove metal by means of electric spark erosion [16]. In this process an electric spark is used as the cutting tool to cut (erode) the work piece to produce the finished part to the desired shape. The metal-removal process is performed by applying a pulsating (ON/OFF) electrical charge of high-frequency current through the electrode to the work piece. This removes (erodes) very tiny pieces of metal from the work-piece at a controlled rate.

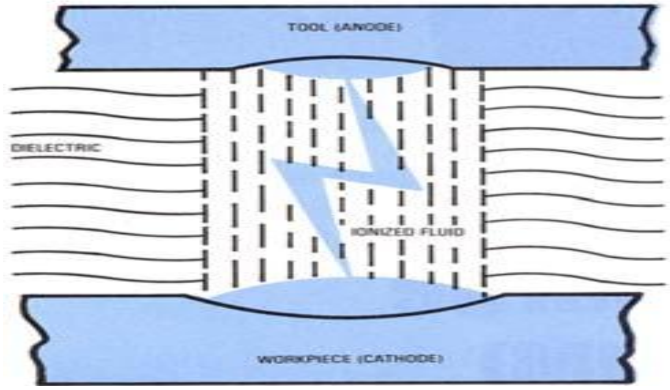

Fig I. Action of spark between electrode and work-piece [16]

A. EDM Process

EDM spark erosion is the same as having an electrical short that burns a small hole in a piece of metal it contacts [16]. With the EDM process both the work-piece material and the electrode material must be conductors of electricity.
The EDM process can be used in two different ways:

1. A reshaped or formed electrode (tool), usually made from graphite or copper, is shaped to the form of the cavity it is to reproduce. The formed electrode is fed vertically down and the reverse shape of the electrode is eroded (burned) into the solid work piece.
2. A continuous-travelling vertical-wire electrode, the diameter of a small needle or less, is controlled by the computer to follow a programmed path to erode or cut a narrow slot through the work piece to produce the required shape.

B. Principle of operation

We know that whenever an arc is caused by an accidental short circuit, pitting erosion occurs on the surface of the shorted material. EDM also works on the same principle of erosion by arcing. It involves the controlled erosion of electrically conducting materials by rapid and repetitive discharge of spark between the electrode tool and work piece (hence the name spark erosion) the tool is usually made the cathode and the work piece made the anode. The work piece and tool separated by a small gap and termed as the spark gap. The spark gap ranges from 0.005 mm to 0.05mm depending upon the cutting action required and the current density, this spark gap is either flooded or immersed in a dielectric fluid, the spark discharge is produced by the controlled pulsing and direct current. The frequency ranges from a few hundred to several thousand kilohertz with the application of a suitable voltage across the anode and cathode, electrons are the emitted from the cathode and cause the ionization of the fluid in the spark gap, when more electrons are collected in the gap, the resistance drops causing an electric spark to jump between the work and the tool gap.

Published By:
Blue Eyes Intelligence Engineering
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The spark causes a focused stream of electrons to move with a high velocity and acceleration from the cathode toward the anode, thus creating high compression shock waves .such shock waves result in local rise in temperature to the order of about 10,000 c and cause melting of the metal. The forces of electric and magnetic fields caused by the spark produced a tensile force and tear off particles of molten and soften metal from the work piece, Thereby resulting in the metal and carried away by the flowing dielectric fluid.

Work piece and the tool are separated by the dielectric fluid in a container. The dielectric breaks down when a proper DC voltage (50-450) V is applied across the anode and the cathode, and electrons are emitted from the cathode and the gap is ionized, thereby causing electrical discharge and machining operation. The electro-magnetic field cause compressive forces to act on the cathode thus metal removal from the tool is much slower than the work piece .the duration of the electric pulse is about 0.001 seconds, hence the whole cycle of sparking and metal removal take place in a few microseconds. The particles of the metal so removed are driven away by the flowing dielectric fluid .the current density and the power density used is the order of 10,000a/cm^2 and 500mw/cm^2 respectively.

