Optimisation of Wireedm Parameters for H11 Tool Steel using Correlation - TOPSIS

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Abstract—Machining with Multi Parameter operations like Wire Electro Discharge Machining (Wire EDM) is always a difficult task. The difficulty lies in determining the optimum settings for the required outputs. This owes to the fact that the output responses rarely depend upon a single input. The output invariably is dependent upon a set of input conditions. The primary object of this paper is to determine an optimum set of parameters for machining of H11 tool steel. The experiments were designed using L16 Orthogonal Array and the results were optimized using a new technique namely CORRELATION – TOPSIS. The results have been verified with a validating experiment.

Keywords-WireEDM, Orthogonal Array,Correlation, TOPSIS, Normalisation, Positive Ideal Solution, Negative Ideal Solution

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I. INTRODUCTION

Unlike machining operations like Lathe and milling operations, where the output responses can be predicted with respect to the relevant Input conditions, it is rather a difficult process to do so in WEDM. The fact that, at most of the times, even a single output response is controlled by multiple responses as shown by many researchers like H. Singh et al [1] in his research concluded that the material removal rate (MRR) was directly increasing with the increase in the pulse on time (Ton) and also the peak current while it also decreased with the increase in the (Toff) pulse off time and the (SV) Servo Voltage.

This makes researches being carried out in machining of various materials for studying the effect and the optimisation of input parameters very important. This paper deals with machining of H11 tool steel in using WEDM and optimisation of the process parameters for a select number of output responses.

This paper uses L16 Orthogonal array for design of the experiment and is proposing a methodology using Coefficient of determination derived from the Correlation among the input and output parameters and using the same as the weight factor while calculating the Ideal Solution using Technique for Order of Preference by Similarity to Ideal Solution (*TOPSIS*)

II. RELATED WORKS

A few selected research papers related to optimisation of Wire EDM parameters has been done to study the various methodologies used by the researchers

Sarkar et. al [2] in their research an experimental investigation on single pass cutting of wire electrical discharge machining of γ-TiAl alloy was carried out. The process was remodelled using an additive model based on matrix experiments using orthogonal arrays. The influence of various process parameters was observed using the new model. It was noted that both surface roughness as well as dimensional deviation is independent of the pulse off time. The entire process was also using constrained optimization and Pareto optimization algorithm. Based on constrained optimization algorithm the WEDM process was optimized under single constraint as well as multi-constraint condition. By using Pareto optimization algorithm, the 20 Pareto-optimal solutions were searched out from the set of all 243 outputs. This set of 20 Pareto-optimal can be used as a guideline for optimum machining of γ-titanium aluminide alloy. **Kumar et. al [3]** have based their work upon the optimization of Wire Electrical Discharge Machining process parameters of Incoloy800 super alloy with multiple responses such as Material Removal Rate (MRR), surface roughness and Kerf based. This optimisation technique is based on the Grey–Taguchi Method. The process parameters considered in this research work are Gap Voltage, Pulse On-time, Pulse Off-time and Wire Tension. The researchers have used Taguchi's L9 Orthogonal Array for designing of the experiments. Grey Relational Analysis was used to identify the optimal level of process parameters and the relatively significant parameters were determined by Analysis of Variance. The variation of output responses with process parameters were mathematically modelled by using non-linear regression analysis method and the models were checked for their adequacy. The mathematical model developed was a Grey Taguchi model and the confirmation experiments was performed which showed that this model can be used greatly simplifies the optimization of complicated multiple performance characteristics. This was also proved by conduction of a confirmation experiment. **Ramkrishna and Krishnamoorthy [4]** present a multi response optimization method using Taguchi's robust design approach for wire electrical discharge machining (WEDM) operations. Experimentation was planned as per Taguchi's L16 orthogonal array. The output responses which were observed were material removal rate, surface roughness, and wire wear ratio. The machining parameters were optimized with the multi response characteristics of the material removal rate, surface roughness, and wire wear ratio. To measure the performance characteristics Multi response S/N (MRSN) ratio was applied. For identification of the level of importance of machining parameters Analysis of variance (ANOVA) has been used. An experimental confirmation was also carried out for identification of the effectiveness of the proposed methodology and an improvement was also noticed. **Tang et al [5]**utilises a feed forward neural network to associate the cutting parameters for improving cutting performance. Owing to the complexity of wire electrical discharge machining (wire-EDM), it is very difficult to determine optimal cutting parameters for improving cutting performance. The paper utilizes a feedforward neural network to associate the cutting parameters with the cutting performance. A simulated annealing (SA) algorithm is then

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applied to the neural network for solving the optimal cutting parameters based on a performance index within the allowable working conditions. Experimental results have shown that the cutting performance of wire-EDM can be greatly enhanced using this new approach

All researchers have stated that the problem of setting and finding the optimal input parameters for Wire EDM and for that matter all Multi Criteria machining systems is difficult.

