Implementation of DFA and ANOVA for the Optimization of Composite Performance Attributes

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Abstract

In recent days, the decision making process has become more complex than ever as it has to satisfy several conflicting objectives simultaneously. In the present work, the desirability function analysis (DFA) and analysis of variance (ANOVA) methods have been employed for obtaining the optimal combination of process parameters and to find the significance of process parameters. The turning experiments were carried out on AA7075 material using taguchi's L9 orthogonal array with tungsten carbide insert. From the optimization results, the optimal combination of turning process parameters is obtained at speed of 1500 rpm, feed of 0.3 mm/rev and depth of cut of 1 mm.

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

1. Introduction

In the present era of globalization there is a need for developing the cutting tools which can works at high speeds with longer life and stability. But high production with high cutting speed and feed generates large amount of heat and temperature at the chip-tool interface which ultimately reduces dimensional accuracy, tool life and surface integrity of the machined component. This temperature needs to be controlled at an optimum level to achieve better surface finish and ensure overall machining economy. To reduce this tool with high hardness and temperature resistance like tungsten carbide tools must be used which also provides better surface finish. In real practice the traditional experimental design procedures are too complicated and not easy to use when the number of process parameters is more. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. In view of the fact, that traditional Taguchi method cannot solve a multi-objective optimization problem; to overcome this limitation Desirability Function Analysis has been coupled with Taguchi method. Desirability function analysis (DFA) can provide efficient solution to the uncertainty in multi-input and discrete data problems. It had been most widely used in industry to optimize the multi-response process the multi response characteristics into single response characteristics. It is an effective method to analyze the relational degree between discrete sequences. The advantage of the above method is that many factors can be analyzed using less data. It does not involve complicated mathematical theory or computation like traditional approaches and thus can be employed by engineers without strong statistical background.

The main objective of this paper is to optimize the process parameters in machining of AA7075 alloy with tungsten carbide insert. Moreover, the desirability function analysis was employed in order to convert the multiple performance characteristics into one numerical score called composite desirability value. Based on composite desirability value, the optimal level of parameters can be obtained. The Taguchi's L9 orthogonal array is utilized for experimental investigation. The experimental data were statistically surveyed by analysis of variance (ANOVA) to investigate the most influencing parameters on material removal rate and surface roughness characteristics etc.

2. Experimental Details

In the present work turning experiments were performed on AA7075 cylindrical parts each of 32 mm diameter and 65 mm of length. The machining was done on CNC turret lathe with a tungsten carbide tool. AA7075 has applications in the field of marine, automotive and aviation etc. The chemical composition and mechanical properties of AA7075 are given in the tables 1 and 2.

Table 1. Chemical Composition of AA7075

Aluminium	87.1 to 91.4 %
Chromium	0.18 to 0.28 %
Copper	1.2 to 2.0 %
Iron	0.5 % max
Magnesium	2.1 to 2.9 %
Manganese	0.3 % max
Silicon	0.4 % max
Titanium	0.2 % max
Zinc	5.1 to 6.1 % max
Residuals	0.05% max

Table 2. Mechanical Properties of AA7075

Density	2.8 gm/cm^3
Ultimate Tensile Strength	83000 Psi
Yield Strength	73000 Psi
Hardness	150 BHN
Elongation	3 to 9%

The experiments were conducted as per the taguchi's standard L9 (3^3) orthogonal array with DOF is 8. The selected process parameters with their levels and L9 OA with actual experimental values are specified in the tables 3 and 4.

Table 3. Process Parameters with Their Levels

Parameter	Level1	Level2	Level3
Speed, rpm	1000	1500	2000
Feed, mm/rev	0.2	0.3	0.4
Doc, mm	0.5	0.75	1

Table 4. L9 Orthogonal Array

S.No.	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1	1000	0.2	0.5
2	1000	0.3	0.75
3	1000	0.4	1
4	1500	0.2	0.75
5	1500	0.3	1
6	1500	0.4	0.5

7	2000	0.2	1
8	2000	0.3	0.5
9	2000	0.4	0.75

3. Methodology

Desirability Function Analysis (DFA)

Taguchi method can be applied to analyze the process parameters for single performance characteristics only, where as Desirability function analysis can be effectively used for analyzing the multi performance characteristics. DFA method was introduced by Derringer and Suich (1980). The method makes use of an objective function, D(X), called the desirability function and transforms an estimated response into a scale free value d_i called desirability. The desirable ranges are from zero to one (least to most desirable, respectively). The factor settings with maximum total desirability are considered to be the optimal parameter conditions. In this analysis the optimization of multiple performances characteristics can be determined as per the steps given below.

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.

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

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.

$$d_i = \begin{cases} 0, & \hat{y} \leq y_{min} \\ \left(\frac{\hat{y} - y_{min}}{y_{max} - y_{min}}\right)^r, & y_{min} \leq \hat{y} \leq y_{max,} r \geq 0 \\ 1, & \hat{y} \geq y_{max} \end{cases}$$

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.

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

Where the ymin represents the lower tolerance limit of ŷ, the ymax 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, using the following equation (k).

Here D_g is the overall desirability value, d_i is the individual desirability value of ith quality characteristic and n is the total number of responses.

$D_g = (d_1 * d_2 * d_3 \ldots\ldots\ldots d_n)^{\frac{1}{n}}$..............Eq(1)

Here, D_g = Composite 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 Material removal rate (MRR) is measured as the product of speed, feed and depth of cut in cm^3/min. Surface roughness characteristics for each machined components was taken with surface tester at three different positions and the average is taken as final values. The obtained results were depicted in table 5.