C. Parameters affecting EDM process

A number of controlling variables play an important role in the entire Electric Discharge machining process. A few of them are:

(i) Pulse duration (ii). Pulse interval time (iii). Discharge current (iv). Erosion diameter (v). Erosion depth

The few process parameters which are useful in analyzing the EDM process accuracy and efficiency are as below:

(i). Metal removal rate (ii). Electrode wears (iii). Surface Roughness (iv). Power consumption by the Machine

Fig II. Controller of EDM

D. Experimental Procedure

The metal removal was carried out using SPARKONIX based electric discharge machining as shown in figure 3 & 4. Figure 3 shows the schematic diagram of setting of electrode. Figure 4 shows the schematic diagram of work-piece and electrode setup. The various controller of the machine were given above. In the experiment a copper electrode was used and mild steel was used as work-piece material. In the experiment a copper electrode with 29.2 mm diameter was used. All experiment was carried out with same electrode and kerosene oil was used as dielectric fluid. A direct current up-to 35 A was used for various readings. For calculating more accurate result six readings were carried out as shown in figure 5. Experimental set up are shown in figure 3 & 4.

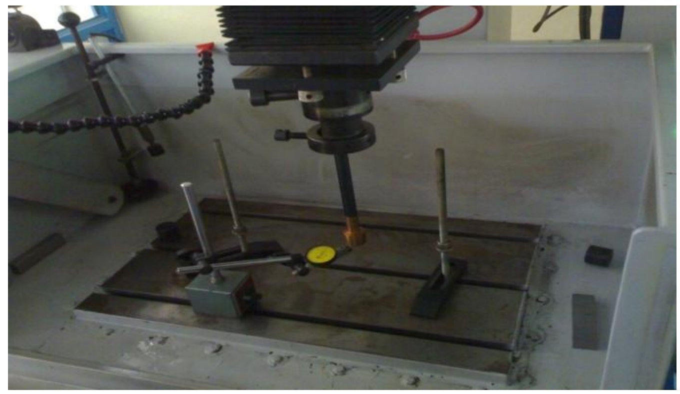

Fig III. To check level of the lower surface of the copper electrode

Initially the lower surface was made parallel to the bed of the EDM machine. After measuring the thickness all around the diameter to the electrode fixed the electrode into the chuck. After that the level was checked to avoid some manual error during fixing the electrode.

Initially thickness of the copper electrode = 15 mm.

Finally calculated thickness of electrode = 14 mm (approximate)

So, average wear-out of the electrode = (15-14)/6

= 0.166666 mm

For a clear view about the current and surface roughness relationship graph between current and surface roughness was drawn as shown in figure 6.

Table I. surface roughness at various values of current

Sr. no.	Current (ampere)	Time (minutes)	Depth of cut (mm)	Surface Roughness (µm)
1	12	20	0.5	17.58
2	16	16	0.5	25.79
3	18	13	0.5	31.23
4	20	11	0.5	41.12
5	22	10	0.5	57.53
6	24	8	0.5	71.27

Similarly, to know about a relationship between current and material removal rate the graph between then was drawn in figure 7. From the graph roughness of the surface is directly related to the current density.

As current density increases surface become more and more rough. The graph indicates that material removal rate is also directly related to the current density.

Fig IV. Setup of work piece & electrode

As the current density increases material removal rate also increases in the same proportion.

Table II. Material removal rates at various values of current

Sr. no	Current (amp)	Time (min)	Depth of cut (mm)	Material Removal Rate =(∏*r*r*D.O.C)/time Mm^3/min
1	12	20	0.5	17.58
2	16	16	0.5	25.79
3	18	13	0.5	31.23
4	20	11	0.5	41.12
5	22	10	0.5	57.53
6	24	8	0.5	71.27

Fig V. Work-piece for final analysis

III. OPTIMIZATION OF MATERIAL REMOVAL RATE

In many engineering activities, it is very difficult to obtain an explicitly or implicitly formalized description of the system which could them be optimized. Recently most of the research work is devoted to the methods for finding a statistically-experimental model of such systems. These methods are based on the experiments and their aim is to determine an investigation program which is compromise between a required number of investigations in real life condition and their in formativeness.

