MULTI-OBJECTIVE OPTIMIZATION IN MACHINING (TURNING) OF ALUMINIUM

Thesis submitted in partial fulfilment of the requirements for the Degree of

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In

Mechanical Engineering

By

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Certificate of Approval

This is to certify that the thesis entitled **MULTI-OBJECTIVE OPTIMIZATION IN MACHINING (TURNING) OF ALUMINIUM** submitted by ***Sri Kumar Parijat*** has been carried out under my supervision in partial fulfilment of the requirements for the Degree of ***Bachelor of Technology*** in ***Mechanical Engineering*** at National Institute of Technology, Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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Abstract

The present study highlights a multi-objective optimization problem by applying both TOPSIS and Utility concepts coupled with Taguchi method through a case study in machining (turning) of pure Aluminium. The study aimed at evaluating the best process environment which could simultaneously satisfy multiple requirements of quality and productivity. In view of the fact, the traditional Taguchi method cannot solve a multi-objective optimization problem; to overcome this limitation, TOPSIS and Utility concepts have been coupled with Taguchi method. These two concepts have been adopted to convert a multi-response optimization problem into a single response optimization problem; in which CC (Closeness Coefficient) and U (Utility Index), respectively serve as the representative single objective function for optimization. The study combined TOPSIS/Utility and Taguchi method for predicting optimal setting. Based on Taguchi's Signal-to- Noise ratio (S/N), analysis has been made on the CC/U and optimal process environment has been selected finally which corresponds to highest S/N Ratio of the CC/U. Optimal result has been verified through confirmatory test. The case study indicates application feasibility of the aforesaid methodology proposed for multi-response optimization and off-line control of multiple quality and productivity characteristics in Aluminium machining.

Contents

Item	Page No.
Chapter-1: Preliminaries	
1.1 Turning	7
1.2 Surface Roughness	8
1.3 Literature Review	9
Chapter-2: The TOPSIS-based Taguchi Approach	
2.1 Taguchi method	11
2.2 TOPSIS	15
2.3 Experimental Works	17
2.4 Experimental Results and Discussion	18
Chapter-3: The Utility-based Taguchi Approach	
3.1 Introduction	21
3.2 Algorithm for Utility approach	21
3.3 Experimental Works	22
3.4 Experimental Results and Discussion	24
Chapter-4: Conclusion	27
References	28

LIST OF FIGURES

Fig 2.1: Nominal-the-Best (NB)/ Target-is-Best (TB) ------------------------------------ 13
Fig 2.2: Lower-the-Better (LB) --- 14
Fig 2.3: Higher-the-Better (HB) -- 15
Fig 2.4: Main Effects Plot for S/N Ratios in TOPSIS based Taguchi Approach ------- 20
Fig 3.1: Main Effects Plot for S/N Ratios in Utility based Taguchi Approach --------- 25

LIST OF TABLES

A. TOPSIS Based Taguchi Approach
Table 2.1: Level values of input parameters -- 17
Table 2.2: L9 Design Matrix --- 18
Table 2.3: Experimental Data -- 19
Table 2.4: S/N ratios of observed results -- 19

B. Utility Based Taguchi Approach
Table 3.1: Level values of input parameters -- 23
Table 3.2: L9 Design Matrix --- 23
Table 3.3: Experimental Data -- 24
Table 3.4: S/N ratios of observed results -- 25

CHAPTER-1: Preliminaries

1.1 Turning

Turning is a machining process in which the job (work piece) is rotated on the chuck and a single point cutting tool is fed into it radially, axially or both the ways simultaneously to give required (usually cylindrical surfaces). The axis of the cylindrical surface generated is often parallel work piece axis, while feed rate is given axial to the machine spindle. Once the cutting starts, the spindle speed and other cutting parameters will remain constant, the tool and work piece will remain in contact during the time the surface is being turned. At the same time, the cutting Spindle speed and cut dimensions will be constant when a cylindrical surface is being turned.

