Optimization study of process parameters using genetic algorithm in EDM

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KEYWORDS

EDM,
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ABSTRACT

Productivity and quality in production/manufacturing have great concerns in competitive global market; manufacturing units mainly focuses on these in relation to the process and product developed subsequently. Electrical Discharge Machining process, even now it is an experience process, wherein still the selected parameters are often far from the maximum, and at the same time selecting optimization parameters is costly and time-consuming affair. Material Removal Rate during the process has been considered in this work as a productivity estimate with the objective to maximize it, also have better surface roughness, taken as important output parameter, in the process. These two opposite objectives have been simultaneously satisfied by selecting an optimal process environment, optimal parameter setting. In this work, objective function is obtained using Regression Analysis and tested for optimization using Genetic Algorithm technique. The model is shown to be effective; MRR and Surface Roughness shown improved when used optimized machining parameters.

1. Introduction

Manufacturing using non-conventional or unconventional (also non-traditional - in the sense that they do not employ traditional tools for metal removal) energy sources such as light, sound, chemical, mechanical, electrical and ions are evolved to meet special needs. The devolvement of harder machining materials, industry needs to use by virtue of its high strength to weight ratio, heat resistance and hardness qualities (have wide use in nuclear, aerospace and space engineering). These unconventional method sexistin the world of manufacturing out of the need to machine special materials, that found in the special applications. Electric Discharge Machining (EDM), machining by using electric spark through controlled gap between tool and workpiece, discovered in 1770s by an English Scientist. In 1943, Russian scientists shown, its erosive principle can be controlled for machining. EDM commercially available in mid-1980s. It has been replacing grinding, milling, drilling and other traditional machining Operations and is now a well-established machining option in the manufacturing world. It is capable to machine components out of hard materials or can produce geometrically complex shapes, with required precision. It is widely used in mould and die making industries, nuclear industries, aeronautics and aerospace. It has also made its presence felt in the fields such as medical, sports and surgical, optical, instruments, including automotive R&D areas. EDM can be used to machine irregular geometries in small batches or even on job-shop basis. Its work material is to be electrically conductive to machine.

EDM parameters such as voltage, current, Pulse on Time (T_{on}), Pulse off Time (T_{off}), duty cycle etc., are primarily considered by research community and machining output studies on material

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removal rate (MRR) and surface roughness is outlined in this work. Product quality and cost is directly impacted by material properties and machining parameters, (Venkata Rao. R. et al., 2011). Thus, optimization of process parameters is essential that paves the way for the best machining condition. Optimization techniques play a vital role to increase the quality of the product by identifying suitable levels machining parameters for a specific machining condition. Multi-objective optimization of EDM process parameters using optimization orthogonal array using grey relational analysis for Titanium grades with brass as electrode (Dhanabalan. S et al., 2011) was discussed. EDM process parameters were also studied (Saha, S.K. et al., 2009) with tubular copper tool electrode and mild steel workpiece.

A study (G. K. M. Rao et al., 2009) to use the technological data given by the OEMs, that shows the selection of best parameters for maximizing MRR and to minimize surface roughness gave inferior outcome. Genetic algorithm (K. Wang, H. L. et al., 2003) with artificial neural network in exploring and optimizing conflicting objectives such as MRR and surface roughness was presented. Investigation (Karthikeyan, R. et al., 1999) of EDM process parameters for optimizing MRR and surface roughness while machining AL-SIC composite, which is hard to machine by conventional machine because of its abrasive nature, was studied. EDM was used (Dewangan, S. et al., 2011) for machining tool steel and effect of various cutting parameters in analyzing and thereby for obtain optimum machining conditions. EDM process modelling and optimization study was done (Joshi, S, N et al., 2011). A mathematical model based on surface response methodology (Bhattacharyya B. et al., 2007) was presented. The model draws formulation for optimum combination of minimum surface roughness, white layer thickness and surface crack density. An integrated approach [combining Taguchi's Parameter design, Response Surface Methodology, Back propagation neural network (BPNN) and Genetic Algorithm (GA)] has been suggested (Tzeng C.J. et al., 2013) in determining optimal parameter settings for the WEDM.

It is evident from the previous investigations; there are many techniques available for studying optimization of EDM process parameters. The objective of this investigation is to propose optimum set of EDM process parameters that provide maximum material removal rate at the same time providing better surface (i.e., minimize the surface roughness). The complex combinatorial nature of process variables together with multi-objective characteristics requires investigation of a non-conventional optimization technique for obtaining desired experimental outcome. Genetic Algorithm (GA) among the recent methods that are from the inspiration of evolution theory found to provide a better approach in searching solution space of multi objective optimization.

