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Preference Number Based Taguchi-Utility Method for the Optimization of Multiple Responses

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Abstract

In the present study a multi-objective optimization approach called taguchi-utility method is employed to find the optimal process parameters in turning of AA7075 material. Cutting speed, feed and depth of cut were taken as the process parameters at three different levels. Taguchi's standard L9 (3^3) orthogonal array has been followed for conducting the experiments. Utility method converts the multi-responses into a single equivalent response in terms of utility index. ANOVA is employed to find the contribution of the process parameters and it is found that depth of cut has the high influence on the overall utility index.

Keywords: *Material Removal Rate (MRR), Surface Roughness (R_a), Taguchi-Utility, ANOVA.*

INTRODUCTION

In machining, two major performance characteristics considered are material removal rate and surface roughness as they directly reflects the total productivity and the aesthetical appearance of the product. The manufacturers are striving in attaining these two characteristics simultaneously for a set of process parameters. Hence, it is customary to choose appropriate process parameters which yields better multiple responses concurrently. There are many factors which influences material removal rate and surface roughness like cutting parameters, work piece properties, tool geometry and working conditions etc. In ancient days the selection of process parameters is done by referring the books or by past experience but it always leads to spoilage of resources and finally loss to the organization. To solve this problem, Denichitaguchi has proposed a special design called an orthogonal array which helps in extracting the maximum information from the limited alternatives. Taguchi's traditional method is a robust design but it can be applied for solving the single responses and not for the multiple responses. To overcome this utility concept has been developed to solve the multi-objective optimization problems. In the proposed approach, utility values of individual responses are used to calculate the overall utility index. Finally the overall utility index is optimized using taguchi's higher-the-better characteristic.

EXPERIMENTATION

The experiments were conducted on CNC turret lathe to machine AA7075 work pieces. The selected material has extensive applications in marine, automotive and aviation fields due to its high strength-to-density ratio. AA7075 is basically aluminium based alloy its composition is given in the table 1. The mechanical properties of AA7075 are given in the table 2. Taguchi's standard L9 orthogonal array has been followed for the experiments for the selected process parameters given in the table 3. The combinations/alternatives of the chosen process parameters are given in the table 4.

***Table 1.**Chemical Composition of AA7075*

Element	**Weight %**
Al	87.1-91.4
Zn	5.1-6.1
Cu	1.2-2.0
Cr	0.18-0.28
Fe	0.5 max
Mg	2.1-2.9
Mn	0.3 max

***Table 2.**Mechanical Properties of AA7075*

Property	**Value**
Density	2.8 gm/cm^3
Ultimate Tensile Strength	83000 Psi
Yield strength	73000 Psi
Hardness (BHN)	150
Rockwell	1387

***Table 3.**Process Parameters and Their Levels*

	I	II	III
Speed, rpm	1000	1500	2000
Feed, mm/rev	0.2	0.3	0.4
Doc, mm	0.5	0.75	1

***Table 4.**Actual L9 OA*

S.No.	S	F	D
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

METHODOLOGY

Utility may be defined as the effectiveness/fitness of a product or a process in reference to the levels of expectations to the customers. In general, the performance evaluation of any manufacturing process depends on the number of output characteristics that involved. Therefore,it is essential to estimate an overall utility of a product/process by considering the relative contribution of all the quality characteristics. Utility theory provides a methodological framework for the evaluation of alternative attributes provides to the decision maker. It followsthe utility maximization principle, according to which the best choice is the one that provides the highest satisfaction to the decision maker.

According to the utility theory, if X_i is the measure of effectiveness of an attribute i and there are n attributes evaluating the outcome space, then the overall utility function can be expressed as

$$U(X_1, X_2, \dots \dots \dots, X_n) = f\big(U_1(X_1), \quad U_2(X_2) \dots \dots \dots, U_n(X_n)\big)$$

Here, $U_i(X_i)$ is the utility of the ith attribute.

The overall utility function is the sum of individual utilities if the attributes are independent and is given as

$$U(X_1, X_2 \ldots\ldots\ldots X_n) = \sum_{i=1}^{n} U_i(X_i)$$

The overall utility function after assigning weights to the attributes can be expressed as

$$U(X_1, X_2 \ldots\ldots\ldots X_n) = \sum_{i=1}^{n} W_i U_i(X_i)$$

The preference number can be expressed on the logarithmic scale as follows

$$P_i = A * \log\left(\frac{X_i}{X_i'}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq.(1)}$$

Here, X_i is the value of any quality characteristic or attribute i, X_i' is just acceptable value of quality characteristic or attribute i and A is a constant.

