Surface Quality Optimization of Al-5Cu Alloy using Utility Theory Coupled with Taguchi Method

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ABSTRACT

Optimum machining parameters with desired surface finish is very difficult to achieve because these quality features are highly correlated. There are several parameters that controls directly or indirectly the response parameters. The present investigation highlights a multi-objective optimization problem by applying utility concept coupled with Taguchi method through a case study of Al-5Cu (Duralumin) alloy by simple turning operation in a computer numerically controlled (CNC) Lathe machine. This study evaluates the best process environment which satisfies multiple surface quality requirements. A confirmatory test was done to verify the optimum result. The parameters used in the experiment were reduced to three cutting parameters, cutting speed, depth of cut, feed rate. Other parameters such as tool nose radius, tool material, workpiece length, workpiece diameter, and workpiece material was taken as constant.

Keywords: Multi-objective optimization; utility concept; Taguchi method; surface roughness, CNC Lathe.

1. INTRODUCTION

To increase the quality of any machined part, for increasing the productivity CNC machine tools plays a great role. It requires less operator effort. Many researchers investigated the surface roughness of the machined surface in CNC Lathe in the past few years. To remove metal from the outer diameter of a rotating workpiece turning is one of the basic machining operation. The part to be removed is rotated while single point cutting tool is moved parallel to the axis of rotation. The parameters affecting turning operation are: cutting speed, feed and depth of cut. Surface quality of any machined product is influenced by direct as well as interactive effects of the process parameters in different machining environments. Therefore it is necessary to select the most favorable process environment capable of producing desired surface quality. Jiao et al. [1] used a fuzzy adaptive network (FAN) for modeling surface roughness in simple turning operation. Ozel et al. [2] had developed models based on feed-forward neural networks for predicting accurately surface roughness and flank wear of the cutting tool in dry turning operation of AISI H13 steel using CBN tools. Pal et al. [3] developed a back propagation neural network for predicting surface roughness in turning operation. Abburi et al. [4] had developed a knowledge based system for the prediction of surface roughness using neural networks and fuzzy set theory in turning process. Lin et al. [5] adopted a network to construct a prediction model for surface roughness and cutting force in turning operation. Sahin et al. [6] developed a surface roughness model for turning of mild steel with coated carbide tools using Response Surface Methodology, it was found that feed rate is the most dominating factor, surface roughness increases with increase in feed rate, and decreases with increase in cutting speed, depth of cut. Wang et al [7] for predicting surface roughness developed an empirical model using nonlinear regression analysis. They used six process parameters, namely feed, cutting tool angle, hardness of the workpiece, depth of cut, spindle speed, cutting time. In the present study, multi-objective optimization problem has been used to select the best process parameters (cutting speed, feed, depth of cut) to optimize multiple surface quality parameters of Al-5Cu alloy in CNC Lathe machine. Multiple surface roughness parameters are centre line average roughness (R_a), Average maximum height of the profile R_z, Maximum height of the profile R_t, Mean spacing of local peaks of the profile S_a . Because of the limitation of Taguchi method to solve a multi-objective Optimization problem, utility concept has been coupled with Taguchi method. It has converted the multi-objective optimization problem into a single objective optimization problem and thus the single objective optimization situation has been solved by Taguchi method.

2. UTILITY CONCEPT

According to the utility theory [8,9], if X_i is the measure of effectiveness of an attribute(or quality characteristics) i and there are n attributes evaluating the outcome space, then the joint utility function can be expressed as: $U(X_1,X_2,\ldots,X_n) = f\,(U_1(X_1),U_2(X_2),\ldots,U_n(Xn))$.

(1)

Here $U_i\,(X_i)$ is the utility of the i_{th} attribute. The overall utility function is the sum of individual utilities if the attributes are independent, and expressed as: $U(X_1,X_2,\ldots,X_n) = \sum_{i=1}^{n} U_i(X_i)$. (2)

The attributes may be assigned weights depending upon the relative importance or priorities of the characteristics. The overall utility function after assigning weights to the attributes can be expressed as:

$$U(X_1,X_2,\ldots,X_n)= \sum_{i=1}^{n} W_i.U_i(X_i). \quad (3)$$

Here W_i is the weight assigned to the attribute i. the sum of the weights for all the attributes must be equal to 1. A preference scale for each quality characteristic is constructed for determining its utility value. Two arbitrary numerical values(preference number) 0 and 9 are assigned to the just acceptable and the best value of the quality characteristic respectively. The preference number P_i can be expressed on a logarithmic scale as: $P_i = A \times \log\left(\frac{X_i}{X_i^{'}}\right)$. (4)

Here X_i is the value of any quality characteristics or attributes i, $X_i^{'}$ is just an acceptable value of quality characteristic or attribute i and a is a constant. The value A can be found by the condition that if $X_i = X^*$(where X^* is the optimal or best value), then $P_i=9$.

Therefore, $A = \frac{9}{\log \frac{X^*}{X_i^{'}}}$. (5)

The overall utility can be expressed as: $U = \sum_{i=1}^{n} W_i . P_i$. (6)

Subject to the condition: $\sum_{i=1}^{n} W_i = 1$. (7)

In the proposed approach utility values of individual responses are accumulated to calculate overall utility index. Overall utility index servers as the single objective function for optimization.

3. EXPERIMENTAL DETAILS

3.1 Work piece material used

Pure aluminum 320 gm and 5% pure copper (16 gm) were melted in a muffle furnace at a temperature of 950°C and it was kept in the furnace for 20 minutes to have an uniform distribution of Cu in Al melt. It makes the Al-Cu alloy called Duralumin. Duralumin is the trade name of one of the earliest type of age-hardenable aluminium alloys. It was first used in rigid airship frames, and then it was quickly spread throughout the aircraft industry. It is also being used in precision tools because of its light weight and strength. The molten metal was then poured in the metallic mold of length 50 mm and diameter of 18 mm and thus specimens were prepared for performing the turning operation in CNC Lathe.

