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PREDICTION OF PROCESS PARAMETERS IN CNC END MILLING OF UNS C34000 MEDIUM LEADED BRASS

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ABSTRACT

The study highlights optimization of CNC milling process parameters to provide better surface finish The surface finish has been identified as quality attribute and is assumed to be directly related to productivity. In order to build up a bridge between quality and productivity, an attempt made to optimize aforesaid quality attribute in small and medium size companies involved with heterogenic product demand. With the more precise demands of modern engineering products, the control of surface texture together with dimensional accuracy has become more important. This paper outlines the Taguchi optimization methodology, which is applied to optimize cutting parameters in end milling operation. The study was conducted in machining operation in UNSC34000 medium leaded brass. The milling parameters evaluated were cutting speed, feed rate and depth of cut. The experiments were conducted by using L-25 orthogonal array as suggested by Taguchi. Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA) are employed to analyze the effect of milling parameters on surface roughness. Main effects of process parameters on the quality characteristics have been analyzed. The results show that the optimum parameters of machining by CNC End Milling Machine for given set of parameters.

Key words: *CNC End Milling, Optimization, Cutting Conditions, DOE, ANOVA and Surface Roughness*

1. Introduction

It has long been recognized that conditions during cutting, such as feed rate, cutting speed and depth of cut, should be selected to optimize the economics of machining operations, as assessed by productivity, total manufacturing cost per component or some other suitable criterion. Since long researchers showed that an optimum cutting speed exists, this could maximize material removal rate. Manufacturing industries have long depended on the skill and experience of shop-floor machine-tool operators for selection of cutting conditions and cutting tools.

CNC milling is an indispensable process for manufacturing industry. The general trends of developing this process include reducing the machining cost and time as well as increasing the precision and accuracy. The process parameters in the milling process have different levels of effects on different product geometries thereby increasing the complexity in parameter setting. Thereby, if a robust milling technique that has the characteristics of high speed and low cost, and is able to produce high quality products with a wide application base, can be developed within a short time, the competitiveness of the manufacturing industry will inevitably be increased. With this in mind, this paper uses Taguchi's DOE method, to develop a milling technique with the above mentioned qualities.

The surface quality is one of the most specified customer requirements and the major indicator of surface quality on machined parts is surface roughness. The surface roughness is mainly a result of various controllable or uncontrollable process parameters and it is harder to attain and track than physical dimensions are. These machines are capable of achieving reasonable accuracy and surface finish. So, there is a need for a tool that should evaluate the surface roughness before the machining of the part and which, at the same time, can easily be used in the production-floor environment contributing to the minimization of machining time and cost of production for the desired surface quality. The goal of this study is to obtain a mathematical model that relates the surface roughness to three cutting parameters in end milling, precisely to the cutting speed, feed rate and depth of cut. The study reveals the correlation between the cutting parameters and experimental values of roughness

Although the aims of all the processes are to obtain the desired shape, size and finish. The selection of a particular process depends on several factors, which includes the shape and size of the finished component,

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precision required in the volume of production, cost of material and process and its availability. The commonly used method for obtaining the desired shape, size and finish is machining, which involves removal of excess material in the form of chips. CNC End milling is one of the most versatile manufacturing processes. Popularity of milling for machining application is increasing mainly due to the introduction of High Speed Machining (HSM), made possible by improvements in the design and operation of milling machines and tools. Most frequently, milling involves the generation of flat faces and slots. However, its application for contour milling is growing with the availability of CNC milling machines.

2. Literature Review

An extensive literature survey was carried out and the facts as extract are discussed in this paragraph. Exhaustive literature survey was carried out and the available relevant information was presented under the following headings. It is the conceptual framework of a methodology for quality improvement and process robustness that needs to be emphasized.

Taguchi methods, developed by Dr. Genichi Taguchi, refer to techniques of quality engineering that embody both statistical process control (SPC) and new quality related management techniques. Most of the attention and discussion on Taguchi methods has been focused on the statistical aspects of the procedure; it is the conceptual framework of a methodology for quality improvement and process robustness that needs to be emphasized. The entire concept can be described in two basic ideas:

1. Quality should be measured by the deviation from a specified target value, rather than by conformance to preset tolerance limits.
2. Quality cannot be ensured through inspection and rework, but must be built in through the appropriate design of the process and product

Through the proper design of a system, the process can be made in sensitive to variations, thus avoiding the costly eventualities of rejection and/or rework. In order to determine and subsequently minimize the effect of factors that cause variation, the design cycle is divided into three phases of System Design, Parameter Design, and Tolerance Design.