With so many MCDM tools available, the choice of these tools also poses a difficult task. A few researches have also been done in this regard wherein **Valesquez and Hester [6]** has done a study on various MCDM tools namely Multi-Attribute Utility Theory (MAUT), Analytic Hierarchy Process (AHP), Case-Based Reasoning (CBR), Data Envelopment Analysis (DEA), Fuzzy Set Theory, Simple Multi-Attribute Rating Technique (SMART), Goal Programming (GP), ELECTRE, PROMETHEE, Simple Additive Weighting (SAW), Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS). This research aims at listing the advantages, disadvantages and the suitability of MCDM tools to their specific functions. This work has stated that TOPSIS is a simple and easy to use program with the drawback of not considering the correlation of attributes and difficulty in giving weights to the various attributes. **Sun and Li [7]** have done a study on MCDM tools for finding the best tool in aircraft selection problem. A study of TOPSIS, SAW, ELECTRE, Permutation Method, Hierarchical Tradeoffs, Interctive SAW, Linear Assignment Method, AHP, Multi Dimension Scaling, LINMAP, Goal Attainment, Goal Programming, Parametric Method, EUT, Physical Programming and MAUT was made and evaluation method was developed for it. TOPSIS was chosen as the best MCDM tool.

Having reviewed some of the work being done in the field of Wire EDM and it parameter optimisation techniques, the next chapter explains about the Objectives of this present work and the research methodology being used.

III. MATERIAL SELECTED

H11 tool steel was chosen as the material for the study and optimisation. The reasons for the same being:-
   a. Not much research has been made for study of H11 steel in wire EDM process
   b. It is suitable for designing highly stressed structural parts such as aircraft landing gear
   c. It is one of the most predominantly used Chromium Hot Work tool steels

Its composition is as follows:

Table I Chemical Composition of H11

Element	Content (%)
Carbon, C	0.33-0.43
Manganese, Mn	0.20-0.50
Silicon, Si	0.80-1.20
Chromium, Cr	4.75-5.50
Nickel, Ni	0.3
Molybdenum, Mo	1.10-1.60
Vanadium, V	0.30-0.60
Copper, Cu	0.25
Phosphorous, P	0.03
Sulphur, S	0.03

Iron, Fe	Balance

The size of the specimen is at 20mm X 60mm with the thickness kept at 10mm.

The hardness of the specimen was measured at 52.5 (Rockwell C) air-cooled from 982°C, 45 minutes.

IV. SELECTION OF INPUT PARAMETERS AND OUTPUT RESPONSES

A. Input Paramters

a) **Ton – Pulse On Time** - The duration of time (µs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.

b) **Toff – Pulse Off Time -** The duration of time (µs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.

c) **Ip – Peak Current** - Current is measured in (amp) Allowed to per cycle. Discharge current is directly proportional to the Material removal rate.

d) **WT – Wire Tension –** The unit depends upon the manufacturer of the machine and thus is taken up in machine units. It is the amount of tension given to the wire in order to reduce the tapering effect and to maintain the straightness of the wire.

B. Output Paramters

a. **Surface Roughness** (µm) :- Surface Roughness is one of the most important output characteristics in WireEDM. This output response finds its place in almost all of the researches done in Wire EDM. (Lower the Ra value, better it is)

b. **Cutting Speed (mm/min)** :- Cutting speed forms a very important criteria when calculating the MRR. The formula for calculation of MRR is given as :-

$$MRR = ktv_c\rho \text{ [7]} \qquad (1)$$

Where, k is the Kerf width (mm), t is the thickness of work piece (mm), vc is the Cutting speed (mm/min) and ρ is the Density of the work piece material (g/mm3).