2. Experimental Setup & Investigation

The workpiece used is C45 steel (melting point: 1540^{0}c, Composition: 0.447C-0.751 Mn-0.318 Si-0.022S-0.024P), a common material that is used in preparing injection mould die. Joemars AZ50 EDM (Fig 1) is used to machine C45 Steel and to test process parameters (input and output) that are considered for the experimental investigation/observation.

The EDM machine specifications are in Table 1. Table 2 shows characteristics/specifications of EDM resource used, and the working conditions used for the experiments are given in Table 3.

Fig. 1. Joemars AZ50 die sinking EDM machine.

Table 1
Specifications of joemars AZ50 EDM.

XY Travel (mm)	300×250
Z Travel (mm)	300
Worktable (mm)	650×350
Max Work Piece Size (mm)	800×500×300
Supply Voltage (V)	72
Discharge Current (A)	25
Servo System	Electro Mechanical

Table 2
Characteristics of EDM.

Mechanism of material removal	**Controlled erosion through a series of electric spark**
Spark frequency (kHz)	200-500
Spark gap (mm)	0.010 – 0.5
Max. Material Removal Rate (gm/min)	5000
Sp. Power Consumption (W/ mm3/ min)	2-10
Tool material	Copper, Brass, Graphite, Ag-W alloys, Cu-W alloys.
MRR/TWR (gm/sec)	0.1-10

Table 3
EDM working conditions.

Parameter	**Level 1**	**Level 2**	**Level 3**
Discharge Current (amps)	10	15	20
Pulse Time ON (µs)	6	7	8
Pulse Time OFF (µs)	4	5	6
Tool Material	Copper	Brass	Graphite

Copper, Brass, Graphite electrodes were used for drilling holes in C-45 block. All the experiments were performed with normal polarity where work piece acts as a cathode and electrode as anode. Total 27 experiments were conducted having 6 levels of controlled variables. Input or controlled variable are discharge current, pulse time ON and pulse time OFF and their effects of output or experimental variables material removal rate (MRR) and surface roughness (SR) are observed and recorded.

Material Removal Rate (MRR) is calculated by using following formula.

$$MRR = \frac{Wi - Wf}{P * t} \quad (1)$$

Where, W_i- Weight before machining, W_f- Weight after machining, P- Density of C-45 and t - Time of machining.

Table 4
Experimental outcome – Machining C45 steel by different tool materials and input parameters.

No	**I**	**T_{on}**	**T_{off}**	**Tool Material**	**MRR**	**SR**
1	10	6	4	Cu	0.0204	3.6
2	10	6	5	B	0.0588	2.64
3	10	6	6	G	0.05	4.08
4	10	7	4	B	0.05	2.51
5	10	7	5	G	0.02272	3.35
6	10	7	6	Cu	0.08333	2.74
7	10	8	4	G	0.03225	3.37
8	10	8	5	Cu	0.06521	3.29
9	10	8	6	B	0.01034	2.59
10	15	6	4	Cu	0.24285	3.44
11	15	6	5	B	0.02272	2.46
12	15	6	6	G	0.1	3.18
13	15	7	4	B	0.01785	2.41
14	15	7	5	G	0.07142	4.68
15	15	7	6	Cu	0.3333	4.35
16	15	8	4	G	0.1	3.92
17	15	8	5	Cu	0.125	3.9
18	15	8	6	B	0.05263	2.71
19	20	6	4	Cu	0.3	3.68
20	20	6	5	B	0.02777	2.25
21	20	6	6	G	0.1111	3.43
22	20	7	4	B	0.05882	2.3
23	20	7	5	G	0.1111	3.35
24	20	7	6	Cu	0.4	4.03
25	20	8	4	G	0.08333	3.24
26	20	8	5	Cu	0.1428	3.71
27	20	8	6	B	0.04545	2.7

Surface roughness (SR, in this work Ra is observed, Ra is the arithmetic average of height of the surface above and below the center line), representing the quality of a machined surface, which is a geometric irregularity of the surface. The value of Ra (in µm- microns) is measured using Mitutoyo SJ 201 Surface Roughness Tester. The data collected with respect to MRR and SRR from the 27 experiments are presented in Table 4.