One of the most basic cutting processes, turning can be done both on the external surface or internal surface (boring) of the job. The starting work piece can be generated by casting, forging, extrusion, or drawing. Turning can be done manually, in an conventional version of lathe, which regularly needs continuous superintendence by the operator, or by employing a Computer-controlled (CNC) and automated lathe which does not require much supervision.. Turing can be of various types- straight turning, taper turning, profiling or external grooving. and can be used to produce material profiles like straight, conical, curved, or grooved work pieces. Each group of work piece materials has a predefined set of tool angles that ensure optimum turning performance. In turning, process parameters like cutting tool geometry and materials, depth of cut, feed rate, number of passes, spindle speed and use of cutting fluids will impact the costs, MRRs, cutting forces, tool life and other performance parameters like the surface roughness, the degree circular and dimensional deviations of the product.

The various process parameters that we considered in this optimization process are:-

Cutting spindle speed: In any machining operation, Cutting spindle speed (or surface spindle speed) is the rate at which the work piece rotates past the cutting edge of tool. It is expressed in m/min.

$$Vc = \frac{\pi DN}{1000}\ m/min$$

$$2D = D1 + D2 \text{ mm}$$

where, N is in rpm.

Feed rate: Feed rate is the speed at which the cutting edge of tool is fed, that is, advanced against the job. It is the distance moved by tool per unit movement of the job. It is expressed in mm/revolution.

Depth of Cut: Distance of engagement between tool and job. It is expressed in mm.

Depending on Depth of Cut, machining can be divided into:-

- Roughing (0.6-2mm)
- Semi-finishing (0.2-0.6mm)
- Finishing (<0.2mm)

1.2 Surface Roughness

Surface roughness, or often referred to as roughness, is a measure of the texture of a surface. It is quantified by the vertical deviation, in the normal direction, of a real surface from its ideal form. Rough surfaces have larger deviations, while smooth surfaces have smaller deviations. Roughness can also be viewed as the high frequency, short wavelength component of texture of the surface. It mainly originates due to Feed rate motion.

Assuming the tool has no curvatures, and has a single sharp point, we can deduce that

$$h_m = f / (\cot \Phi + \cot \Phi_1)$$

$$\Rightarrow h_m \propto f, \Phi, \Phi_1$$

1.3 Literature Review

Title	Name of Author	Journal of issue	Year of issue	Findings
Application of surface roughness when turning polyamide using ANN-IHSA approach	Madic et al.	International Journal of Engineering and Technology, Vol.1 (4), 432-443.	2012	Taguchi's L_{27} OA was used to conduct experiments using process parameters of Spindle speed, Feed rate, Depth of cut and Tool Nose radius to optimize the performance parameter of Surface Roughness. The Artificial Neural Network (ANN) model thus created was coupled with Improved Harmony Search Algorithm (IHSA) to achieve optimization.
Parametric analysis and optimization of turning operation by using Taguchi approach	Sahoo	International Journal of Modern Engineering Research, Vol.3 (4), 2154-2156	2013	Taguchi's method was used to optimize turning using process parameters of Spindle Speed, Feed rate and Depth of cut. One variable was varied along its parametric space while the other 2 variables were kept fixed.
Optimization of process parameters using Taguchi approach with minimum quantity lubrication for turning	Chaudhari et al.	International Journal of Engineering Research, Vol.1 (4), 1268-1273.	2011	Taguchi's method was used to optimize turning using process parameters of Spindle Speed, Feed rate and Depth of Cut to optimize Material Removal Rate and Surface Roughness. Increase in Spindle speed and Depth of Cut and decrease in Feed Rate ensured optimum values of MRR and Surface Roughness
Enhancement of surface finish for CNC turning cutting parameters by using Taguchi method	Kanase and Jadhav	Indian Journal Of Research, Vol.3 (5), 88-91	2013	Taguchi's method was used to optimize CNC turning of various materials and varied tool inserts at a given set of process parameter values to optimize the performance parameter. The experiments were carried out for all materials with one variable varied along its parametric space while the other variables were kept fixed.
Application of Taguchi method in optimization of tool flank wear width in turning operation of AISI 1045 Steel	Mishra and Gangele	Industrial Engineering Letters, Vol. 11-18.	2012	Taguchi's method using a L_9 OA coupled with Analysis of Variance was used to optimize tool flank wear using the process variable of Spindle speed, Feed rate and Depth of Cut. AISI 1045 steel was turned using tungsten carbide tool. Spindle speed was found to be the most significant process parameter in the turning process.
Parametric analysis of copper for cutting processes using turning operations based on Taguchi	Sodhi and Singh	International Journal of Research In Mechanical Engineering & Technology,	2013	Taguchi's method was used to optimize the performance parameter of Surface Roughness with process parameters as Spindle speed, Feed rate and Depth of Cut. The machining (turning) was carried out

