Optimization of Turning Parameters through Desirability Function Analysis (DFA)

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Abstract

In present days the manufacturers are facing the challenges in attaining the high productivity, quality and overall economy in the field of manufacturing by machining. The present work is to investigate the effect of the process parameters on the multiple responses of material removal rate (MRR) and surface roughness (R_a). A series of experiments were carried out on AA6061 material using coated tungsten carbide inserts on CNC machine. Speed, feed, depth of cut and nose radius are considered as the process parameters and taguchi's standard L18 orthogonal array (OA) has been followed for conducting the experiments. The optimal setting of process parameters was done by employing taguchi method coupled with the desirability function analysis (DFA) and analysis of variance (ANOVA). From the results, it is concluded that depth of cut is the most influencing factor for the combined desirability index value. The optimal combination of process parameters for multi-response value is obtained at Nose radius of 0.4 mm, speed of 2500 rpm, feed of 0.15 mm/rev and depth of cut of 1.2 mm respectively.

Keywords: Material Removal Rate (MRR), Surface Roughness (R_a), Taguchi method, Desirability Function Analysis and ANOVA.

1. INTRODUCTION

Desirability function analysis (DFA) provides an efficient solution to the uncertainty in multi-input and discrete data problems. It is frequently used approach for the large scale industries to optimize the multi-responses by converting the multi response characteristics into a single response characteristic. It is an effective method to analyze the relational degree between discrete sequences. The advantage of the method is that many factors can be analyzed from less available data. It does not involve complicated mathematical theory or computation like traditional approaches and thus can be employed by engineers without strong statistical background. Taguchi methodology can be applied for analyzing the best process parameters for single performance characteristics only, where as desirability function analysis can be effectively used for analyzing the multi performance characteristics incorporating all the parameters at a time. By taking into consideration of all the advantages desirability function analysis has been employed in the present work for optimizing the multiple objectives.

2. EXPERIMENTAL DETAILS

2.1. Work Piece Details

For conducting the experiment aluminium grade AA6061-T6 has been taken as the work piece. It has high applications aircraft fittings, camera lens mounts, couplings, marine fittings, pistons, magneto parts, hinge pins and bike frames etc. The chemical composition and mechanical properties of AA6061 are given in the tables 1 and 2.

Table 1. Chemical Composition of AA6061-T6

Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Others
95.8-98.6	0.04-0.35	0.15-0.4	0.7 max	0.8-1.2	0.15 max	0.4-0.8	0.15 max	0.25 max	0.15 max

Table 2. Mechanical Properties of AA6061-T6

Density (gm/cm3)	Tensile strength (MPa)	Yield Strength (MPa)	Elongation (%)	Poisson's ratio	Hardness (BHN)
2.7	310	276	12-17	0.33	95

2.2. Selection of Process Parameters and Orthogonal Array

In turning the basic controllable process parameters are speed, feed and depth of cut. In the present work four parameters were taken at three different levels as given in the table 3. For the selected parameters at three levels the suitable taguchi standard L18 orthogonal array has been chosen and mentioned in the table 4.

Table 3. Process Parameters and Their Levels

Parameter	Levels		
	1	2	3
Nose Radius, mm	0.4	0.8	-
Speed, RPM	1500	2000	2500
Feed, mm/rev	0.1	0.15	0.2
Depth of Cut, mm	0.4	0.8	1.2

Table 4. Taguchi L18 Orthogonal Array

S.No.	Nose Radius	Speed	Feed	Depth of Cut
1	0.4	1500	0.1	0.4
2	0.4	1500	0.15	0.8
3	0.4	1500	0.2	1.2
4	0.4	2000	0.1	0.4
5	0.4	2000	0.15	0.8
6	0.4	2000	0.2	1.2
7	0.4	2500	0.1	0.8
8	0.4	2500	0.15	1.2
9	0.4	2500	0.2	0.4
10	0.8	1500	0.1	1.2
11	0.8	1500	0.15	0.4
12	0.8	1500	0.2	0.8
13	0.8	2000	0.1	0.8

14	0.8	2000	0.15	1.2
15	0.8	2000	0.2	0.4
16	0.8	2500	0.1	1.2
17	0.8	2500	0.15	0.4
18	0.8	2500	0.2	0.8

3. METHODOLOGY

Desirability function analysis (DFA) is one of the most widely used methods in industry for the optimization of multi – response characteristics. Desirability function analysis is used to convert the multi response characteristics into single – response se characteristic in terms of composite desirability (D_g).

