Optimization of Wire EDM Parameters on Machining Incoloy 825 Using Grey Taguchi Technique & Genetic Algorithm

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***Abstract* - The super alloys having high hardness, toughness and impact resistance are being developed mechanical industry. The super alloys are used in Marine, Aerospace, Nuclear industries etc. Such materials are difficult to be machined by traditional machining process.**

This paper outlines an experimental study to optimize the process parameters of Wire Electrical Discharge Machining (Wire EDM) for Incoloy 825 super alloy. The objective of optimization is to attain minimum Surface Roughness (Ra) and maximum Material Removal Rate (MRR) individually and simultaneously. In this study, Incoloy 825 super alloy of 20 mm thickness is used as a work piece. Four parameters were chosen as process variables Viz., pulse on time, pulse off time, wire tension, and spark gap voltage. The experiments are conducted based on Taguchi's L_{27} orthogonal array (OA), for each experimental run Ra was calculated by using Talysurf, MRR was calculated by using mathematical relationship. The best relationship for process variables were identified by using Grey-Taguchi analysis. By using Genetic algorithm optimization technique the optimal setting is obtained for Ra and MRR individually and finally, Pareto optimal sets are obtained by using NSGA algorithm provides suitable combination of process variables for achieving minimum surface roughness and maximum MRR simultaneously.

***Key words:* WEDM; Ra; MRR; Grey relational analysis.**

Nomenclature	
WEDM	Wire Electrical Discharge Machining
OA	Orthogonal array
R_a	Surface roughness
MRR	Material removal rate
$Z_i(k)$	Grey relational generation value
γ_i	Grey relational grade
GA	Genetic algorithm
NSGA	Non-Dominated sorting genetic algorithm
R^2	Regression co-efficient
LB	Lower bound
UB	Upper bound

I. INTRODUCTION

Technologically advanced industries such as aeronautics, nuclear reactors, auto mobile, marine, space and others have been demanding materials like High Strength Temperature Resistant alloys (HSTR). To meet higher demands like better surface finish, low values of tolerances, higher production rates, complex shapes, automated data transmission, non-traditional machining processes are more correctly named as advanced machining processes which have been developed. Wire EDM process is one among the thermo electric advanced machining processes. In thermo electric methods, the energy is supplied in the form of heat light or electron bombardment. The energy is concentrated onto a small area of work piece resulting in melting or vaporization and melting both. Wire EDM is a process which is capable of machining the materials economically & accurately. This process is widely used for machining hard and tough but electrically conductive materials.

Wire EDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. In Wire EDM process a wire is used as an electrode and deionised water as dielectric fluid. However, Wire EDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05 – 0.30 mm, which is capable of achieving very small corner radii. A nozzle is employed to inject the dielectric in the machining area in Wire EDM. Electrodes (wire and work piece) are connected to a pulsed DC supply. Heat is generated due to sparking results in the melting of work piece and wire material, and sometimes parts of the material may even vaporize. This process gives a high degree of accuracy and good surface finish. Complex shapes, dies of various types, press tools can be prepared by using wire EDM. The schematic diagram of Wire EDM process is as shown in figure.1.

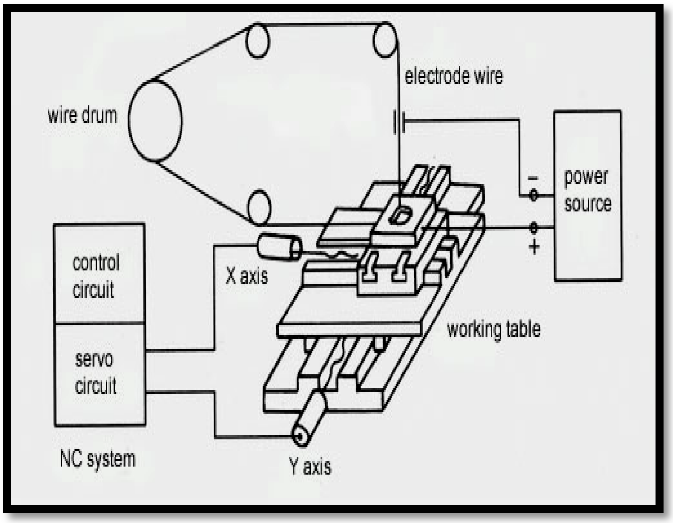

Fig. 1 Schematic diagram of Wire EDM process

Selection of optimal machining parameters plays an important role. Improperly selected parameters may result in serious problems like short circuit and wire breakage. Based on the literature review the process parameters and optimization method are selected.