method		Vol. 3(2), 20[illegible]		on an conventional lathe.
Effect of machining conditions on MRR and surface roughness during CNC Turning of different materials Using TiN coated cutting tools – A Taguchi approach	Dave et al.	International Journal of Industrial Engineering Computations,Vol.-3, 925–930	2012	Taguchi's method, coupled with ANOVA was employed to optimize Dry Turning process on various grades of EN materials with TiN coated tools. The machining was carried out in a CNC turning centre. Various cutting parameters were employed in the design to get optimal values of Surface Roughness and MRR. Depth of Cut was found to affect MRR most significantly and type of insert was found to affect Surface Roughness in a larger way.

CHAPTER-2 : The TOPSIS-based Taguchi Approach

2.1 Taguchi Method

A full factorial design provides all possible permutations of experiments for a given set of factors. Since most processes involve a large quantity of factors, a full factorial design will provide a too many number of experimental options. Taguchi constructed a set of general design guidelines for factorial experiments to reduce the number of experiments in a practically feasible level. This method uses orthogonal arrays to determine the minimal number of experiments to be conducted which could give sufficient information of all process parameters that affect concerned performance parameter. Orthogonal arrays require the user to choose the level combinations of Input Design Variables for initial experimentation

Each Orthogonal array, out of the many versions available, is meant for a definite number of independent design variables and their predefined levels. For example, to conduct an experiment to determine the effect of 3 different exclusive variables, each being provided with 3 set(level) values, the L_9 Orthogonal array is used. Orthogonal arrays assume that the factors are independent of each other, and variations in one factor does not incur variations in the other.

The Design of Experiment using the Orthogonal Array is more efficient, compared to other conventional statistical designs; the degree of freedom approach is used to determine the required number of experiments to be conducted, using the following formula.

$$N_{Taguchi}= 1+ \sum(L_i-1)$$

The Design of Experiment involves the following steps:

1) Selecting process variables that are independent of one another
2) Selecting required number of levels for each selected variable
3) Choose the type of orthogonal array to be employed
4) Input the process variables to the orthogonal array
5) Carry out the required number of experiments

6) Record and evaluate the data

7) Infer the data.

Taguchi also introduced the concept of ‘robust design’, to find the controllable variables for which Noise or Variation has least effect on products or process’s functional characteristics. The effect of noise can be calculated using the ratio S/N or Signal-to-Noise ratio, where ‘S’ is the standard deviation of the Performance Parameter for each inner Array experiment and N is the total number of experiment in the outer orthogonal array. This ratio includes the functional vibration due to Noise and is used to create robust design control parameter settings to ensure noise independent machining.

The concepts behind the Taguchi methodology are:

1. Quadratic Loss Functions (or Quality Loss Function) : to calculate the loss bore due to divergence from target performance.
2. Signal-to-Noise (S/N) Ratios: used for predicting the environmental quality through laboratory experiments.
3. Orthogonal Arrays (OA): used for collecting sufficient information about controllabe process factors (design parameters) with a minimum quantity of experiments.

The different S/N ratio characteristics have been given below:

1. Nominal-the-Best (NB) or Target-the-Best (TB)

2. Lower-is-Better (LB)

3. Higher-is-Better (HB)

Nominal-the-Best (NB) or Target-the-Best (TB)

According to this criteria, it is required to produce products with properties closest to a predefined target value, and any deviations, above or below the set value, is unacceptable and quadratic in nature (example: diameter of a shaft).

$$\eta_j^i = -10\log_{10}\left[\frac{1}{l}\sum_{k=1}^{l}\frac{\overline{y}_j^{i\,2}}{S_j^{i\,2}}\right]$$

The following graph depicts Nominal-the-Best (NB) characteristics.