STEP 1: Calculate the individual desirability (d_i) for the corresponding responses using the formula proposed by Derringer and Suich. There are three forms of the desirability functions according to the response characteristics.

Nominal-the-best:

The value of ŷ is required to achieve a particular target T. when the ŷ equals to T, the desirability value equals to 1; if the departure of ŷ exceeds a particular range from the target, the desirability value equals to 0, and such situation represents the worst case.

$$d_i = \begin{cases} \left(\frac{\hat{y} - y_{min}}{T - y_{min}}\right)^s, & y_{min} \le y \le T, s \ge 0 \\ \left(\frac{\hat{y} - y_{min}}{T - y_{min}}\right)^t, & T \le y \le y_{min,} T \ge 0 \\ 0 & \end{cases}$$

Where the y_{max} and y_{min} represent the upper and lower tolerance limits of ŷ and s and t represent the indices.

Larger-the-better:

The value of ŷ is expected to be the larger the better. When the ŷ exceeds a particular criteria value, which can be viewed as the requirement, the desirability value equals to 1; if the ŷ is less than a particular criteria value, which is unacceptable, the desirability equals to 0.

$$d_i = \begin{cases} 0, & \hat{y} \le y_{min} \\ \left(\frac{\hat{y} - y_{min}}{y_{max} - y_{min}}\right)^r, & y_{min} \le \hat{y} \le y_{max,} r \ge 0 \\ 1, & \hat{y} \ge y_{max} \end{cases} ; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Eq. (1)$$

Where the y_{min} represents the lower tolerance limit of ŷ, the y_{max} represents the upper tolerance limit of ŷ and r represents index.

Smaller-the-better:

The value of ŷ is expected to be the smaller the better. When the ŷ is less than a particular criteria value, the desirability value equals to 1; if the ŷ exceeds a particular criteria value, the desirability value equals to 0.

$$d_i = \begin{cases} 1, & \hat{y} \le y_{min} \\ \left(\frac{\hat{y} - y_{max}}{y_{min} - y_{max}}\right)^r, & y_{min} \le \hat{y} \le y_{max}, r \ge 0 \\ 0, & \hat{y} \ge y_{min} \end{cases} ; \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Eq.(2)$$

Where the y_{min} represents the lower tolerance limit of ŷ, the y_{max} represents the upper tolerance limit of ŷ and r represents the weight.

The s, t and r in above Equations indicate the weights and are defined according to the requirement of the user. If the corresponding response is expected to be closer to the target, the weight can be set to the larger value; otherwise, the weight can be set to the smaller value.

STEP 2: The individual desirability values have been accumulated to calculate the overall desirability,

$$D_g = \sqrt[w]{(D_1^{w_1} * D_2^{w_2} \dots\dots\dots * D_i^{w_i})}; \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{Eq. (3)}$$

Where, Di and wi are the individual desirability and weight of the response Yi.
W is the sum of the individual weights and
D_g is the Composite Desirability or overall desirability.

STEP 3: Determine the optimal parameter and its level combination. The higher composite desirability value implies better product quality.

STEP 4: Performing Analysis of variance (ANOVA) for the most significant parameter. ANOVA establishes relative significance of parameters.

STEP 5: The final step is to predict and verify the quality characteristics using the optimal level of the design parameters.

4. RESULTS & DISCUSSIONS

The turned work pieces are tested for two output characteristics namely material removal rate and surface roughness. The material removal rate is measured as the ratio of the weight differences to the density in cm^3/min and the surface roughness is with SJ-210 surf test in µm. The obtained results of the two characteristics were given in the table 5.

Table 5. Experimental Results of Responses

S.No.	MRR (cm^3/min)	R_a (µm)
1	6.0317	1.0260
2	18.0952	0.7003
3	36.1905	1.4467
4	8.0423	0.2903
5	24.1270	1.2833
6	48.2540	1.4037
7	20.1058	0.6003
8	45.2381	0.6667
9	20.1058	1.4400
10	18.0952	0.6500
11	9.0476	1.0177
12	24.1270	1.9253
13	16.0847	0.6873
14	36.1905	1.3177
15	16.0847	1.7583

16	30.1587	0.6020
17	15.0794	1.2053
18	40.2117	1.8610

For the experimental results, the individual desirability values are obtained using equations 1 and 2 and the values are given in the table 6. Finally, the individual desirabilites are combined interms of composite desirability (D_g) using the equation 3.