Table 1: Selected levels for cutting

Parameter	Unit	Level 1	Level 2	Level 3
Cutting Speed	rpm	500	550	600
Feed	mm/min	6.4	8.0	9.6
Depth of Cut	mm	0.2	0.4	0.6

Table 2: Design of Experiment with measured roughness parameters

Sl No.	L_9 Orthogonal Array			Measured roughness parameters								Overall utility index	S/N ratio
	N	f	d	R_a	Utility values of R_a	R_z	Utility values of R_z	R_t	Utility values of R_t	S_a	Utility values of S_a		
	500	6.4	0.2	0.41200	9.00000	2.9067	6.56407	3.2400	7.14914	2.6567	9.00000	7.9283	17.9836
	500	8.0	0.4	0.56367	0.23035	3.3733	2.84427	3.8400	4.76269	2.7000	8.42167	4.0647	12.1806
	500	9.6	0.6	0.56833	0.00000	3.4767	2.08987	3.9667	4.30673	2.8667	6.27855	3.1688	10.0179
	550	6.4	0.4	0.52467	2.23638	2.9367	6.30751	3.4833	6.13209	2.6733	8.77718	5.8633	15.3628
	550	8.0	0.6	0.43267	7.63041	2.6367	9.00000	2.8400	9.00000	3.2100	2.23235	6.9657	16.8593
	550	9.6	0.2	0.49967	3.60232	3.1433	4.60876	3.6000	5.66922	3.1500	2.90732	4.1969	12.4586
	600	6.4	0.6	0.54867	0.98497	3.7800	0.00000	5.3900	0.00000	3.4167	0.00000	0.2462	12.1742
	600	8.0	0.2	0.51833	2.57652	3.2933	3.44397	4.5733	2.30794	2.8633	6.32100	3.1478	9.9601
	600	9.6	0.4	0.51900	2.54038	3.0667	5.22521	3.6000	5.66922	3.3033	1.20743	3.6606	11.2710

4. RESULTS AND DISCUSSIONS

Experimental data regarding surface quality features corresponding to L_9 orthogonal array, design of experiment (table 2) have been explored to calculate utility values of individual quality attributes by using equations (4-6). Lower the better (LB) criterion has been used for all the surface roughness parameters. In all the cases, minimum observed value has been treated as the most expected (highly desired) value. This is because all surface roughness characteristics follow Lower-the-better criteria. The objective of the present investigation is to improve surface finish, which means all the roughness parameters values should be as minimum as possible. Individual utility measures of the responses are also furnished in table 2. The overall utility index has been calculated using equation 6, with their corresponding (signal-to-noise) S/N ratio. In this computation it has been assumed that all quality features are equally important (same priority weightage). Figure 1 reflects S/N ratio plot for overall utility index; S/N ratio being computed using equation 8. The overall utility index is then optimized (maximized) using Taguchi method.

Taguchi's higher-the-better criterion has been used to maximize the overall utility index.

$$\text{SN (Higher-the-Better)} = -10 \log \left[\frac{1}{t} \sum_{i=1}^{t} \frac{1}{y_i^2} \right]. \quad (8)$$

Here t is the number of measurements, and y_i is the measured i_{th} characteristic value i.e. i_{th} quality indicator. Optimal parameter setting has been evaluated from figure 1. Thus the optimal setting should confirm highest utility index (HB criterion). The predicted optimal setting becomes N2 f2 d1. After evaluating the optimal parameter settings, the next step is to predict and to verify the optimal result using confirmatory test.

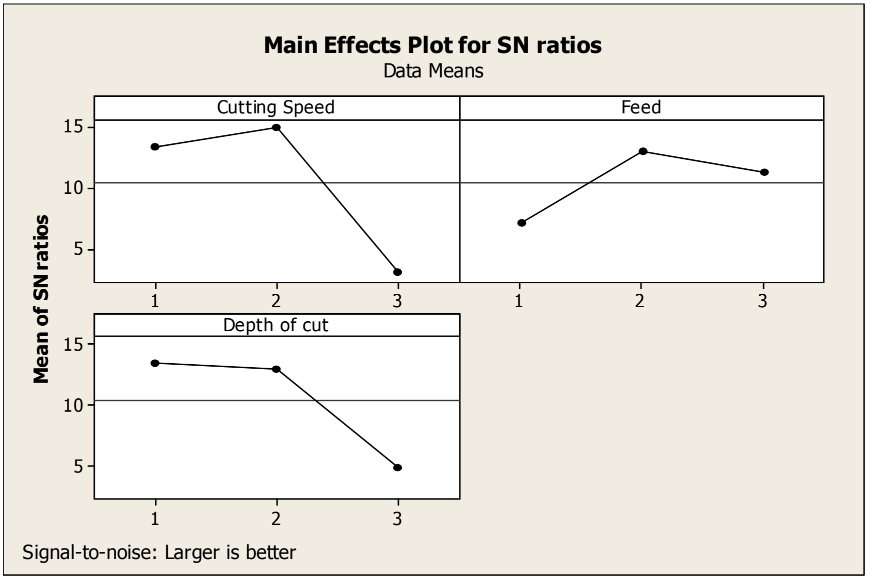

Fig 1: Evaluation of optimal setting

5. CONCLUSION

For finding the optimum parameters using utility based Taguchi method, it has been found fruitful. This approach is quite efficient to solve a multi-response optimization problem. Confirmatory test has been done and it has validated the setting of the parameters determined by utility based Taguchi method.

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