Previously, some of researchers have investigated to optimize process variables in Wire electrical discharge machine. J.B.Saedon, Norkamal Jaafar, Mohd Azman, Nor Hayati Saad [8] et.al, have reported on effect of process parameters such as pulse off time, peak current, wire feed rate, wire tension on responses such as surface roughness, cutting rate and material removal rate using multi objective optimization of Ti alloy through orthogonal array and grey relational analysis in Wire EDM. Muthu Kumar v, Suresh Babu A, Venkata Swamy R and Raajenthiren M [7] et.al, have investigated the optimization of Wire EDM parameters of Incoloy 800 super alloy with multiple responses using Grey-Taguchi technique. M Durai Raja, D Sudharsun, N Swamy Nathan [9] et.al, analysed that the process parameters in WEDM with stain less steel using single objective Taguchi method and Multi objective using grey relational grade. Varun A, Nasiana Venkaiah [3] et.al, experimentally investigated the new optimization technique by combining grey relational analysis with genetic algorithm. Anoop Mathew Kurian, Dr Binu c. Yeldose, Ernest Markase Mathew [10] et.al, have reported that effect of Wire EDM variables on surface roughness of stainless steel 15-5ph by using Taguchi design and ANOVA. The parameter pulse duration was found to be the most effective on the surface roughness followed by the discharge current. SS Mahapatra and Amar Patnaik [11] et.al, studied the optimization of WEDM process parameters using genetic algorithm and Taguchi design of experiment.

The four process parameters pulse on time (Ton), pulse off time (Toff), wire tension (WT), spark gap voltage (SGV) are selected based on the comprehensive literature review. The main objective of this present study is the investigation of process parameter affects on responses and optimization of process variables in Wire EDM of Incoloy 825. By using Minitab 17 software Grey-Taguchi technique is applied to study the effect of process parameters on performance variables. For the optimal selection of process variables, the Genetic algorithm method has been extensively used using Mat lab 2013.

II. EXPERIMENTAL PROCEDURE

A. *Experimental Setup*

All experimental runs were carried out on four-axis Electronica sprint cut elpuls55 Wire EDM machine. The electrode material used was 0.25 mm diameter of brass wire. A small gap is maintained in between wire and work piece i.e. 0.3 mm and de-ionized water is used as dielectric. A nozzle is employed to inject the dielectric in the machining area in Wire EDM. The work piece material is clamped on the work table; it is shown in figure.2. Whenever sparking takes place between two electrodes (wire and work piece) a small amount of material is removed from each of the contacts. A collection tank is located at the bottom to collect the used wire erosions and then is discarded. The wire once used cannot be reused again, due to the variation in dimensional accuracy.

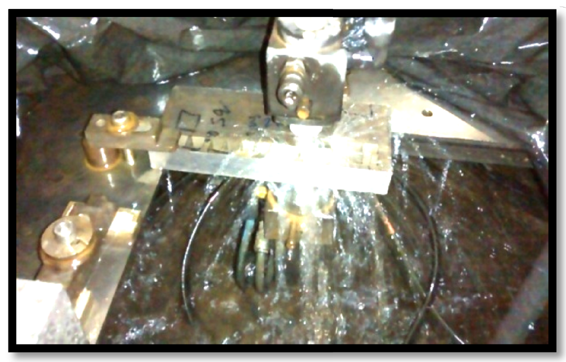

Fig. 2 Work piece clamped on the Wire EDM work table

In this research, the experimental design has four process parameters namely, pulse on time, pulse off time, wire tension and spark gap voltage. The process responses considered in the present study are: Surface roughness (Ra) and material removal rate (MRR). Surface roughness (Ra) measurement is done by using a Talysurf (Mitutoyo). Ra is the arithmetic mean deviation of the assessed profile. MRR was calculated by using the formulae given below:

$$MRR = ktVc\rho \qquad \text{Eq. (1)}$$

Where,

k is the kerf width (0.3 mm),

t is the thickness of the work piece (20 mm),

Vc is the cutting rate (mm/min), displayed on the screen during machining

ρ is the density of the material (8.14×10^{-3} g/mm^3)

In the machining process parameter design, 3 levels with equal space of process parameters are selected as shown in table1.