The Taguchi Method was developed 50 years ago and has been used with great success to optimize automobile and other product manufacturing. More recently, The Taguchi Method was applied to direct mail and web applications. The Taguchi Method takes a number of elements on a page with one or more alternatives for each element and dictates exact combinations that will allow estimating the positive or negative effect of each element/alternative.

Taguchi tests have been run on email, PPC ads and Landing Pages with great success. Where an AB Split Test might create a 5 − 10% improvement, a Taguchi test cycle will regularly return 25 − 45% improvement and has been known to improve results by 100% or more.

{Aggarwal et al. [1]} have worked on the interaction graphs for a two-level combined array experiment design. Their conclusion is that quality can be obtained by robust design. {Benardos & Vosniakos [2]} have presented the Prediction of surface roughness in CNC face milling using neural networks and Taguchi's design of experiments. They predicted that surface roughness is influenced by feed, speed and depth of cut.

Determination of the chip geometry, cutting force and roughness in free form surfaces finishing milling, with ball end tools is the study by {Bouzakis et al. [3]}. Bryne's {Bryne [4]} study on Taguchi's approach to parameters design signifies the methodologies adopted in the study. {Dae et al. [5]} has studied the issue of optimization in a face milling operation.

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The studies by {Jiju & Frenin [8]} on Taguchi's design of experiment for engineers is how to select the problem and implement it using the methodologies to enhance quality, reduce process variability and wastages of time a well as other factors. Surface roughness performance was studied by {John et al. [9]}. Their study is how to identify and decide optimum parameters in End-Milling operations

Similarly, {Kishawy & Elbestawi [10]} have presented case studies on the effects of process parameters on material side flow during hard turning. They concluded that through the proper design of a system, the process could be made insensitive to variations, thus avoiding the costly eventualities of rejection and/or rework. In order to determine and subsequently minimize the effect of factors that cause variation, the design cycle is divided into three phases of System Design, Parameter Design, and Tolerance

Design. The similar views has been expressed by {Mandara & Joseph [11]} in their research work entitled multiple regression-based multilevel in-process surface roughness recognition system in milling operation. {K. Arun Vikram, Ch. Ratnam[12]} created a model for the prediction of the average surface roughness in terms of cutting speed, feed and depth of cut using Regression Analysis.

{Wang & Chang [13]} have done experimental study of surface roughness in slot end milling. They advocate that the optimization of process parameter can greatly enhance surface roughness. According to {Resit et al. [14]}, Quality and cost are the main ingredients in Taguchi's approach to design optimization.

A case study by {Robert et al. [15]} on tool path feed rate optimization suggests that quality and cost as well as other variations can be minimized. The area of product development, although a "soft" area in terms of technology (especially in a field such as composites), is however perhaps all the more important due to the changes in paradigm necessary for a successful completion of the product realization process. Not only does the development effort need an integrated team, but it also depends heavily on team dynamics, procedures, and even intangibles such as trust and team loyalty suggests {Ryan [16]}. {Thomson et al. [17]} have analyzed the effectiveness of DOE on injection molding operation by Taguchi Methods. The conclusion emphasizes that the approaches would find successful applicability in regions where the culture and people are in many cases asymmetrically aligned with the needs and productivity demands.

A methodology of decision support system was given by {Vidal et al. [18]} for optimizing the selection of parameters when planning milling operations. {Warner & Connor [19]} have found that through application of Taguchi's design of experiment the product quality and productivity have improved as optimization of the process parameter played a crucial role in molding process.

The real frame work was developed by the study conducted by {Tzeng and Chen [20]}on two phased parameter optimization for better accuracy by Taguchi's robust design method, which prompted the two phase analysis technique with Taguchi's DOE and simultaneous optimization procedure to give away the various parameters on surface roughness requirements followed by a case study. {Sai and Bouzid [21]} developed the simulation models and analysis of the chip formation and the surface roughness for up face milling process conducted to get the optimal parameters and suggested to consider the more number of parameters with higher levels of analysis to get the best set of parameters including the cutting force, tool wear rate and wet or dry process.

3. Problem Definition

The CNC based job order companies involved in precision components manufacturing to equipment manufacturers of Japan & Germany and to the local market inside India. The study reveals the surface roughness is the most important requirement along with geometrical and dimensional qualities. A considerable number of studies have researched the effects of the cutting speed, feed, depth of cut, nose radius and other factors on the surface roughness. A case study method is adopted for parameter study and design of experiment (DOE) with analysis of variance (ANOVA) and regression analysis (RA).