Table 5. Experimental Results of Responses

S.No.	MRR (cm^3/min)	R_a (µm)	R_q (µm)	R_z (µm)
1	9.21	2.11	2.44	9.04
2	24.85	5.02	6.07	22.68
3	32.57	9.17	10.5	36.10
4	20.57	2.03	2.36	8.54
5	39	7.16	8.27	26.94
6	24.85	11.59	13.41	43.96
7	41.14	3.35	3.87	13.26
8	27	7.25	8.34	26.08

9	39.85	11.75	13.56	45.37

The individual desirability (d_i) values of the responses can be obtained using higher the better and lower the better characteristics respectively. From the individual desirability values the composite desirability (D_g) can be found using the equation 1 and the values were given in the table 6.

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

S.No.	d_i of MRR	d_i of R_a	d_i of R_q	d_i of R_z	Dg
1	0.0000	0.9918	0.9929	0.9864	0
2	0.4898	0.6924	0.6688	0.6161	0.6114
3	0.7316	0.2654	0.2732	0.2517	0.3399
4	0.3558	1	1	1	0.7723
5	0.9330	0.4722	0.4723	0.5004	0.5681
6	0.4898	0.0165	0.0134	0.0383	0.0451
7	1	0.8642	0.8652	0.8718	0.8985
8	0.5572	0.4630	0.4661	0.5238	0.5009
9	0.9596	0.0000	0	0	0

For the composite desirability values Taguchi's higher the better characteristic is used for setting the optimal combination of process parameters. The S/N mean values of the D_g are given in the table 7.

Table 7. Response Table for S/N Ratios of D_g

Level	S	f	D
1	-31.215	-27.725	-37.640
2	-11.357	-5.063	-28.839
3	-28.978	-38.763	-5.071
Delta	19.858	33.700	32.569
Rank	3	1	2

For the S/N ratio values of composite desirability (D_g) main effect plot is drawn and shown in the figure 1. From the figure it is observed that on the composite desirability values the feed has high effect and speed has least effect. The optimal combination of process parameters for the multi objective function from the main effect plot is obtained at speed of 1500 rpm, feed of 0.3 mm/rev and depth of cut of 1 mm respectively.

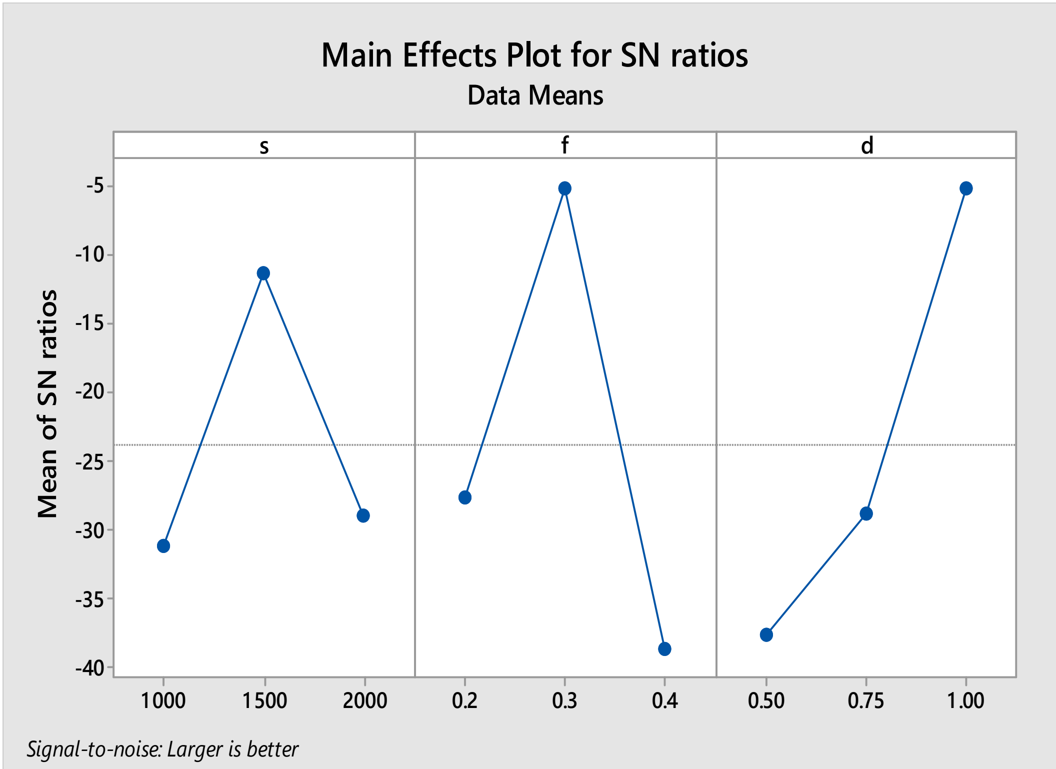

Figure 1. Main Effect Plot for Means of D_g

Analysis of variance (ANOVA) is employed for finding the influence and the contribution of individual factors on the composite desirability. From the results shown in the table 8, it is clear that the feed is the high influencing factor and followed by depth of cut and speed.

Table 8. ANOVA Results of D_g

Source	DF	Adj SS	Adj MS	F	Contribution
S	2	0.04327	0.02164	0.19	4.7156
F	2	0.37013	0.18507	1.61	40.3376
D	2	0.27434	0.13717	1.19	29.8982
Error	2	0.22984	0.11492		25.0485
Total	8	0.91758			100

5. Conclusions

- The optimal combination of turning process parameters for the multi objective function is obtained at speed of 1500 rpm, feed of 0.3 mm/rev and depth of cut of 1 mm.
- ANOVA results of composite desirability concluded that the feed is the high influencing factor and followed by depth of cut and speed.
- 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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