The units of parameters used in this study are as follows; current (I) in amps, pulse time on (T_{on})

in µs, pulse time off (T_{off}) in µs, MRR in mg/min and surface finish (SR) in µm. Tool materials considered for the experiments include brass (B), Copper (Cu) and Graphite (G).

3. Results and Discussion

Experiments conducted and data is collected from 27 experiments on electrical discharge machining of work piece material C45 Steel. The tool material is considered for the work are made of copper, brass, and graphite. This experimental outcome is analyzed for their optimum values using MATLAB and Minitab software's. Minitab is used for obtaining objective function and Matlab's GA toolbox is used to optimize the objective function using Genetic algorithm. Effect of input parameters data means are shown in figure 2 and figure 3. It is observed from fig 2, from the data means that the MRR has relation of increasing linearly with the discharge current increases and changes its slope for the further increase in its value. MRR shows increasing its value up to 7 µm of pulse time ON and then starts decreasing as the pulse time ON increased, also it can be seen as decrease in the MRR value as the pulse time OFF increase up to 5 µm and its value slowly increases as the pulse time OFF reaches 6 µm. It can be seen from the fig 3, that as discharge current value increases the surface roughness increased significantly and then reduced as the value increased further. The pulse time ON shown increasing surface roughness value up to some extent is improved and then it reduces. Finally, as the pulse time OFF raised the surface roughness is improved and slowly the slope of line showing surface roughness is decreased as the value further increased.

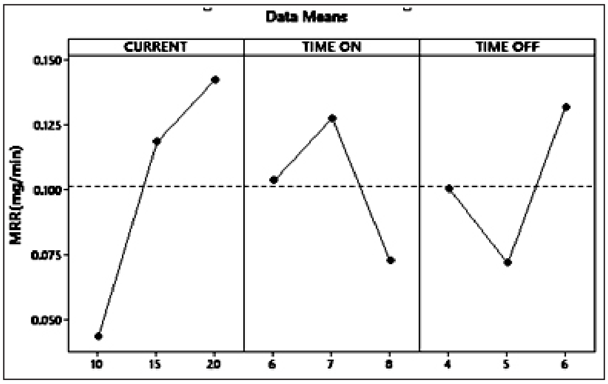

Fig. 2. Effect of input parameters on MRR.

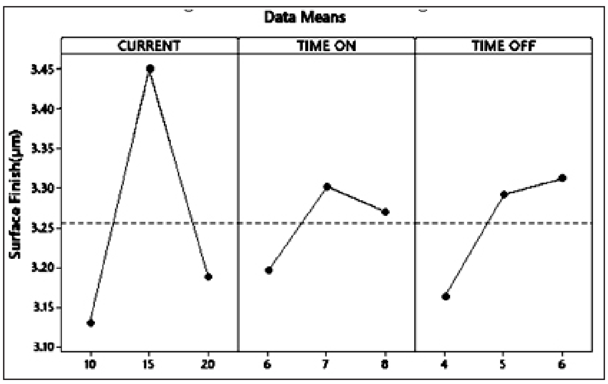

Fig. 3. Effect of input parameters on surface roughness.

The Regression equation obtained using linear regression analysis in Minitab against MRR for the input parameters current, pulse time on and pulse time off is obtained as following form.

MRR= -0.017 + 0.00986* current - 0.0154 * time ON+0.0156* time OFF (2)

Values of Coefficients, Analysis of variance (ANOVA) of equation is found from Minitab are shown in Table 5 and 6. The P-value indicates here for current as a significant input parameter for the experiments in study.

The residual plots, figure 4, are drawn and used to observe any linear relationship exists between the explanatory and response variable. If the residual forms a non- linear pattern, the relationship

Table 5
Coefficient, SE-Coefficients, T-value, P-values of MRR equation from regression.

Term	Coefficient	SE coefficient	T-Value	P-Value
Constant	-0.017	0.208	-0.08	0.936
Current	0.00986	0.00455	2.17	0.041
Pulse Time ON	-0.0154	0.0227	-0.68	0.506
Pulse Time OFF	0.0156	0.0227	0.69	0.500

Table 6
Analysis of Variance (ANOVA) DF, Adj SS, Adj MS, F-Value, P-Value.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.052368	0.017456	1.87	0.162
Current	1	0.043741	0.043741	4.70	0.041
Time ON	1	0.004251	0.004251	0.46	0.506
Time OFF	1	0.004376	0.004376	0.47	0.500
Error	23	0.214184	0.009312	----	----

between the explanatory and response variable will be non-linear. A "Good" residual plot will look as if there is no pattern i.e. points should randomly scattered. The residual plot shown in figure 4, is a scatter plot of residual versus the explanatory variable, with residual on Y-axis and MRR on X-axis. Form the residual plot, it can be concluded that there is good linear relationship exist between response variables and MRR.