Figure 2.1: Nominal-the-Best (NB)/ Target-the-Best (TB)

Lower-is-Better (LB)

Lower-is-Better criteria for S/N ratio always predict values pessimistically. It includes quality characteristic which has the undesired output such as defects in product like surface roughness, pin holes or unwanted by-product. The formula for these characteristics is:

$$\eta_j^i = -10\log_{10}\left[\frac{1}{l}\sum_{k=1}^{l} {y_{jk}^{i}}^{2}\right]$$

The following graph (figure 2.2) portrays Lower-is-Better (LB) characteristics.

Figure 2.2: Lower-is-Better (LB)

Higher-is-Better (HB)

Larger-is-better characteristic includes the desired output such as bond strength, material removal rate and agricultural yield. The formula for these characteristics is:

$$\eta_j^i = -10\log_{10}\left[\frac{1}{l}\sum_{k=1}^{l}\frac{1}{{y_{jk}^i}^2}\right]$$

The following graph (figure 2.3) portrays Higher-is-Better (HB) characteristics

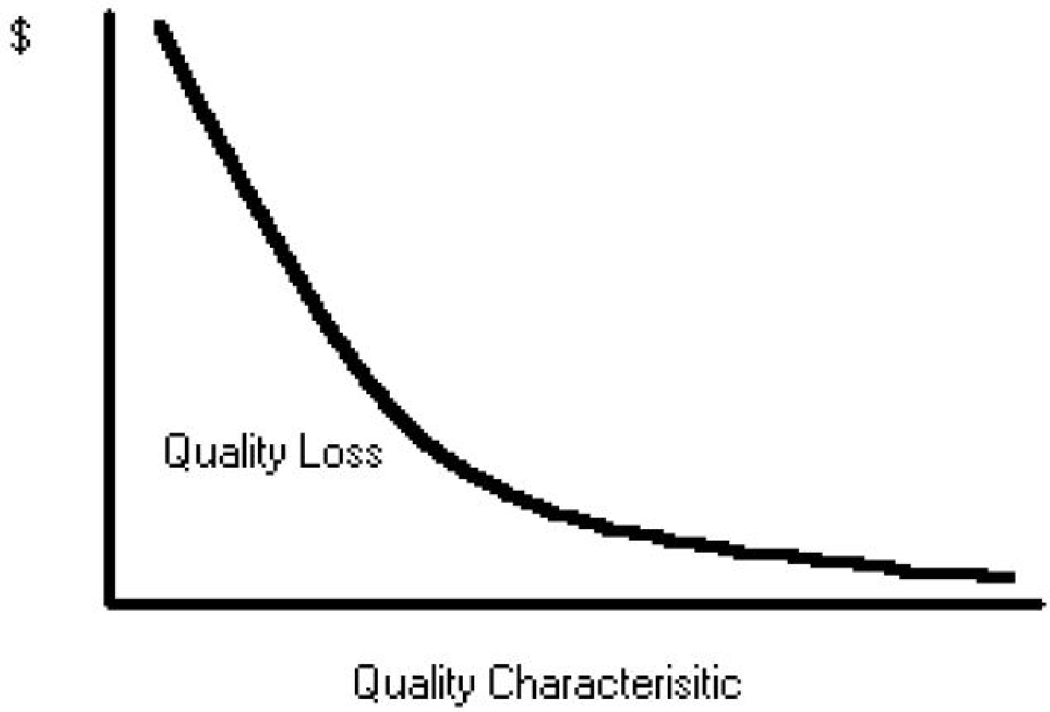

Figure 2.3**:** Higher-is-Better (HB)

2.2 TOPSIS

The technique for order of preference by similarity to ideal solution is a multi-criteria decision analysis method, based on the theory that the optimum alternative should have the least geometric distance from the positive ideal solution and the largest geometric distance from the negative anti-ideal solution. The algorithm compares a set of alternatives by allotting weights to each criterion and calculating the geometric distance between each alternative and the ideal alternative , which is the best score for the given criterion. The criterion are normalized to ease the aggregation process. Optimization methods like TOPSIS allow flexibility in terms that a poor result in one criterion may be compensated by a good result in another, and thus it is a more practical form of modelling

Assumptions- 1) Effect of each process parameter on the performance parameter should be monotically increasing or decreasing.