Table 1. Process Parameters And Their Levels

Process parameters	Units	Notation	Levels		
			1	2	3
Pulse on time	µs	A	0.6	0.95	1.25
Pulse off time	µs	B	26	38	52
Wire tension	G	C	500	850	1400
Spark gap voltage	Volts	D	20	40	60

B. *Work Piece Material*

In this experiment, Rectangular block of 175 mm X 125 mm X 20 mm thickness of Incoloy 825 super alloy was used as work piece material. Incoloy 825 is High strength temperature resistant alloy. The chemical composition and mechanical properties of Incoloy 825 are shown in table 2 and table 3 respectively.

Table 2. Chemical Composition (Wt. %) Of Incoloy 825

i	Cr	Mo	Mn	Cu	Si	C	S	Ti	Al	Fe
38-46	19-23	2.5-3.5	Max1.00	1.5 – 3.0	Max 0.05	Max 0.05	Max 0.03	0.6-1.2	Max 0.2	Min 22

Table 3. Mechanical Properties Of Incoloy 825

Yield strength (Mpa)	Ultimate tensile strength (Mpa)	Melting point temperature ^0c	% of elongation
220	550	1400	30

C. *Design Of Experiments (DOE)*

Design of experiment technique is used for obtaining maximum number of output values from minimum number of experiments in terms of run, time, and money. In Taguchi technique, an orthogonal array (OA) is used to reduce the number of experimental runs for identifying the optimal machining process parameters. To determine the main effects, an OA requires minimal number of experimental runs. The choice of an appropriate orthogonal array depends upon the total degree of freedom (DOF) required for studying mean and interaction effects. In this study, there are four process parameters and three levels each so, the DOF for this experimental design is 18. The available designs for four process parameters with 3 levels are L_9, L_{27}, and L_{81}. As no interactions are available in L_9 array, L_{27} OA has been selected for this present experiment. By using Taguchi technique L_{27} OA has been used in this experiment. The Experimental design using L_{27} OA is as shown in table 4. The condition for using L_{27} OA is that, the total Degree of freedom (DOF) for selected OA must be greater than that of total DOF required for the experiment. L_{27} OA has been selected for this experiment as per Taguchi technique.

Table 4. Design Of Experiment For Process Parameters And Experimental Results

Exp. Run	Pulse on time (Machine unit)	Pulse off time (Machine unit)	Wire tension (Machine unit)	Spark gap voltage (Machine unit)	Vc (mm/min)	MRR (g/min)	Ra (µm)
1	110	50	4	20	1.42	0.0693	2.1855
2	110	50	7	40	1.37	0.0669	2.632
3	110	50	10	60	0.79	0.0385	1.758
4	110	56	4	40	0.72	0.0352	1.7865
5	110	56	7	60	0.57	0.0278	1.655
6	110	56	10	20	0.92	0.0449	2.1035
7	110	63	4	60	0.56	0.0274	1.7225
8	110	63	7	20	1.06	0.0518	2.3785
9	110	63	10	40	0.81	0.0396	1.9755
10	117	50	4	20	3.83	0.1871	2.791
11	117	50	7	40	2.95	0.1441	2.61
12	117	50	10	60	1.98	0.0967	2.627
13	117	56	4	40	2.15	0.1050	2.6245
14	117	56	7	60	1.52	0.0742	2.5265
15	117	56	10	20	2.37	0.1157	2.769
16	117	63	4	60	1.09	0.0532	2.2665
17	117	63	7	20	2.08	0.1016	2.7165
18	117	63	10	40	1.63	0.0796	2.6865
19	123	50	4	20	3.28	0.1602	2.7885
20	123	50	7	40	3.58	0.1748	2.4365
21	123	50	10	60	2.48	0.1211	2.6995
22	123	56	4	40	3.34	0.1631	3.124
23	123	56	7	60	2.39	0.1167	2.835
24	123	56	10	20	2.36	0.1153	3.194
25	123	63	4	60	1.84	0.0899	3.0625
26	123	63	7	20	3.19	0.1558	3.199
27	123	63	10	40	2.69	0.1314	3.197