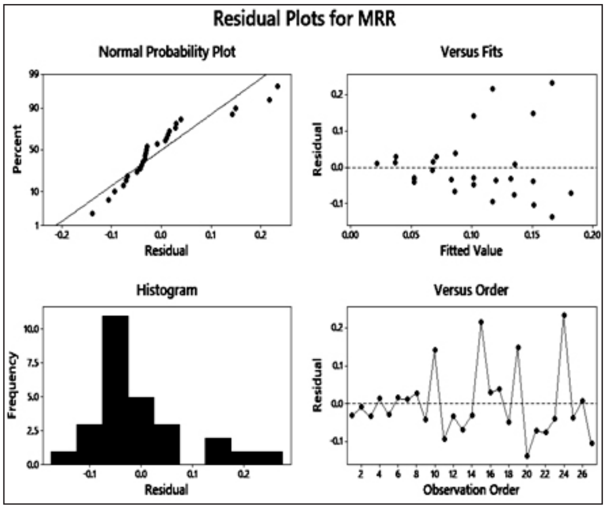

Fig. 4. Residual plot for MRR.

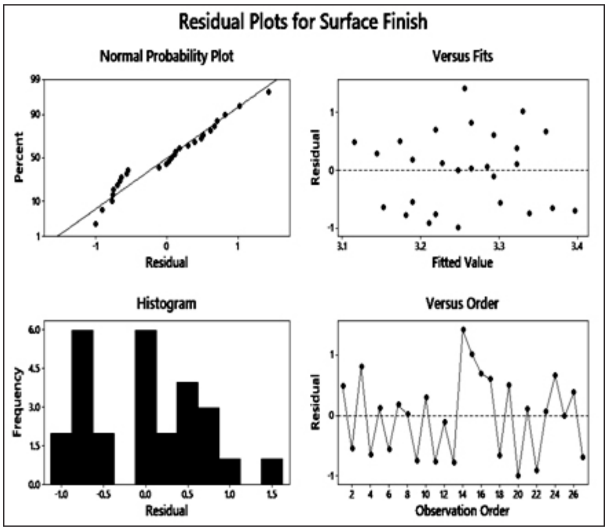

Fig. 5. Residual plot for surface roughness.

Also, regression analysis in studying surface roughness against current, pulse time on and pulse time off obtained from Minitab is as in the following equation form.

Surface finish= 2.54+0.0058*current+0.037*Pulse time ON+0.074*Pulse time OFF (3)

Regression Coefficients, Analysis of variance (ANOVA) for the output parameter surface roughness are obtained using statistical toolbox

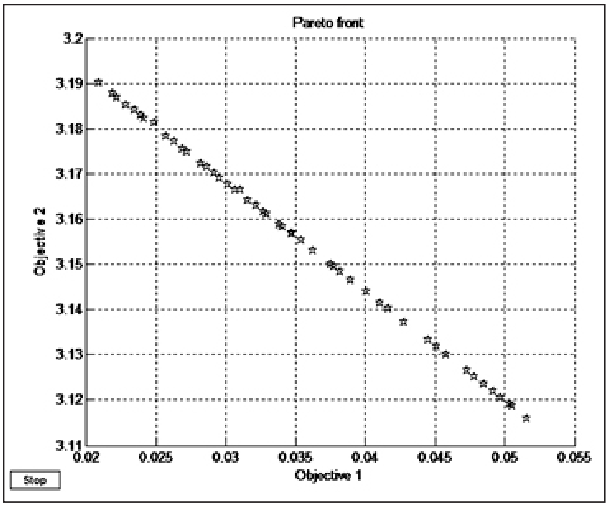

Fig. 6. The pareto optimal front for MRR and surface roughness.

Table 7
Coefficient, SE-coefficients, T-value, P-value of SR equation.