2) The process parameters (criterion) must be independent and exclusive of one another

2.2.1 TOPSIS Algorithm

1) Form the Decision Making matrix:

$$X=(x_{ij})_{n*m}=\begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix}$$

where columns are criteria and Rows are alternatives

2) Normalization of Decision Making matrix:

$$R=(r_{ij})_{n*m}=\begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nm} \end{bmatrix}$$

where $r_{ij}= x_{ij}/(\sum x_{ij}^2)^{1/2}$

3) Computation of weighted Normalized Decision Matrix:

Taking weight vector, $W=[w_1, w_2, \ldots\ldots w_n]$, $\sum w_j=1$, where w_i= weight criteria of criteria c_i

$$V= (v_{ij})_{n*m} = \begin{bmatrix} v_{11} & \cdots & v_{1m} \\ \vdots & \ddots & \vdots \\ v_{n1} & \cdots & v_{nm} \end{bmatrix}$$

where ,$V_{ij}=(r_{ij}*w_j)$

4) Selection of the Ideal alternative and Anti-ideal alternative:

A^*= Ideal Alternative = $[v_1^* \ldots\ldots v_n^*]$

A =Anti ideal alternative = $[v_1 \ldots\ldots vn]$

where, $v_i^*=\{\max v_{ij} |_{j \in \Omega b}, \min v_{ij} |_{j \in \Omega c} \}$

$v_i=\{ \min v_{ij} |_{j \in \Omega b}, \max v_{ij} |_{j \in \Omega c} \}$

where Ω_b stands for 'Higher is better' criteria

Ω_c stands for ' Lower is better' criteria

5) Determine geometric distance of each alternative from ideal alternative:

D_i^*=distance between A^k and A_i = $(\sum(v_{ij}-v_j^*)^2)^{1/2}$, i=1,2,…..n

D_i^- =distance between A^- and $A_i = (\sum(v_{ij}-v_j)^2)^{1/2}$, i=1,2….n

Closeness coefficient $C_{ci}=D_i^-/(D_i^*+D_i^-)$, which is a 'higher is better' criteria

6) Final decision making matrix thus reduces to

$$X^* = [\ C_{c1} \quad C_{c2} \quad ..... \quad C_{cn}]^T$$

2.3 Experimental Works

In this study, TOPSIS based Taguchi method has been used for single characteristics optimization and determine the relationship between the process variables, hence the experiments were conducted according to the Taguchi design of experiments.

2.3.1 Work material and Cutting tool

A commercially available single point HSS (High Spindle speed Steel) tool was used as cutting tool material and was used to machine a round aluminium bar of diameter 20 mm.

2.3.2 Design of experiments

Experiments were conducted according to the Taguchi design of experiments. which uses an Optimization Algorithm to cover the parametric space with the minimum number of experiments. In present research, three different process parameters (factors) namely Spindle speed, Feed rate and Depth of Cut, were allotted three different levels. (See table 2.1)

Table 2.1: Level values of input parameters

S.No	Parameter	Unit	Level 1	Level 2	Level 3
1	Spindle speed	rpm	465	605	787
2	Feed rate	mm/rev	0.06	0.07	0.08
3	Depth of Cut	mm	0.6	0.9	1.2

To choose the appropriate Optimization Algorithm (OA), we need to calculate the Degree of Freedom of the design of experiment. Here, we have 3 parameters, each at 3 different levels, hence Degree of Freedom (DOF) can be calculated as, Eq.1

$$(DOF)_R = P\ (L - 1) \quad .$$

where, P = number of factors, L = number of levels

Here, $(DOF)_R = 3\ (3 - 1) = 6$

The DOF required for the experiment should be less than or equal to the DOF of OA, hence, L_9 OA (6<9) is chosen(See Table 2.2). We assign each process parameter to a column of the OA and 9 permutations of variable combinations are, thus, determined. The performance parameter that we intend to optimize in this study is Surface Roughness and Tool Tip Temperature. The “smaller-is-better” quality characteristic applies to both the performance parameters and is used calculate the signal-to-noise (S/N) ratio of the performance parameter.