Table 6. Individual and the Composite Desirability Values of the Responses

S.No.	d_i of MRR	d_i of R_a	D_g
1	0.0000	0.5500	0.0008
2	0.2857	0.7492	0.4627
3	0.7143	0.2927	0.4573
4	0.0476	1.0000	0.2182
5	0.4286	0.3926	0.4102
6	1.0000	0.3190	0.5648
7	0.3333	0.8104	0.5197
8	0.9286	0.7698	0.8455
9	0.3333	0.2968	0.3145
10	0.2857	0.7800	0.4721
11	0.0714	0.5551	0.1991
12	0.4286	0.0000	0.0000
13	0.2381	0.7572	0.4246
14	0.7143	0.3716	0.5152
15	0.2381	0.1021	0.1559
16	0.5714	0.8094	0.6801
17	0.2143	0.4403	0.3072
18	0.8095	0.393	0.1784

Now the composite desirability values are analysed using taguchi method. The signal to noise ratios for the values of D_g are given in the table 7. The S/N ratios were shown in main effect plot to identify the main effecting parameter on the multiple response. From the figure 1 it is clear that depth of cut is the main effecting parameter and followed by speed, feed and nose radius.

Table 7. Response Table for Means of D_g

Level	Nose Radius	Speed	Feed	Depth of Cut
1	0.4215	0.2654	0.3859	0.1993
2	0.3259	0.3815	0.4567	0.3326
3		0.4742	0.2785	0.5892
Delta	0.0957	0.2089	0.1782	0.3899
Rank	4	2	3	1

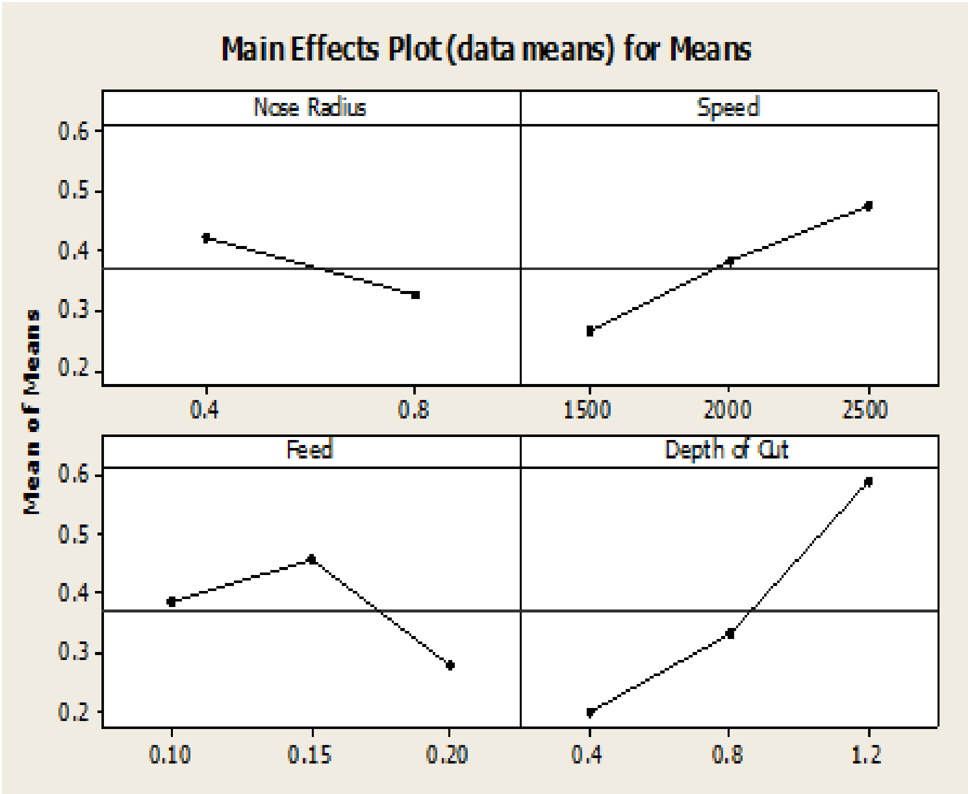

Figure 1. Main Effect Plot for Means of D_g

Analysis of variance is conducted to test the significance of the process parameters on the multi response. From the table 8, it is observed that depth of cut and cutting speed have the high significance and nose radius has low significance. Residual plots were drawn and shown in the figure 2 and it is clear that the residuals are following the normal distribution.