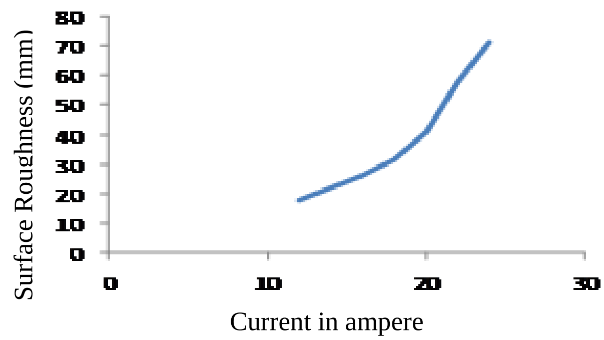

Fig VI. Effect of current on surface roughness

The data thus obtained are analyzed by means of regression methods and then the mathematical model of the system is then obtained. This model describes the functional dependence between input variables and out variables. The forms of approximation functions can be considered different. For the EDM process formulation same techniques have been applied and the relationships have been developed as specified objective functions in the problem [2].

In Electric Discharge machining process, main input quantities are Pulse Duration, Pulse Interval, Amplitude of Discharge current, Erosion surface, Erosion depth and applied current. Whereas the main output quantities are Metal removal rate, Electrode wear, Power consumption, Surface roughness and Dimensional shape accuracy of the work piece.

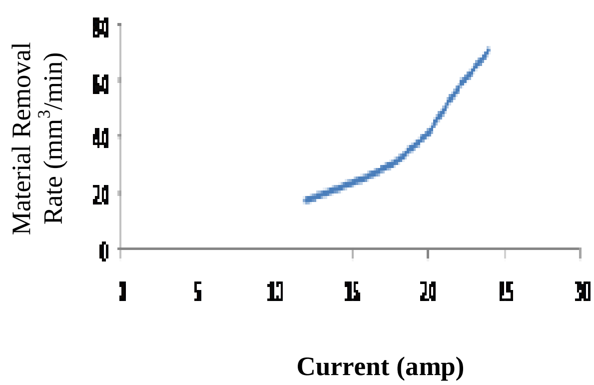

Fig VII. Effect of current on material removal rate

A theoretically recommended approach to the problem of finding a mathematical description of the EDM process would be to carry out investigations in the whole region of the space of input variables.

The space of variables can be restricted to the region which is physically sensible and sets of equations are obtained. These sets of equations give a mathematical description of the EDM process which is the basis for building the optimization model. In the present model, the decision variables are those input quantities whose values are set on the machine i.e. Pulse duration, Pulse interval time and discharge current. If the erosion surface does not change in the machining process and depth of erosion is also known in advance, these two input quantities are treated as parameters. The choice of the objective and constraint functions depends on the user requirement. The output quantities usually chosen as objective functions are: maximizing metal removal rate, minimizing tool electrode wear rate.

The surface roughness and the dimension and shape accuracy of the work piece can be taken as the third and fourth objective functions in case of the accurate machining. In this process rough machining has been considered, so these two quantities may be considered as constraints or they may be omitted. Similarly, the power consumption by the machine may be either a new objective function or the constraint or it may be discarded.

In the problem formulation a particular case of EDM process has been analyzed. It is granted that cylindrical copper electrode is to be used as a tool and mild steel as the machining material. It is assumed to have constant dielectric pressure and average working voltage while taking the experimental readings which are to be used further for regression analysis.

The Objective Functions of the problem formulated after regression analysis of the investigations are as below

$$Q=e^{11.744} I^{11.744+0.032\ln Ti+0.022\ln To+0.0205\ln\Phi+0.026\ln g} Ti^{1.555+0.047\ln To+2.76\ln\Phi+0.051\ln g} To^{-0.107-.174\ln\Phi+0.155\ln g} \Phi^{-1.067-0.124\ln g} g^{-0.742} \quad \ldots\ldots\ldots\ldots \text{(i)}$$