Table 2.2: L9 Design Matrix

Expt. No.	Parameter 1	Parameter 2	Parameter 3
1	465	0.06	0.6
2	465	0.07	0.9
3	465	0.08	1.2
4	605	0.06	0.9
5	605	0.07	1.2
6	605	0.08	0.6
7	787	0.06	1.2
8	787	0.07	0.6
9	787	0.08	0.9

2.3.3 Experimental planning

The machining was carried out on an Lathe (Make: HMT NH-26) according to the L_9 OA & each experiment was repeated three times for getting a more accurate reading i.e.9x3 = 27 experiments were conducted. Surface roughness was measured using a Profilometer (Model: SJ-210, Make: MITUTOYO) and the Tool tip temperature was measured using Non-Contact Infrared Thermometer of AR882 make, having a temperature range of -18^{0}C to 200^{0}C.

2.4. Experimental Results and Discussion

The experimental data and S/N ratios, conducted according to the selected design of experiment is recorded in Table 2.3**.**

Table 2.3: Experimental Data

Expt. No.	**Surface Roughness (µm)**				**Tool Tip Temp. (^oC)**
	Trial 1	**Trail 2**	**Trail 3**	**Average**	
1	2.293	3.593	3.66	3.182	29.5
2	5.207	5.089	5.192	5.162666667	30.2
3	2.693	3.055	3.452	3.066666667	41.4
4	3.952	5.472	4.42	4.614666667	29.8
5	6.558	7.074	7.96	7.197333333	55.7
6	2.495	3.064	3.131	2.896666667	29.5
7	10.21	9.816	10.25	10.092	44.3
8	5.382	3.526	4.714	4.540666667	30.2
9	3.201	3.003	3.03	3.078	36.5

To determine the effect of the process parameters (Spindle speed, Feed rate and Depth of cut) on the performance parameters (Surface Roughness and Tool Tip Temperature), a Taguchi Design of Experiment was created using MINITAB 16 and the S/N Ratios were calculated, using the value of Closeness Coefficient(CC). The CC is determined from the combination of Surface Roughness and Tool Tip Temperature. The S/N Ratios are given below in Table 2.4.

Table 2.4: S/N ratios of observed results

Expt. No.	Closeness Co-efficient	S/N Ratio
1	0.899	-0.924
2	0.715	-2.913
3	0.719	-2.862
4	0.755	-2.439
5	0.428	-7.375
6	0.999	-0.009
7	0.311	-10.155
8	0.757	-2.422
9	0.777	-2.192

The MINITAB 16 gives the output of Main effects plot for S/N Ratios. The plot is shown below in Figure 2.4