Thus observation of this response is very important as it is used for calculation of MRR which is also one of the most important responses in Wire EDM. (Higher the CS value, better it is)

c. **Gap Current** (**amp**) – This is one of the "bad" discharges in Wire EDM and badly affects the performance of the machine [8]. (Lower the value, better it is)

V. MACHINE USED

ELECTRONICA SPRINTCUT – 734
   a. 4 axes CNC with precision guideways
   b. Maximum cutting speed of 160 mm^2/min
   c. Best surface finish – 0.8 µ Ra
   d. Taper $\pm$30°/50 mm
   e. Flushing pressure – 12 kgf
   f. Wire feed (max) – 12m/min
   g. Wire Tension – (max) – 12 grams
   h. Voltage Range – 0 – 100 V

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Figure 1 Wire EDM Sprintcut 734

i.   Tool – Soft Brass wire of 0.25 mm thickness
j.   Dielectric used – Deionized or Distilled water

VI.   EXPERIMENTAL WORK

A.   Design of Experiments

For the present work a 4 level 4 factor L16 factorial design was developed. **MINITAB** software has been used to design the orthogonal array for the present work.

The levels for the Input parameters selected, Pulse on Time (Ton), Pulse off time (Toff), Peak Current (Ip) and Wire Tension (WT) are shown in the Table 1 and the design matrix is depicted in Table 2

Table 1 Levels used for Input parameters

S. No	Parameter	Unit	Level			
			1	**2**	**3**	**4**
1	Ton	μsec	15	20	25	30
2	Toff	μsec	30	40	50	60
3	Ip	mA	140	160	180	200
4	Wf	Machine units	5	6	7	8

B.   Conduction Of Experiments

The experiments were conducted adhering strictly to the orthogonal array design. The roughness of surface was measured using **Mitutoyo's Surftest J210** and the cutting speed and the Gap current was observed from the machine itself.

C.   Design Matrix

Table 2 Design matrix

Expt. Number	Input Process parameters			
	Ton	**Toff**	**Ip**	**Wf**
C1	1	1	1	1
C2	1	2	2	2
C3	1	3	3	3
C4	1	4	4	4
C5	2	1	2	3
C6	2	2	1	4
C7	2	3	4	1
C8	2	4	3	2
C9	3	1	3	4
C10	3	2	4	3
C11	3	3	1	2
C12	3	4	2	1
C13	4	1	4	2
C14	4	2	3	1
C15	4	3	2	4
C16	4	4	1	3

D.   Response Table

Table 3 shows the response table for the experiment conducted

Table 3 Response Table

Expt. No.	Input Process parameters				Output Responses		
	Ton	**Toff**	**Ip**	**WT**	**GC**	**CS**	**Ra**
C1	15	30	140	5	5.500	3.000	2.928
C2	15	40	160	6	3.000	3.190	2.919
C3	15	50	180	7	1.800	1.920	2.232
C4	15	60	200	8	1.000	1.250	2.322
C5	20	30	160	7	6.000	2.110	3.770
C6	20	40	140	8	4.800	3.500	3.139
C7	20	50	200	5	2.900	3.240	2.798
C8	20	60	180	6	1.000	1.200	2.882
C9	25	30	180	8	6.000	3.600	2.690
C10	25	40	200	7	7.000	3.300	3.409
C11	25	50	140	6	2.700	2.630	3.254
C12	25	60	160	5	1.200	1.900	2.026
C13	30	30	200	6	0.800	3.200	3.514
C14	30	40	180	5	5.500	3.000	3.713
C15	30	50	160	8	4.000	3.460	3.216
C16	30	60	140	7	2.500	1.800	3.033

VII.   CORRELATION TOPSIS

The drawback of TOPSIS as highlighted by many researchers is the subjective weight factor which is to be allocated to each criterion. This weight factor although has the condition that all weights must sum up to 1, the weights

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still becomes subjective and can vary from person to person, which in turn will affect the results.

This optimisation technique developed will aim to address this matter by using the normalised Coefficient of Determination, R, as the weight factor for the criterion.