$$\delta = e^{-81.509} I^{5.634-0.349\ln Ti-0.335\ln To+0.119\ln\Phi+0.174\ln g} Ti^{3.726-0.051nTo-0.344\ln\Phi+0.253\ln g} To^{13.609-2.045\ln\Phi+0.207\ln g} \Phi^{12.219-0.171\ln g} g^{-3.102} \quad \ldots\ldots\ldots\text{(ii)}$$

$$N=e^{-0.663} I^{1.341-0.066\ln} Ti^{0.119\ln To+0.14\ln\Phi+0.053\ln g} Ti^{0.23+0.0711nTo0.048\ln\Phi+0.0.016\ln g} To^{0.845-0.197\ln\Phi-0.058\ln g} \Phi^{0.557-0.003\ln g} g^{0.005} \quad \ldots\ldots\ldots\ldots\text{(iii)}$$

Constraints

$Ti \geq 500 \times 10^{-6}$ The pulse duration in Seconds does not exceed

$Ti \leq 2000 \times 10^{-6}$ - Minimum and Maximum Limits

$To \leq 250 \times 10^{-6}$ - The pulse Interval time in Seconds does not exceed

$To \geq 125 \times 10^{-6}$ - Minimum and Maximum Limits

$I \leq 35$ - The Discharge Current in Amperes does not exceed

$I \geq 1$ - Minimum and Maximum Limits

$\Phi \leq 50$ - The Erosion Diameter in mm does not exceed

$\Phi \geq 20$ - Minimum and Maximum Limits

$g \leq 5$ - The Erosion Depth in mm does not exceed

$g \geq 0.1$ - These minimum and Maximum Limits

$V = 60 \pm 3$ - The applied working Voltage is kept almost constant

P= 60.8 Pa - Dielectric pressure is kept almost constant and equal to this value for a case when cylindrical

This problem is a case of Multi- Criteria Optimization type with different Mini-Max constraints and objective Functions Conditions. For a given set of constraint each objective function can be evaluated by using any nonlinear programming technique or by using Genetic algorithms. However, in each case there is no guarantee to get optimized results of the parameters when other objective functions are not taken into account. A number of some other approaches exist to solve a Multi-objective function problem but all of them are either derivative function based or assumes suitable penalty functions for the account of other objective function. While solving such cases, the approximate solution is achieved but is considerably away from the exact solutions. The integrated problem is formulated as a bi-criterion model to handle both tangible and intangible costs. The model is solved using a modified Chebyshev goal programming method to achieve a preferred compromise between the two conflicting and non-commensurable criteria.

In the above problem formulation, it is clear that for a given set of entry constraints variables, the objective functions are of following types:

(i). Q, Material removal rate : To be maximized

(ii). δ, Electrode Wear in percentage : To be minimized

(iii). N, power consumption in Watts : To be minimized

When multi- criteria model is developed, the nature of the objective functions are conflicting type and the combination of objective Function for Metal removal rate with other two objective functions in terms of electrode wear and power consumption makes objective function mini-max type.

According to the Bi-Criteria Model formulation to the above problem, such combination of Mini-Max type objective functions along with constraints is considered and the optimal values of the parameters and objective functions are evaluated at particular instances.

A. Mathematical analysis

Case I: considering objective functions (i) and (ii)

Maximize

$$Q=e^{11.744} I^{11.744+0.032\ln Ti+0.022\ln To+0.0205\ln\Phi+0.026\ln g} Ti^{1.555+0.047\ln To+2.76\ln\Phi+0.051\ln g} To^{-0.107-0.174\ln\Phi+0.155\ln g} \Phi^{-1.067-0.124\ln g} g^{-0.742}$$

Minimize

$$\delta = e^{-81.509} I^{5.634-0.349\ln Ti-0.335\ln To+0.119\ln\Phi+0.174\ln g} Ti^{3.726-0.051nTo-}$$

$^{0.344\ln\Phi+0.253\ln g}To^{13.6092.045\ \ln\Phi+0.207\ln g}\Phi^{12.219-0.171\ln g}g^{-3.102}$