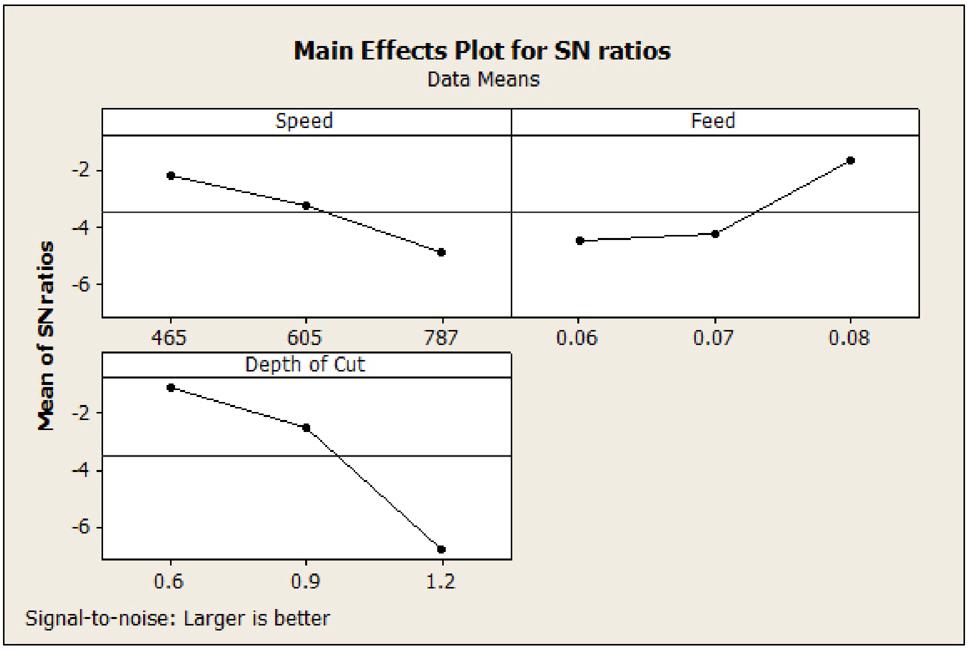

Fig. 2.4: Main Effects Plot for S/N Ratios

We have used the 'Smaller-is-Better' criteria for the performance parameters, but the S/N Ratio is optimized using the 'Larger-is-Better' criteria. It can be seen from Figure 1, that the first level of Spindle speed(A1) , third level of Feed rate (B3) and the first level of Depth of Cut (C1) provide best value of Surface Roughness and Tool Tip Temperature . Hence, the optimum process parameters were found out to be: Speed=465 rpm, Feed= 0.08 mm/rev and Depth of Cut= 0.6 mm.

CHAPTER-3: The Utility-based Taguchi Approach

3.1 Introduction

Quality is an important aspect that users require in their product or services. So, modern quality control science focuses on that their product should be made as per the customer requirements. A user values a product performance based on number of varied quality aspects of the product. This performance valuation of varied attributes can be aggregated to give a composite index, ensuring better decision making. The utility of a product on a given aspect measures the usefulness of the product. and the satisfaction that each aspect provides to the user. The utilities of each quality aspect of the product is summed to determine the overall utility of the product.

Thus, the utility theory theoretizes that the utility maximization principle is the background of the decision making process. The best option provides the most contentment to the user.

3.2 Algorithm for Utility Approach

We assume that X_i is effectiveness of the characteristic 'i' and there are 'n' characteristics in the parametric space. The combined utility functions can be calculated as follows:

$$U(X_1, X_{2,\ldots\ldots,} X_n) = f(U_1(X_1), U_2(X_2), \ldots\ldots, U_n(X_n)) \quad .$$

The utility theory assumes the characteristics are independent of each other. The individual utilities are summed to determine the overall utility function as follows:

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

Suppose 'w_i' is the weight assigned to characteristic 'i'. The overall Utility function thus becomes:

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

The Preference number is calculated as follows:

$$P_i = A^* \log(X_i / X_{ideal-}) \quad .$$

Here, X_i is the value of quality characteristic 'i'.

X_{ideal-} is the worst value of quality characteristics from 'i' to 'n' (Anti- Ideal solution).

The value of 'A' (constant) can be found out by putting $X_1 = X_{ideal}$ in the above equation (where X_{ideal} is the best value of quality characteristic from 'i' to 'n' i.e. the Ideal Solution).

Therefore, $A = 9 / (\log(X_i / X_{ideal-}))$.

The overall Utility function is given by the expression below:

$$U = \sum_{i=1}^{n}(w_i P_i)$$.

subject to the condition

$$\sum_{i=1}^{n}(w_i) = 1$$.

Overall Utility index that has been determined, viewed the problem as a single objective function for optimization. The Utility function would be Higher-is-better (HB) criteria type. Therefore, to optimize the quality characteristic, its corresponding utility function must be maximized.

3.3 Experimental Works

In this study, Utility based Taguchi method has been used for single characteristics optimization and determine the relationship between the process variables, hence the experiments were conducted according to the Taguchi design of experiments.

3.3.1 Work material and Cutting tool

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	Trial 1	Trail 2	Trail 3	Average	
1	2.293	3.593	3.66	3.182	29.5
2	5.207	5.089	5.192	5.162666667	30.2
3	2.693	3.055	3.452	3.066666667	41.4
4	3.952	5.472	4.42	4.614666667	29.8
5	6.558	7.074	7.96	7.197333333	55.7
6	2.495	3.064	3.131	2.896666667	29.5
7	10.21	9.816	10.25	10.092	44.3
8	5.382	3.526	4.714	4.540666667	30.2
9	3.201	3.003	3.03	3.078	36.5

To determine the effect of the process parameters (Spindle speed, Feed rate and Depth of cut) on the performance parameters (Surface Roughness and Tool Tip Temperature), a Taguchi Design of Experiment was created using MINITAB 16 and the S/N Ratios were calculated, using the value of Utility Index. The Index is determined from the combination of Surface Roughness and Tool Tip Temperature. The S/N Ratios are given below in Table 3.4.