III. METHODOLOGY

Material removal rate was calculated by using equation 1 and surface roughness was measured by using Talysurf instrument. The experimental results for surface roughness (Ra) and material removal rate (MRR) are included in table4. The main objective of this investigation is optimization of process variables for multiple responses in WEDM. Taguchi method is suitable for single response optimization only, but optimization of multiple responses is completely different from single response optimization. So, for optimizing multiple response characteristics, grey relational analysis coupled with Taguchi technique is employed in this paper.

A. Grey relational analysis

The experimental results obtained from surface roughness and material removal rate are presented in table 4. Grey relational grade is the final response for optimizing process parameters with Taguchi analysis, which is attained from the following steps.

B. Grey relational generation

Grey relational generation is the first step in grey relational analysis in which experimental results should be normalized in the range of 0 to 1. For normalizing surface roughness (Ra) data, lower-the-better (LB) criterion is used (equation 2) and for normalizing material removal rate data, higher-the-better (HB) criterion is used (equation 3).

$$Z_{ij} = \frac{\max y_{ij} - y_{ij}}{\max y_{ij} - \min y_{ij}} \qquad \text{Eq. (2)}$$

$$Z_{ij} = \frac{y_{ij} - \min y_{ij}}{\max_{ij} - \min_{ij}} \qquad \text{Eq. (3)}$$

Where,

Z_{ij} is the grey relational generation value,

Max. y_{ij} is the greatest value of y_{ij} for k^{th} response,

Min y_{ij} is the smallest value associated with y_{ij} for k^{th} response,

i=1,2,....n , j=1,2....n and k=1,2,...m. n.

n is the number of experimental data items,

m is the number of responses.

C. Grey relational coefficient

After normalizing Ra and MRR response data, Grey relational coefficients are calculated to exhibit relationship between the ideal and actual normalized experimental results. The grey relational coefficient ε_i (k) can be expressed as:

$$\gamma(Yo(k), Yi(k)) = \frac{\Delta_{min} + \varphi\,\Delta_{max}}{\Delta_{oi}(k) + \varphi\,\Delta_{max}} \qquad \text{Eq. (4)}$$

Where,

$\Delta_{oi} = Y_{oi}(k) - Y_i(k)$, Δ_{oi} is the difference of absolute value between Y_0 (k) and Y_i (k).

$\Delta_{Min}$is the minimum value of Δ_{oi} and

$\Delta_{min}$is the maximum value of Δ_{oi}.

$\varphi$is the identification coefficient.

The value of φ in the range of 0 and 1, however, the recommended value of the distinguishing coefficient $\varphi$is 0.5, due to moderate distinguishing effects and good stability of outcomes, φvalue is taken as 0.5 for further analysis. The grey relational coefficient values for Ra and MRR are shown in table 5.

D. Grey relational grade and grey relational ordering

Grey relational grade is taken as overall process response instead of multiple process responses such as Ra and MRR. Grey relational grade is calculated by averaging the grey relational coefficient values of multi responses as follows and it is indicated by γ_i.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \varepsilon i\ (k) \qquad \text{Eq. (5)}$$

Where, n= number of process responses

Higher value of grade indicates the best relational grade between the Y_o (k) and Y_i (k). Table 5 shows that the grey relational grade and their orders.

Table 5. Grey Relational Coefficient For Ra And MRR & Grey Relational Grade

Exp. No.	Material removal rate	Ra	Grey Grade	Order
1	0.5004	0.4637	0.48205	20
2	0.4910	0.6281	0.55955	19
3	0.3797	0.8563	0.618	15
4	0.3663	0.3613	0.3638	25
5	0.3351	0.3333	0.3342	27
6	0.4054	0.4401	0.42275	23
7	0.3333	0.3473	0.3403	26
8	0.4323	0.5265	0.4794	21
9	0.3842	0.4060	0.3951	24
10	0.9316	0.7071	0.81935	5
11	0.8275	0.6182	0.72285	9
12	0.6101	0.6258	0.61795	16
13	0.6452	0.6248	0.6350	14
14	0.5397	0.5827	0.5612	18
15	0.6919	0.6953	0.6936	11
16	0.4379	0.4888	0.46335	22
17	0.6306	0.6684	0.6495	13