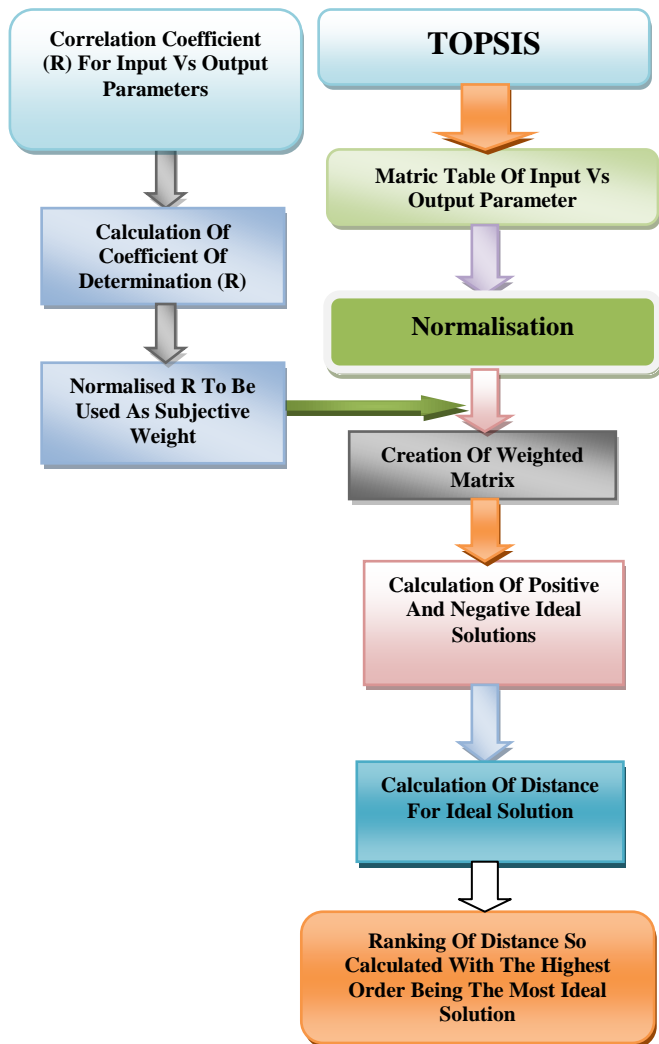The following flowchart gives an idea of the technique used.

Figure 2 Flowchart for Correlation TOPSIS

A. Correlation

The Pearsons Correlation Coefficient (r) for the output parameters against the Input Parameters is calculated using the formula as per (2)

$$r = \frac{\sum_i (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_i (x_i - \overline{x})^2} \sqrt{\sum_i (y_i - \overline{y})^2}} \qquad (2)$$

The Coefficient of Determination (R) is the square of the Correlation Coefficient (r) and explains how much of the variability of a factor can be caused or explained by its relationship to another factor.

The following table 4 lists out the (r) and (R) for the Input parameters and the output responses selected.

Table 4 List for calculated (r) and (R)

S. N	I/P	GC		CS		Ra	
		(r)	(R)	(r)	(R)	(r)	(R)
1	Ton	0.093	0.009	0.271	0.073	0.458	0.210
2	Toff	-0.648	0.420	-0.670	0.449	-0.549	0.301
3	Ip	-0.157	0.025	-0.027	0.001	-0.077	0.006
4	WT	0.165	0.027	0.032	0.001	-0.024	0.001

B. Normalisation of Coefficient of Determination

The normalisation of the Coefficient of Determination (R) was done in order to satisfy the condition applied in allotment of Weight factor in TOPSIS whereby the sum of all weights must be equal to 1.

Table 5 hows the value of normalised Coeeficient of Determination

Table 5 Table for R for Input Vs Output

		OUTPUT RESPONSES		
		CS	Ra	GC
INPUT PARAMETERS	Ton	0.13971300	0.40570000	0.017991407
	Toff	0.856913429	0.581702105	0.874076182
	Ip	0.001368180	0.011459478	0.051176716
	WT	0.002004895	0.001108811	0.056755695

C. TOPSIS

The following are the steps for traditional TOPSIS
Step 1: Construct normalized decision matrix.
This step transforms various attribute dimensions into non-dimensional attributes, which allows comparisons across criteria.
Normalize scores or data as follows:

$$r_{ij} = x_{ij}/ (\Sigma x^2_{ij}) \quad \text{for } i = 1, \dots, m; \, j = 1, \dots, n \qquad (3)$$

Step 2: Construct the weighted normalized decision matrix.
Assume we have a set of weights for each criteria w_j for j = 1,…n.
Multiply each column of the normalized decision matrix by its associated weight.
An element of the new matrix is:

$$v_{ij} = w_j \, r_{ij} \qquad (4)$$

Step 3: Determine the ideal and negative ideal solutions.
Ideal solution.

$$A^* = \{ v_1^*, \dots, v_n^* \}, \text{ where} \qquad (5)$$
$$v_j^* = \{ \max_i (v_{ij}) \text{ if } j \in J ; \, \min (v_{ij}) \text{ if } j \in J' \} \qquad (6)$$