Subjected to Constraints

$Ti \geq 500 \times 10^{-6}$ $\quad$ $Ti \leq 2000 \times 10^{-6}$

$To \leq 250 \times 10^{-6}$ $\quad$ $To \geq 125 \times 10^{-6}$

$I \leq 35$ $\quad$ $I \geq 1$

$\Phi \leq 50$ $\quad$ $\Phi \geq 20$

$g \leq 5$ $\quad$ $g \geq 0.1$

Case II: considering objective functions (i) and (iii)

Maximize

$$Q=e^{11.744}I^{11.744+0.032\ln Ti+0.022\ln To+0.0205\ln\Phi+0.026\ln g}Ti^{0.555+0.047\ln To+2.76\ln\Phi+0.051\ln g}To^{-0.107-0.174\ln\Phi+0.155\ln g}\Phi^{-1.067-0.124\ln g}g^{-0.742}$$

Minimize

$$N=e^{-0.663}I^{1.341-0.066\ln Ti-0.119\ln To+0.14\ln\Phi+0.053\ln g}Ti^{0.23+0.0711nTo-0.048\ln\Phi+0.0.016\ln g}To^{0.845-0.197\ln\Phi-0.058\ln g}\Phi^{0.557-0.003\ln g}g^{0.005}$$

Subjected to Constraints

$Ti \geq 500 \times 10^{-6}$ $\quad$ $Ti \leq 2000 \times 10^{-6}$

$To \leq 250 \times 10^{-6}$ $\quad$ $To \geq 125 \times 10^{-6}$

$I \leq 35$ $\quad$ $I \geq 1$

$\Phi \leq 50$ $\quad$ $\Phi \geq 20$

$g \leq 5$ $\quad$ $g \geq 0.1$

Step 2: Solve the problem with one objective at a time

The problem is solved by using generalized genetic algorithm for the given set of constraints and only one objective function at a time. As we see the two objectives conflict to each other in each case.
Minimize δ leads to a lower value of Q while maximizing Q leads to an considerable increase in the value of δ in case I and in case II, Minimize N leads to a lower value of Q while maximizing Q leads to a considerable increase in the value of N. Neither solution can be considered desirable particularly when the Differences are substantial as shown in the table 3. This calls for a compromise solution by modified Chebyshev Goal programming problem in the next step.
Step III: Formulation and solution by modified Chebyshev Goal programming problem.
The problem can be formulated by using this bi-criterion approach for each case as below:
Case I:
Subjected to: Maximize Ω

$$\Omega \leq \frac{(value\_maxQ - value\_maxQ)}{(value\_maxQ_2 - value\_maxQ_1)} = \frac{(value\_maxQ - 6.54651)}{231.33935}$$

$$\Omega \leq \frac{(value\_min\delta_2 - value\_min\delta)}{(value\_min\delta_2 - value\_min\delta_1)} = \frac{(0.9866789 - value\_min\delta)}{0.8043291}$$

$Ti \geq 500 \times 10^{-6}$ $\quad$ $Ti \leq 2000 \times 10^{-6}$

$To \leq 250 \times 10^{-6}$ $\quad$ $To \geq 125 \times 10^{-6}$

$I \leq 35$ $\quad$ $I \geq 1$

$\Phi \leq 50$ $\quad$ $\Phi \geq 1$

$g \leq 5$ $\quad$ $g \geq 0.1$

Table III. Calculations for Case 1 & 2

Case I			
	Minimize δ, mm	Maximize Q, mm/min	Difference
Value _Min δ	0.1823498	0.9866789	0.8043291
Value_max Q	6.546541	237.885891	231.33935
Case II			
	Minimize N, Watt	Maximize Q, mm/min	Difference
Value_min N	43.18557102	3283.59375	3240.408179
Value_max Q	5.826525852	237.885891	232.0593651

Similarly, for case II

Subjected to: Minimize Δ

$$\Delta \leq \frac{(value\_maxQ - value\_maxQ)}{(value\_maxQ_2 - value\_maxQ_1)} = \frac{(value\_maxQ - 5.826525852)}{232.0593651}$$

$$\Delta \leq \frac{(value\_minN_2 - value\_minN)}{(value\_minN_2 - value\_minN_1)} = \frac{(3283.59375 - value\_minN)}{3240.408179}$$