Table 8. ANOVA Results of D_g

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Nose Radius	1	0.04118	0.04118	0.04118	3.77	0.081
Speed	2	0.13144	0.13144	0.06572	6.02	0.019
Feed	2	0.09656	0.09656	0.04828	4.42	0.042
Depth of Cut	2	0.47121	0.47121	0.23560	21.56	0.000
Error	10	0.10926	0.10926	0.01093		
Total	17	0.84965				

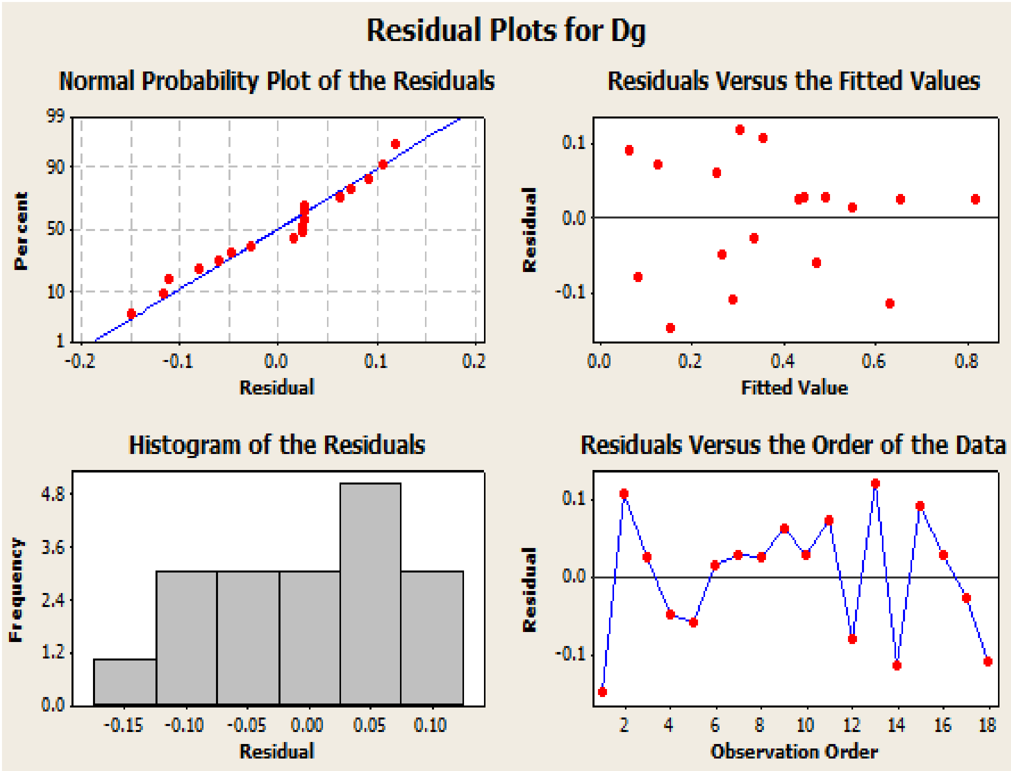

Figure 2. Residual Plots for D_g

5. CONCLUSIONS

From the experimental, Desirability Function Analysis (DFA) and ANOVA the following conclusions can be drawn

- The optimal combination of process parameters for the multi objective function is obtained at Nose radius of 0.4 mm, speed of 2500 rpm, feed of 0.15 mm/rev and depth of cut of 1.2 mm respectively.
- ANOVA results of composite desirability concluded that the the depth of cut is the high influencing factor and followed by Speed, feed and nose radius respectively.
- The normal probability and the constant variance assumptions of ANOVA are verified from the residual plots of composite desirability (D_g).
- This Desirability function analysis (DFA) method is very simple in calculations and can be apply for any industrial multi-objective problems effectively.

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