Negative ideal solution.

$$A' = \{ v_1', \dots, v_n' \}, \text{ where} \qquad (7)$$
$$v_i' = \{ \min_i (v_{ij}) \text{ if } j \in J ; \, \max (v_{ij}) \text{ if } j \in J' \} \qquad (8)$$

Step 4: Calculate the separation measures for each alternative.
The separation from the ideal alternative is:

$$S_i^* = [\Sigma (v_j^* - v_{ij})^2]^{\frac{1}{2}} \qquad i = 1, \dots, m \qquad (9)$$

Similarly, the separation from the negative ideal alternative is:

$$S'_i = [\Sigma (v'_j - v_{ij})^2]^{½} \qquad i = 1, …, m \qquad (10)$$

Step 5: Calculate the relative closeness to the ideal solution C_i^*

$$C_i^* = S'_i / (S_i^* + S'_i) , \qquad 0 < C_i^* < 1 \qquad (11)$$

Select the option with C_i^* closest to 1.

Step 1 Matrix For Output Responses

Table 6 Matrix for Output Responses

Expt	CS	Ra	GC
C1	3	2.928	5.5
C2	3.19	2.919	3
C3	1.92	2.232	1.8
C4	1.25	2.322	1
C5	2.11	3.77	6
C6	3.5	3.139	4.8
C7	3.24	2.798	2.9
C8	1.2	2.882	1
C9	3.6	2.69	6
C10	3.3	3.409	7
C11	2.63	3.254	2.7
C12	1.9	2.026	1.2
C13	3.2	3.514	0.8
C14	3	3.713	5.5
C15	3.46	3.216	4
C16	1.8	3.033	2.5

Step 2 – Normalised Matrix

Table 7 Normalised Matrix for Output Responses

Expt no	CS	Ra	GC
C1	0.0492	0.0480	0.0902
C2	0.0523	0.0479	0.0492
C3	0.0315	0.0366	0.0295
C4	0.0205	0.0381	0.0164
C5	0.0346	0.0619	0.0984
C6	0.0574	0.0515	0.0788
C7	0.0532	0.0459	0.0476
C8	0.0197	0.0473	0.0164
C9	0.0591	0.0441	0.0984
C10	0.0541	0.0559	0.1149
C11	0.0432	0.0534	0.0443
C12	0.0312	0.0332	0.0197
C13	0.0525	0.0577	0.0131
C14	0.0492	0.0609	0.0902
C15	0.0568	0.0528	0.0656
C16	0.0295	0.0498	0.0410

Step 3 – Calculation of Weight Matrix

Weight matric for all the Input parameters are calculated using the weight factor as the normalized Coefficient of Determination found in table 6

I. Weight matrix for Ton

Table 8 Weighted Matrix for Ton Vs Output Responses

Expt no	CS	Ra	GC
C1	0.006877	0.006712	0.012608
C2	0.007313	0.006691	0.006877
C3	0.004401	0.005117	0.004126
C4	0.002865	0.005323	0.002292
C5	0.004837	0.008642	0.013754
C6	0.008023	0.007196	0.011003
C7	0.007427	0.006414	0.006648
C8	0.002751	0.006607	0.002292
C9	0.008253	0.006167	0.013754
C10	0.007565	0.007815	0.016047
C11	0.006029	0.007459	0.006189
C12	0.004356	0.004644	0.002751
C13	0.007336	0.008055	0.001834
C14	0.006877	0.008512	0.012608
C15	0.007932	0.007372	0.009170
C16	0.004126	0.006953	0.005731

II. Weight matrix for Toff

Table 9 Weighted Matrix for Toff Vs Output Responses

Expt no	CS	Ra	GC
C1	0.042180208	0.041167883	0.077330382
C2	0.044851622	0.041041343	0.042180208
C3	0.026995333	0.031382075	0.025308125
C4	0.017575087	0.032647481	0.014060069
C5	0.029666747	0.053006462	0.084360417
C6	0.049210243	0.044134558	0.067488333
C7	0.045554625	0.039340074	0.040774201
C8	0.016872083	0.04052112	0.014060069
C9	0.05061625	0.037821587	0.084360417
C10	0.046398229	0.047930777	0.098420486
C11	0.036977983	0.045751466	0.037962188
C12	0.026714132	0.028485701	0.016872083
C13	0.044992222	0.049407084	0.011248056
C14	0.042180208	0.052205038	0.077330382
C15	0.04864784	0.045217183	0.056240278
C16	0.025308125	0.042644191	0.035150174