Term	Coefficient	SE coefficient	T-Value	P-Value
Constant	2.54	1.51	1.67	0.0108
Current	0.0058	0.0331	0.17	0.863
Time ON	0.037	0.166	0.22	0.824
Time OFF	0.074	0.166	0.45	0.657

Table 8
DF, Adj SS, Adj MS, F-value, P-Value.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.1397	0.04657	0.09	0.962
Current	1	0.0150	0.01502	0.03	0.863
Time ON	1	0.0249	0.02494	0.05	0.824
Time OFF	1	0.0998	0.09976	0.20	0.657
Error	23	11.3531	0.049361	---	---

Table 9
Values obtained using GA toolbox (Matlab).

I	Ton	Toff	MRR	SR
10	6	4	0.0516	3.116
10.00210627	7.997875911	4.001414771	0.020875549	3.190038318
10.00347716	6.28457954	4.000910608	0.047265965	3.126616995
10.00127612	6.752256462	4.0012722	0.040047679	3.143935033
10	6	4	0.0516	3.116
10.00210627	7.997875911	4.001414771	0.020875549	3.190038318
10.00037862	6.246308989	4.000736855	0.04782207	3.125170156
10.00218176	6.425141582	4.000864869	0.045087824	3.131806893
10.00174885	7.142123319	4.001340209	0.034049452	3.158367882
10.00111622	7.396892469	4.000553372	0.030107495	3.167732445
10.00202314	7.21699117	4.00129033	0.032898413	3.161135892
10.00025781	6.873995338	4.000274091	0.03814729	3.148359606
10.001694	7.915802713	4.001370595	0.022134722	3.18699595
10.00177006	7.870925416	4.001221038	0.02282425	3.185324864
10.00393518	6.651544205	4.000430992	0.041611744	3.140161853
10.00049246	6.999451111	4.00034617	0.036218709	3.153008164
10.00183929	7.302483141	4.000645318	0.031569962	3.164250298
10.0098232	7.837611686	4.001398244	0.023419449	3.184152077
10.00278546	6.380818751	4.000864998	0.04577635	3.130170459
10.00190044	7.496899936	4.001041142	0.028582721	3.171473365
10.00089543	6.157371279	4.00066505	0.049195686	3.121877144
10.00060943	6.125243203	4.000291722	0.049681815	3.120659121
10.00657039	7.805772176	4.001019928	0.023871803	3.182927153
10.00225841	7.361153607	4.000734275	0.030671957	3.166430119
10.01498356	7.061743574	4.00094401	0.035411613	3.155441274
10.00148085	7.607359793	4.001030482	0.026877336	3.175557157
10.00210627	7.935375911	4.001414771	0.021838049	3.187725818
10.00088121	7.460345527	4.000924309	0.029133787	3.170106294
10.00100006	7.585236284	4.000948125	0.027212013	3.174729704
10.00122339	7.521642808	4.00092702	0.028193225	3.172376479
10.00161963	6.685261106	4.000431931	0.041069687	3.141396018

Table 9
Values obtained using GA toolbox (Matlab).

I	Ton	Toff	MRR	SR
10.00239961	7.100333876	4.000677158	0.034689082	3.156776381
10.00048997	6.82444875	4.000349256	0.038913769	3.146533291
10.00323082	7.266971568	4.001207055	0.032139324	3.162986009
10.00004134	6.081153554	4.001033899	0.050366772	3.11907943
10.00396425	7.647817994	4.001181455	0.026281121	3.177079686
10.00012494	6.575325735	4.0009087	0.042755391	3.137355021
10.03291774	7.759490548	4.001230848	0.024847616	3.181383156
10.00647773	7.103885528	4.001296656	0.034684261	3.156977288
10.00082819	7.156163715	4.001162364	0.033821378	3.158868876
10.00422612	6.205149824	4.000930339	0.048496876	3.1236839
10.00393241	6.920271087	4.000323206	0.037471641	3.150096755
10.00043737	6.07075039	4.000175346	0.050517492	3.118633277
10.00439558	6.906669871	4.001249611	0.037700118	3.149664751
10.00370013	7.788572814	4.001302927	0.024112788	3.182295071
10.00192051	7.433650456	4.000921828	0.0295551	3.169124421
10.00061262	7.6830867	4.000395148	0.02569267	3.178307002
10	6.000244141	4	0.05159624	3.116009033
10.00202314	7.23261617	4.00129033	0.032657788	3.161714017
10.00225841	7.345528607	4.008058493	0.03102684	3.166393986
10.00196449	6.46398719	4.00250105	0.044512984	3.133363998

of Minitab and the same are shown in Table 7 and 8.