The value of A can be found by the condition that if $X_i = X^*$ (where X^* is the optimal value), then $P_i = 9$.

$$A = \frac{9}{\log \frac{X^*}{X_i'}}$$

The overall utility can be expressed as

$$U = \sum_{i=1}^{n} W_i P_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq.(2)}$$

subjected to $\sum_{i=1}^{n} W_i = 1$

Overall utility index that has been computed is now treated as a single objective function for the optimization. The best alternative is one with highest overall utility value.

RESULTS AND DISCUSSIONS

The experiments were conducted using taguchi's L9 orthogonal array and the measured responses of fabric elimination charge and floor roughness are given inside the table five. The experimental results of responses are used to calculate application values of person pleasant attributes known as preference wide variety by using the usage of the equations 3 and 4 and the obtained values are given inside the table 6.

Table 5.*Experimental Results*

S.No.	MRR, Cm^3/min	R_a, µm
1	9.21	2.11
2	24.85	5.023
3	32.57	9.17
4	20.57	2.036
5	39	7.16
6	24.85	11.59
7	41.14	3.35
8	27	7.25
9	39.85	11.75

$P_{MRR} = 13.8482 \log(X_i/9.21)$………Eq.(3)

$P_{Ra} = -0.7614 \log(X_i/11.75)$………..Eq.(4)

Table 6.*Preference Numbers of Responses*

S.No.	MRR	R_a
1	0	0.5677
2	5.9687	0.2809
3	7.5959	0.0819
4	4.8317	0.5795
5	8.6802	0.1637
6	5.9687	0.0044
7	9.0015	0.4148
8	6.4686	0.1595
9	8.8090	0

The overall utility index values have been computed using equation 2 by assuming equal priority to both the performance characteristics. For the values of overall utility index values given in table 7, taguchihigher-the-better characteristic is used for the analysis.

Table 7.*Overall Utility Values*

S.No.	U	S/N of U
1	0.2838	-10.9398
2	3.1248	9.8964
3	3.8389	11.6841
4	2.7056	8.6453
5	4.4219	12.9122
6	2.9865	9.5033
7	4.7081	13.4569
8	3.3140	10.4071
9	4.4045	12.8779

Taguchi mean values of the overall utility index were given in the table 8. The main effect plot shown in the figure 1 is indicating thatthe depth of cut is the main effecting parameter and followed by speed and feed respectively. The optimal combination of process parameters which maximizes the overall utility index values are obtained at high levels of speed (2000 rpm), feed (0.4 mm/rev) and depth of cut (1 mm).

Table 8.*Response Table for means of Overall Utility*

Level	s	f	d
1	2.416	2.566	2.195
2	3.371	3.620	3.412
3	4.142	3.743	4.323
Delta	1.726	1.177	2.128
Rank	2	3	1

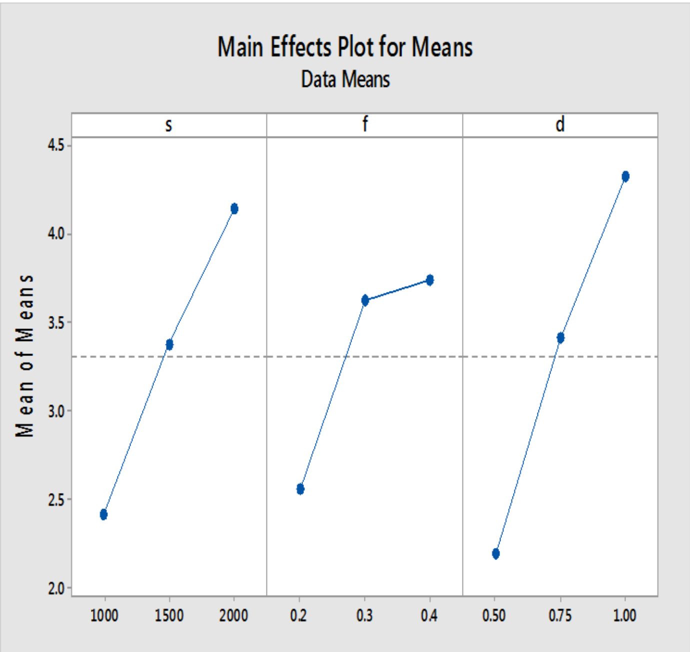

Fig1.*Main Effect Plot for Means of Utility*

Analysis of variance is conducted at 95% of confidence levels in order to find the significance/contribution of the process parameters on the overall utility index values. From the ANOVA results given in the table 9,depth of cut (0.4773) is the highest contributing parameter and feed (0.1753) is the lowest contributing parameter for the utility index. From the normal probability and versus order plots shown in the figures 2 and 3, it is clear that the errors are following the normal distribution and constant variance.