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III. Weight matrix for Ip

Table 10 Weighted Matrix for Ip Vs Output Responses

Expt no	CS	Ra	GC
C1	6.735E-05	5.505E-04	4.618E-03
C2	7.161E-05	5.488E-04	2.519E-03
C3	4.310E-05	4.197E-04	1.511E-03
C4	2.806E-05	4.366E-04	8.397E-04
C5	4.737E-05	7.089E-04	5.038E-03
C6	7.857E-05	5.902E-04	4.031E-03
C7	7.273E-05	5.261E-04	2.435E-03
C8	2.694E-05	5.419E-04	8.397E-04
C9	8.082E-05	5.058E-04	5.038E-03
C10	7.408E-05	6.410E-04	5.878E-03
C11	5.904E-05	6.118E-04	2.267E-03
C12	4.265E-05	3.809E-04	1.008E-03
C13	7.184E-05	6.607E-04	6.718E-04
C14	6.735E-05	6.981E-04	4.618E-03
C15	7.767E-05	6.047E-04	3.359E-03
C16	4.041E-05	5.703E-04	2.099E-03

IV. Weight matrix for WT

Table 10 Weighted Matrix for WT Vs Output Responses

Expt no	CS	Ra	GC
C1	9.869E-05	5.327E-05	5.122E-03
C2	1.049E-04	5.311E-05	2.794E-03
C3	6.316E-05	4.061E-05	1.676E-03
C4	4.112E-05	4.224E-05	9.312E-04
C5	6.941E-05	6.859E-05	5.587E-03
C6	1.151E-04	5.711E-05	4.470E-03
C7	1.066E-04	5.090E-05	2.701E-03
C8	3.948E-05	5.243E-05	9.312E-04
C9	1.184E-04	4.894E-05	5.587E-03
C10	1.086E-04	6.202E-05	6.519E-03
C11	8.652E-05	5.920E-05	2.514E-03
C12	6.250E-05	3.686E-05	1.117E-03
C13	1.053E-04	6.393E-05	7.450E-04
C14	9.869E-05	6.755E-05	5.122E-03
C15	1.138E-04	5.851E-05	3.725E-03
C16	5.921E-05	5.518E-05	2.328E-03

STEP 4 – Calculation Of Positive And Negative Ideal Solution And Distance From Ideal Solution

I. FOR Ton

Table 11 Table for Positve and Negative Ideal Solution for Ton

	CS	Ra	GC
A+	0.008253	0.005117	0.002292
A-	0.002865	0.008642	0.012608

Table 12 Values of S^+, S^- and S for Ton

Expt no	S^+	S^-	S
C1	0.0105286487	0.00445188	0.29717796
C2	0.0049380002	0.00751184	0.60336851
C3	0.0042655742	0.00931297	0.68585915
C4	0.0053910704	0.01083666	0.66778663
C5	0.0124689149	0.00228044	0.15461289
C6	0.0089587221	0.00559206	0.38431318
C7	0.0046190168	0.00782941	0.62894778
C8	0.0056999486	0.01051532	0.64848264
C9	0.0115099456	0.00603857	0.34410721
C10	0.0140333581	0.00588159	0.29533552
C11	0.0050616638	0.00725304	0.58897401
C12	0.0039522566	0.01074103	0.73101622
C13	0.0031125281	0.01167951	0.78958092
C14	0.0109468284	0.00401381	0.26829152
C15	0.0072447769	0.00625324	0.46327096
C16	0.0056764370	0.00719302	0.55892192

II. FOR Toff

Table 13 Table for Positve and Negative Ideal Solution for Toff

	CS	Ra	GC
A+	0.05061625	0.028485701	0.011248056
A-	0.016872083	0.053006462	0.098420486

Table 14 Values of S^+, S^- and S for Toff

Expt no	S^+	S^-	S
C1	0.07245327	0.06240976	0.46276407
C2	0.04244366	0.08219190	0.65945787
C3	0.03958621	0.09087124	0.69655843
C4	0.04371568	0.09963362	0.69504084
C5	0.08121413	0.05631229	0.40946526
C6	0.06305855	0.06937031	0.52383075
C7	0.04133822	0.08339944	0.66859873
C8	0.04424942	0.09963114	0.69245727
C9	0.07846561	0.06438975	0.45073385
C10	0.09180555	0.06067519	0.39792033
C11	0.04136523	0.08288026	0.66706856
C12	0.03760819	0.09775834	0.72217511