The residual plot from Figure 5, is scatter plot of residual versus the explanatory variable, with residual on Y-axis and Surface roughness on X-axis. Form the residual plot, it can be concluded that there is good linear relationship exist between response variables and Surface roughness.

The study optimization by using Genetic Algorithm toolbox in Matlab, objective function considered for optimized estimation of material removal rate is the regression equation obtained in Mini Tab, i.e.,

MRR = -0.017+0.00986*current-0.015* Pulse time ON+0.0156* Pulse time OFF; (4)

and the Objective function for optimized estimation of surface finish is, Regression equation obtained in Minitab, i.e.,

Surface finish= 2.54 + 0.0058 * current + 0.037 * Pulse time ON + 0.074 * Pulse time OFF. (5)

These equations are tested using Matlab's GA Toolbox for optimization. The following parameters of Genetic Algorithm are used to generate optimum solutions by using optimization tool in Matlab.

- Lower boundary condition= [10,6,4]
- Upper boundary condition= [20,8,6]

- Population type/size: double vector /60
- Selection: tournament selection with tournament size = 2
- Crossover fraction = 0.6
- mutation fraction = 0.4
- Mutation: adaptive feasible
- Crossover: intermediate with crossover ratio of 1.1
- Migration direction: forward with fraction of 0.4 and interval of 20
- Distance measure function: distance crowding
- Pareto front population fraction = 0.85
- Termination criteria: 600 generations, stall generations or function tolerance set default value.

The pareto optimal front (Material Removal Rate Vs Surface Roughness) obtained from Matlab's GA toolbox is shown in Fig 6. This graph is used to find out optimal solutions which are displayed in Table- 9.

The optimal solutions, shown in Table 9, are obtained from the above pareto optimal front graph from the run in GA toolbox of Matlab. From the Table 9, and Figure 7, it is concluded that maximum obtained MRR is 0.05211 mg/min (experimental value is 0.05411 mg/min) and minimum surface roughness value as 3.1550µm (experimental value is 2.9811 µm) having discharge current value at 10.00295 amps, Pulse time ON as 7.0522 µs and Pulse time OFF as 4.001038 µs when graphite as a tool material.

This minor change in the MRR value and surface roughness value from theoretical optimal values may be because of approximation considered while obtaining regression equation, which is difficult to rectify theoretically.

4. Conclusion

The C45 steel is machined on Electric discharge machine (EDM) using electrodes made of copper, brass and graphite. The L27 orthogonal array is considered for conducting experiments. Pulse time ON, Pulse time OFF, tool material and current are taken as input parameters from this array. ANOVA analysis is conducted, and multiple regression equation are developed for the set of experiments conducted. optimum values of parameters are obtained by using multi-objective Genetic algorithm toolbox in Matlab. The outcome confirms that discharge current, pulse on time and pulse off time have major effect on material removal rate and surface roughness. The results of the Experiment divulge that the appropriate selection of input parameters will play an important role in Electric Discharge Machining. It can be concluded from the 27 experiments conducted for three levels of four factors in this study include:

- The MRR is increasing with increase in discharge current almost linearly
- The MRR is increasing with increase in pulse time ON initially at slower rate but later the increase is at a faster rate.
- The MRR is decreasing with increase in pulse time OFF almost linearly.
- 10 to 15 amps of current, surface roughness increases with the increase in discharge current but there after surface roughness decreases with increase in discharge current, the same is found in regression analysis by P-value.
- 6 to 7µs of pulse on time the surface roughness increases with increase in pulse on but there after surface roughness decreases with increase in pulse on time.
- 4 to 5µs of pulse off time the surface roughness increases with increase in pulse off but there after surface roughness decreases with increase in pulse off time.

In order to enhance quality of EDM machining of C45 steel, higher discharge current, higher pulse on time and lower pulse off time is recommended. However to decrease the surface roughness higher current, lower pulse on time, higher pulse off time is suggested.

Two conflicting objectives of Material Removal Rate and surface roughness have been optimized as objectives using a multi-objective optimization technique of genetic algorithm with the help of MATLAB solver facility. Non- dominating pareto-optimal sets of material removal rate and surface roughness are obtained.

It is concluded that obtaining maximum MRR of 0.05411 mg/min having minimum surface roughness of 2.9811 µm at input parameters of discharge current of 10.0029 amps, pulse time ON of 7.0522 µs, pulse time OFF value as 4.0010 µs.

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