Table 3.4: S/N ratios of observed results

Expt. No.	Utility Index	S/N Ratio
1	8.66133	18.7517
2	6.75055	16.5868
3	6.39506	16.1169
4	7.24952	17.2062
5	1.21869	1.7179
6	9.00004	19.0849
7	1.62131	4.1973
8	7.21339	17.1628
9	7.27363	17.2350

The MINITAB 16 gives the output of Main effects plot for S/N Ratios. The plot is shown below in Figure 3.1.

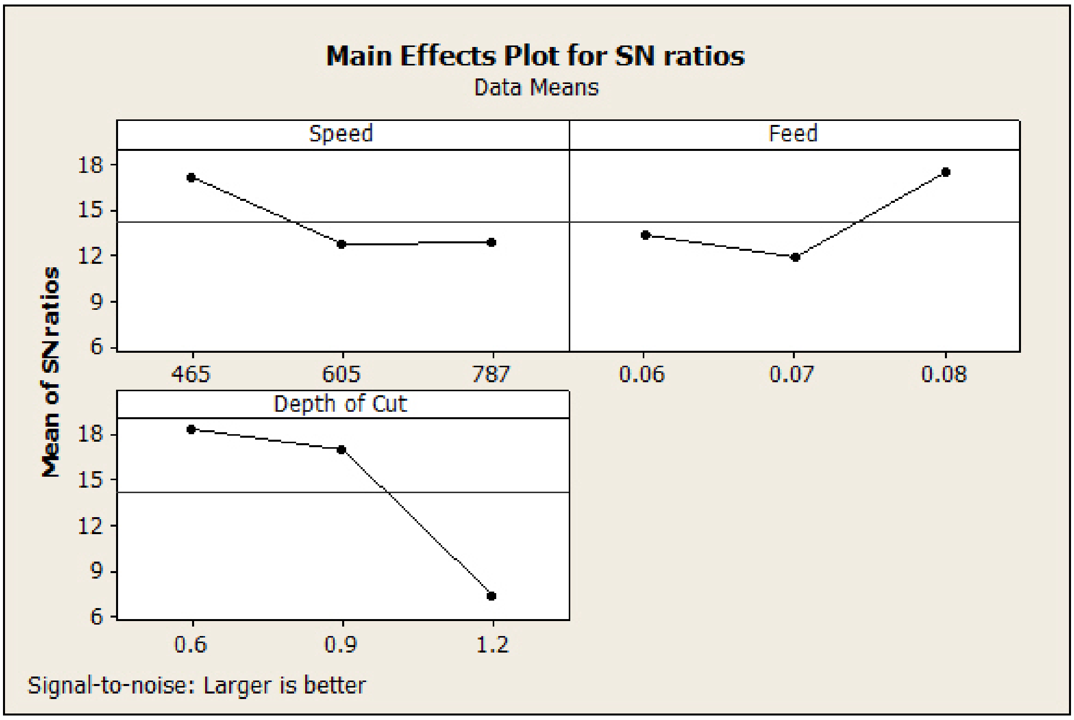

Figure 3.1- Main Effects Plot for S/N Ratios

We have used the 'Smaller-is-Better' criteria for the performance parameters, but the S/N Ratio is optimized using the 'Larger-is-Better' criteria. It can be seen from Figure 1, that the first level of Spindle speed(A1) , third level of Feed rate (B3) and the first level of Depth of Cut (C1) provide best value of Surface Roughness and Tool Tip Temperature . Hence, the optimum process parameters were found out to be: Speed=465 rpm, Feed= 0.08 mm/rev and Depth of Cut= 0.6 mm.

CHAPTER-4: Conclusion

This study presents the application of single characteristics optimization approaches for machining (turning) of Aluminium work piece. The TOPSIS-based Taguchi approach and the Utility-based Taguchi approaches can be utilized in various industrial processes to optimize both single and multi performance characteristics effectively. In the present study, the conclusion drawn is: for obtaining prime values of Surface Roughness and Tool Tip Temperature for machining of Aluminium work piece, optimum combination found out was A1, B3 and C1 i.e. Spindle speed= 465 rpm, Feed rate= 0.08 mm/rev and Depth of Cut= 0.6 mm, which gives best results.

Future Scope:

The project can be further extended to design of mathematical modeling, structural design and analysis of the tools. The optimization techniques can also be implemented at industries for smooth finishing of the job by minimizing tool wear.

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