18	0.5408	0.6537	0.59725	17
19	0.9139	0.7058	0.80985	6
20	1.0000	0.5476	0.7738	7
21	0.7163	0.6600	0.68815	12
22	0.9304	0.9328	0.9316	2
23	0.6964	0.7317	0.71405	10
24	0.6900	0.9952	0.8426	4
25	0.5822	0.8831	0.73265	8
26	0.8895	1.0000	0.94475	1
27	0.7644	0.9982	0.8813	3

IV. FACTOR EFFECTS ON GREY RELATIONAL GRADE

The main effect plot for grey relational grade using Taguchi technique in MINITAB 17 software is shown in fig 3. In the main effect plot, a parameter for which the line has the highest inclination will have more significant effect and the line which is near to horizontal line has no significant effect. From the main effect plot it is clear that pulse on time (A) has more significant effect and Wire tension (c) has less significant effect. Since, Grey-Taguchi method signifies that the best relationship between the variables, where the mean grey relational grade is found to be maximum value. Hence, the best relationship between the variables for minimum surface roughness and maximum material removal rate in Wire EDM process of Incoloy 825 super alloy is A3 B1 C3 D1.

Fig.3. Main effects plot for mean of grey relational grade

V. DEVELOPMENT OF REGRESSION MODELS

The Wire EDM experiments were conducted using the parametric approach of Taguchi's technique. Regression analysis is applied to the experimental data for developing regression models for R_a and MRR using Minitab 17 Software. During regression analysis it was assumed that the process parameters and process responses are linearly related to each other. General first order models were developed to predict the values of R_a and MRR over the experimental region (equation A & equation B). For this experiment regression coefficient (R^2) for R_a was found to be 92.64 % shows that the data are fitted well. And also R^2 value for MRR was found to be 93.04 % shows that the data are fitted well.

$$R_a = -5.92 +0.0717*x_1+0.0059*x_2+0.0122*x_3-0.0083*x_4$$

$$MRR = +0.525-0.0712*x_1+0.00276*x_2+0.0019*x_3+0.00098*x_4$$

A. *Single-objective optimization:*

1) *Genetic algorithm:*

GA is an optimization technique based on natural genetics and natural science. GA works with a coding of parameters. GA converts the multiple parameter optimizations into single parameter optimization. GA gives an optimal set for different conditions. It solves multiple optimization process parameters at a time. The main advantage of GA coding technique is, it divides the search space, while it is continuous. It gives Best individual condition for each response and multiple responses. For solving optimization problem using genetic algorithm the flow chart is as shown in figure 4.

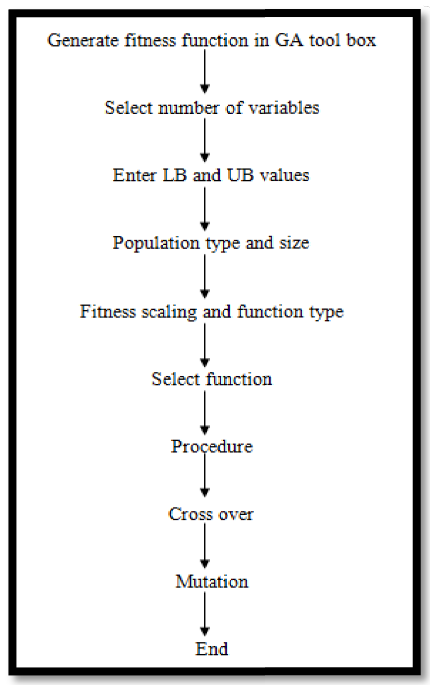

Fig.4. Steps involved in Genetic algorithm

Minimization of R_a using GA tool :-

The objective function for minimizing Surface roughness (R_a) from regression analysis is stated as:

Minimize

$$R_a = -5.92 +0.0717*x_1+0.0059*x_2+0.0122*x_3-0.0083*x_4$$

The process parameters of objective function are limited by its LB and UB are given as

$$110 \le x_1 \le 123$$
$$50 \le x_2 \le 63$$
$$4 \le x_3 \le 10$$
$$20 \le x_4 \le 60$$

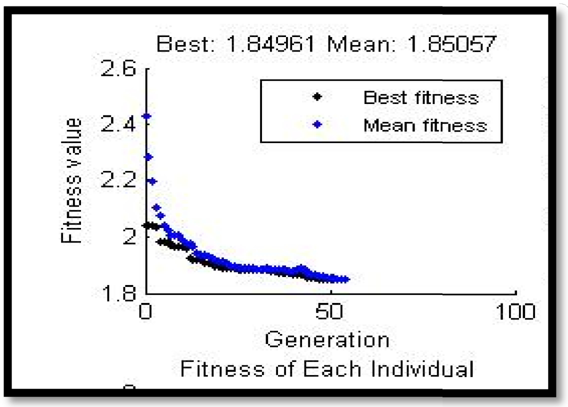

Fig.5. Fitness value plot for R_a

The optimization carried out by using GA parameters is as follows: number of population is 20, cross over fraction 0.8, migration fraction 0.2 and migration interval of 20. Based on the objective function the optimum value of R_a = 1.8495are obtained at 54 iterations and the optimal setting for minimum R_a of 1.8495 is at Pulse on time 110.011, Pulse off time 50.795, Wire tension 4.242, Spark gap voltage 56.467. The fitness value plot for Ra is as shown in figure 5.

Maximization of MRR using GA tool:-

The objective function for maximizing Material removal rate (MRR) from regression analysis is stated as:

Maximize

$$MRR = +0.525-0.00712*x_1+0.00276*x_2+0.0019*x_3+0.00098*x_4$$

The process parameters of objective function are limited by its LB and UB are given as

$$110\le x_1 \le 123$$
$$50\le x_2 \le 63$$
$$4\le x_3 \le 10$$
$$20\le x_3 \le 60$$

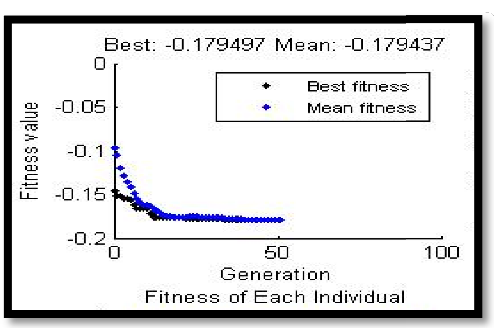

Fig.6. Fitness value plot for MRR

The optimization carried out by using GA parameters is as follows: number of population is 20, cross over fraction 0.8, migration fraction 0.2 and migration interval of 20. Based on the objective function the optimum value of MRR = 0.820506are obtained at 51 iterations and the optimal setting for minimum MRR of 0.820506 is at Pulse on time 122.998, Pulse off time 50, Wire tension 4.128, Spark gap voltage 24.465. the fitness value plot for MRR is as shown in figure 6.

B. Multi objective optimization

The classical optimization techniques such as weighted component, mini-max method, goal programming etc. are not effective for solving multi-objective optimization because they can't find multiple solutions in a single run even though, majority of researchers used classical optimization techniques for finding optimal process variables. In this paper non-dominated sorting algorithm (NSGA) is applied to find the optimal process parameters of Wire EDM process. The multi objective optimization problem for minimum surface roughness and maximum MRR is stated as follows:

Minimum

$$R_a = -5.92 +0.0717*x_1+0.0059*x_2+0.0122*x_3-0.0083*x_4$$

And Maximum

$$MRR = +0.525-0.00712*x_1+0.00276*x_2+0.0019*x_3+0.00098*x_4$$

The process parameters of multi objective function are limited by its LB and HB as given as

$$110 \le x_1 \le 123$$
$$50 \le x_2 \le 63$$
$$4 \le x_3 \le 10$$
$$20 \le x_3 \le 60$$

The above multi objective problem is solved by using Non-Dominated sorting algorithm, the optimization carried by population size of 45. Cross over fraction of 0.8, migration fraction of 0.2, migration interval of 20 and pareto fraction of 0.35. According to algorithm, ranking and sorting of solutions are done. The Pareto optimal solutions for objective function and the corresponding process parameters are tabulated in table 6.