$Ti \geq 500 \times 10^{-6}$ $\quad$ $Ti \leq 2000 \times 10^{-6}$

$To \leq 250 \times 10^{-6}$ $\quad$ $To \geq 125 \times 10^{-6}$

$I \leq 35$ $\quad$ $I \geq 1$

$\Phi \leq 50$ $\quad$ $\Phi \geq 50$

$g \leq 5$ $\quad$ $g \geq 0.1$

The notion is that the best deviation from the two worst values of two objectives is obtained by maximizing Ω and minimizing Δ.

Table IV. Maximum &b minimum value for the δ & Q in different cases

Case I : maximizing Ω			
	Previous calculated value	Final calculated values	Difference
Value _Min δ	0.1823498	0.1904325	0.0080827

Value_max Q	6.546541	132.65478	126.108239
Case II : minimizing Δ			
	Previous calculated value	Final calculated values	Difference
Value_min N	43.18557102	1439.86349	1396.677919
Value_max	5.826525852	112.93497	107.108441

IV. RESULTS ANALYSIS AND DISCUSSIONS

A. Effect of current on surface roughness

Surface roughness increases with increase in current density. As the current increases surface of the final product becomes more and more rough. With the current increases from 12 ampere to 16 ampere surface roughness increases from 17.58 to 25.79 as shown in table 1. Also, current and surface roughness relationship can be graphed as shown in figure 6.

B. Effect of current on material removal rate

Material removal rate increases with increase in current density. As current density increases material removal rate also increases. From table 2 as current density increases from 18 ampere to 22 ampere material removal rate increases from 31.23 to 57.53 mm^3/ minute. Increase of current increase the temperature between the electrode and work-piece due to which more vaporization of work-piece takes place. The graph between material removal rate and current is shown in fig.7.

C. Optimization analysis

On comparison the calculated values by optimization process & by the experimental values it is clear that both the values are not exactly equal but are nearly equal to each other.

1. On measuring the MRR by bi-criteria method & by analyzing it comes out not exactly the same but both are nearly to each other.
2. Similarly, the power consumption (calculated value) is also comes out nearly equal to the power consumption calculated by bi criteria method.

As both the values come out at the current near to 22 to 24 ampere.

From the above result computation it is clear that the results are close enough to take a decision about the behavioral response of the objective functions and the constraints. The developed bi-criterion method for the Electric Discharge machining process optimization is also quite useful for observing the sensitivity of the objective functions. Any set of the objective functions with respect to any set of constraint can be analyzed for their significant behavioral response. This technique seems to be quite useful for solving such constraint based machining parameter optimization problems.

V. CONCLUSION AND FUTURE SCOPE

The present method adopted to solve the optimization problem of EDM process is simple enough and is flexible in selection of objective functions and the constraints for such machining processes. At any stage, the dominance factor of the input variables and output variables contained in the constraints and objective functions can be computed. This technique helps in getting the reliable multi-objective decisions under constrained penalties for the constrained optimization of such processes.

During the solution of the problem, it has been found that the results obtained by the bi-criterion approach show their convergence towards the exact solutions obtained by optimization of objective functions under min-max condition. However, the absolute values of the objective function differ significantly for their absolute values under max-max or min-min condition.

Even though a number of numerical optimization tools in the workbench of the software's are available now a days, such optimization methods are contributing a lot for optimization of machining processes due to their localized flexible nature of the constraints and the interchangeable objective functions. A list of suggested proposals of work which can be carried out beyond the scope of this work is as below.

1. A number of other non-traditional machining methods are available for advanced manufacturing. This method or algorithm may be used for getting the optimized results of the respective processes.
2. The approach can be used for the probabilistic sensitivity analysis of the manufacturing processes including EDM process. This work will give a symbolic justification of the effect of external and internal system variables on the accuracy of surfaces.
3. This approach may be coupled to other optimization algorithms to get multistage multi-criterion optimization by one integrated bi-criterion approach. Then this method will be able to show its importance in real life complex manufacturing problem solution.

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