C13	0.02903558	0.10582750	0.78470328
C14	0.07245327	0.06240976	0.46276407
C15	0.05328799	0.07482348	0.58404983
C16	0.04498052	0.08296978	0.64845316

III.   FOR Ip

Table 15 for Positve and Negative Ideal Solution for Ip

	CS	Ra	GC
A+	8.0816E-05	3.8094E-04	1.0076E-03
A-	2.6939E-05	7.0885E-04	8.3970E-04

Table 16 Values of S^+, S^- and S for Ip

Expt no	S^+	S^-	S
C1	0.00361471	0.00466364	0.56335413
C2	0.00152078	0.00266564	0.63673486
C3	0.00050671	0.00179086	0.77945799
C4	0.00018462	0.00131771	0.87711098
C5	0.00404400	0.00507306	0.55643583
C6	0.00303015	0.00409400	0.57466526
C7	0.00143487	0.00258906	0.64341541
C8	0.00023877	0.00131771	0.84659574
C9	0.00403248	0.00507306	0.55713996
C10	0.00487719	0.00589631	0.54729752
C11	0.00128072	0.00243735	0.65554126
C12	0.00003816	0.00142107	0.97384725
C13	0.00043723	0.00122868	0.73754179
C14	0.00362463	0.00466364	0.56267953
C15	0.00236178	0.00345044	0.59365317
C16	0.00110864	0.00228790	0.67359700

IV.   FOR WT.

Table 17 for Positve and Negative Ideal Solution for WT

	CS	Ra	GC
A+	1.1843E-04	3.6859E-05	6.519E-03
A-	3.9475E-05	6.8588E-05	7.4499E-04

Table 18 Values of S^+, S^- and S for WT

Expt no	S^+	S^-	S
C1	0.00412723	0.00515480	0.55535271
C2	0.00181607	0.00291894	0.61645949
C3	0.00075043	0.00192504	0.71951427
C4	0.00034947	0.00137247	0.79705008
C5	0.00459043	0.00561098	0.55001989
C6	0.00347758	0.00451938	0.56513749

C7	0.00172501	0.00283260	0.62151016
C8	0.00033980	0.00137247	0.80155080
C9	0.00459195	0.00561098	0.54993802
C10	0.00552031	0.00652734	0.54179389
C11	0.00154068	0.00266129	0.63334357
C12	0.00036165	0.00149503	0.80521647
C13	0.00041240	0.00126553	0.75422032
C14	0.00412612	0.00515480	0.55541909
C15	0.00273657	0.00380002	0.58134574
C16	0.00136021	0.00249213	0.64691217

Step 5 – Ranking Of Ideal Solution

Table 19 Table depicting the ranking order

Ideal Solution	for Ton		for Toff		for Ip	
1	C13	0.79	C13	0.78	C12	0.97
2	C12	0.73	C12	0.72	C4	0.88
3	C3	0.69	C3	0.70	C8	0.85
4	C4	0.67	C4	0.70	C3	0.78
5	C8	0.65	C8	0.69	C13	0.74
6	C7	0.63	C7	0.67	C16	0.67
7	C2	0.60	C11	0.67	C11	0.66
8	C11	0.59	C2	0.66	C7	0.64
9	C16	0.56	C16	0.65	C2	0.64
10	C15	0.46	C15	0.58	C15	0.59
11	C6	0.38	C6	0.52	C6	0.57
12	C9	0.34	C1	0.46	C1	0.56
13	C1	0.30	C14	0.46	C14	0.56
14	C10	0.30	C9	0.45	C9	0.56
15	C14	0.27	C5	0.41	C5	0.56
16	C5	0.15	C10	0.40	C10	0.55

VIII.   CONCLUSION

Thus based on the above table 19 the Optimised levels of Input Characteristics are shown in table 20

Table 20 Table depicting the optimised value and their corresponding responses

	Ton	Toff	Ip	WT	GC	CS	Ra
Level	4	1	2	1	NA		
Values	130	30	160	5	1.4	3.48	2.72

Although the individual values for the responses are not the lowest, the combination of the result is the best. The values are for a combined optimised response and the mathematical model has proven that the entire response can be optimised as a combined result.

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