Table 6. Pareto-Optimal Solutions

S.no	MRR	Ra	Ton	Toff	WT	SGV
1	-0.162	2.877	120.44	50.37	4.26	22.33
2	-0.0698	1.998	110.28	50.82	4.39	41.02
3	-0.153	2.779	119.16	50.19	4.23	22.95
4	-0.058	1.910	110.07	51.07	4.38	50.01
5	-0.126	2.510	115.33	50.22	4.36	22.51
6	-0.078	2.047	110.51	50.30	4.24	36.54
7	-0.093	2.195	111.13	50.59	4.36	24.35
8	-0.158	2.832	119.87	50.20	4.23	22.61

9	-0.182	3.073	122.98	50.17	4.23	20.48
10	-0.176	3.031	122.48	50.67	4.23	21.48
11	-0.117	2.455	114.71	50.50	4.85	24.67
12	-0.137	2.638	117.73	50.33	4.38	27.82
13	-0.128	2.535	115.72	50.25	4.33	22.70
14	-0.109	2.384	115.33	50.63	4.45	38.05
15	-0.130	2.582	117.37	50.50	4.49	31.78
16	-0.145	2.725	118.68	50.45	4.45	25.81
17	-0.140	2.677	118.13	50.33	4.56	26.88
18	-0.151	2.774	119.50	50.28	4.31	26.62
19	-0.135	2.618	116.77	50.37	4.65	22.34
20	-0.082	2.096	111.10	50.27	4.38	35.93
21	-0.166	2.913	120.87	50.22	4.35	21.62

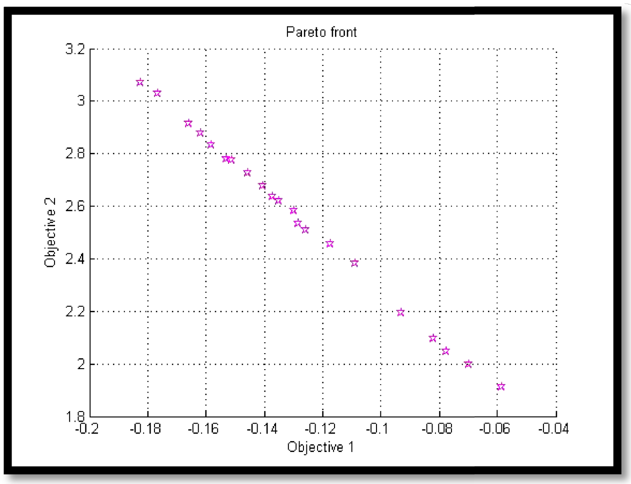

Fig.7: Pareto-optimal front

Figure 7 shows the Pareto optimal front formation that consists of final set of solutions. Since, none of these solutions in the Pareto front optimal sets is obviously better than any other, any of them is acceptable solution. The choice of one solution over the other solution depends upon the requirement of process engineer. It should be noted that all set of solutions are equally good and any set of process parameters can be taken for achieving best surface finish or higher production rate depends upon the requirement of manufacturer.

VI. CONCLUSION

In this research, WEDM experiments were carried out on Incoloy 825 based on parametric approach of the Taguchi method. Grey-Taguchi method and Regression analysis was performed to find out the relationship between certain process parameters like pulse on time, pulse off time, wire tension and spark gap voltage and responses are recorded using Minitab 14 software. General first order model was developed to predict the surface roughness and MRR over the experimental region. Based on Grey-Taguchi method Pulse on time has more significant effect and Wire tension has less significant effect on maximum material removal rate and lower surface finish for machining the Incoloy 825. The optimal setting for R_a and MRR were obtained individually by using genetic algorithm (GA), the optimal process parameter setting form minimum surface roughness is found to be at Pulse on time 110.07, Pulse off time 51.07, Wire tension 4.38, Spark gap voltage 50.01 and optimal setting for maximum MRR is found to be at Pulse on time 122.48, Pulse off time 50.67, Wire tension 4.23, Spark gap voltage 21.48.

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