Table 9.*ANOVA of Overall Utility*

Source	DF	Adj SS	Adj MS	F	Contribution
S	2	4.4876	2.2438	9.17	0.3131
F	2	2.5133	1.2567	5.14	0.1753
D	2	6.8405	3.4203	13.98	0.4773
Error	2	0.4894	0.2447		0.0341
Total	8	14.3308			

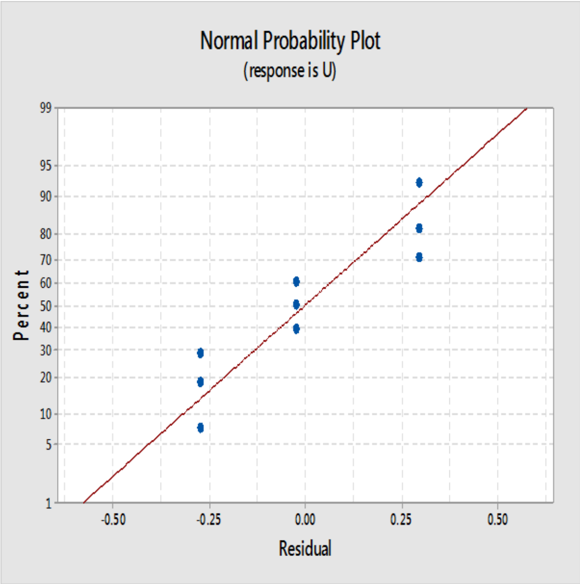

Figure 2.*Normal Probability Plot*

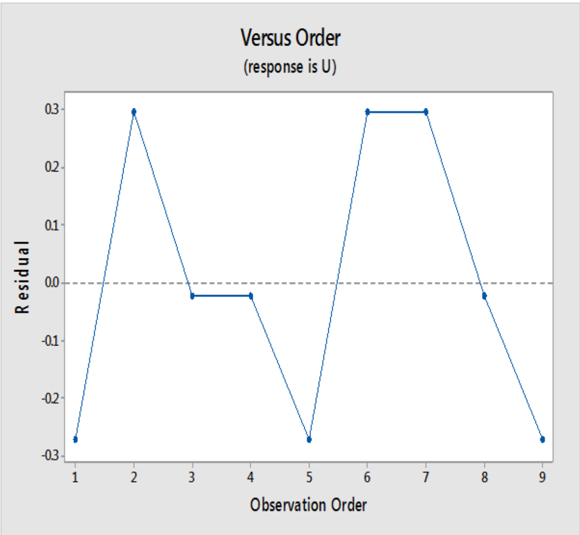

Figure 3.*Versus Order Plot*

Prediction of optimal design

A mathematical model is prepared for the overall utility index by considering the two most significant process parameters at their best levels.

μ_{A3B3} = A3+B3-T

= 4.323+4.142-3.3097 = 5.1553

Confidence interval

$$(CI) = \sqrt{\frac{(F_{95\%,1,doferror} * V_{error})}{\eta_{efficiency}}}$$

$$where, \eta_{efficiency} = \frac{N}{1 + dof}$$

$\eta_{efficiency}$= 9/(1+2+2) = 1.8

V_{error} = 0.2447

F95%,1,2= 18.5128

$$CI = \sqrt{\frac{18.5128 * 0.2447}{1.8}} = 1.5864$$

The predicted optimal range of MRR

$\mu_{A1B3} - CI \leq \mu_{A1B3} \leq \mu_{A1B3} + CI$

$3.5689 \leq \mu_{A1B3} \leq 6.7417$

CONCLUSIONS

- The optimal combination of process parameters which maximizes the overall utility index values are obtained at
  Speed: level-3, 2000 rpm,
  Feed: level-3, 0.4 mm/rev and
  Depth of cut: level-3, 1 mm.
- ANOVA results concluded that depth of cut has the high influence and feed has low influence on the overall utility index.
- The optimal design for the utility index values is predicted andfound in the range of $3.5689 \leq \mu_{A1B3} \leq 6.7417$.

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