Ra is the roughness height between the peak of the profile and its mean line, or the integral of the absolute profile height over the evaluation length as shown in fig.(1)

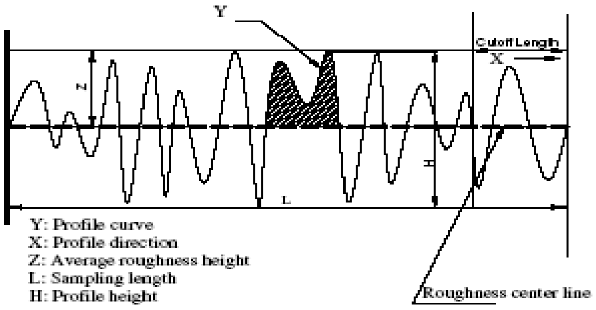

Fig. 1 Surface roughness profile

Therefore, the Ra is specified by this equation:

$$Ra = \frac{1}{L}\int_0^L |Y(x)|dx.$$

From this equation, *Ra* is the arithmetic average deviation from the mean line, *L* is the sampling length, and *Y* is the coordinate of the profile curve.

4. Taguchi's View on Quality

Taguchi proposes a holistic view of quality, which relates quality to cost, not just to the manufacturer at the time of production, but to the customer and society as a whole. Taguchi defines quality as, "The quality of a product is the (minimum) loss imparted by the product to the society from the time product is shipped" {Bryne [4]}. This economic loss is associated with losses due to rework, waste of resources during manufacture, warranty costs, customer complaints and dissatisfaction, time and money spent by customers on failing products, and eventual loss of market share.

4.1 Factors affecting Surface Roughness

The variables that influence the economics of machining operations are numerous. Some of the important ones are machine tool capacity, work piece material and its geometry, tool geometry, vibrations, cutting parameters such as speed, feed, depth of cut and types of coolant used etc. The cutting parameters affect the production rate. The surface roughness, surface texture and dimensional deviations are also affected by the cutting conditions. Ultimately, it has overall impact on the product quality as well as the unit cost of component and productivity.

The principal reasons for controlling the surface roughness is essential to enhance the service life of the components, as it improves the fatigue resistance; and reduces corrosion and initial wear due to lack of irregularities and closer dimensional tolerances.

The economic selection of cutting conditions requires knowledge of technical aspects and cost aspects, which are not easily available in many cases. Surface roughness (Ra) in machining is a measure of micro-geometrical technological quality errors occurred in a product and a factor that greatly influences manufacturing cost. It describes the geometry of the machined surface texture, which is entirely process dependent. The prescribed sampling length as per IS: 2073 150 is 0.8mm for majority of the machining processes and in case of milling operation the Roughness value is 0.32µ to 25µ . Therefore, this may be the basis of optimizing the operational characteristic of the processes.

4.2 Aim and Objective

The principle aim and objective of the present study is to minimize the variation level within the specified target value and to obtain a better surface finish, for better product quality and productivity. The conceptual Signal to Noise Ratio and Pareto ANOVA approaches with Taguchi's design methodology, in the metal cutting operation, has been used in the present analysis.

4.3 Signal to noise ratio

The S/N ratio developed by Dr. Taguchi is a performance measure to choose control levels that best cope with noise. The S/N ratio takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized. While there are many different possible S/N ratios, three of them are considered standard and are generally applicable in the situations below;

- Bigger-the-Better

$$\frac{S}{N_{(\text{Bigger})}} = -10\log\left(\frac{\Sigma\left(1/y_i^2\right)}{n}\right)$$

- Smaller-the-Better

$$\frac{S}{N_{(\text{Smaller})}} = -10\log\left(\frac{\Sigma y_i^2}{n}\right)$$

- Nominal-is-Best

$$\frac{S}{N_{(\text{Nominal})}} = 10\log\left(\frac{\bar{Y}^2}{s^2}\right)$$

In addition to the Signal to Noise Ratio (S/N ratio), the obtained results have been tested using statistical Analysis of Variance (ANOVA) to indicate the impact of process parameters on surface roughness.

4.4 Steps applied in Taguchi methods

Taguchi proposed a standard procedure for applying his method for optimizing any process.

i. Determine the quality characteristic to be optimized
   The first step in the Taguchi method is to determine the quality characteristic to be optimized. The quality characteristic is a parameter whose variation has a critical effect on product quality. It is the output or the response variable to be observed.
ii. Identify the noise factors and test conditions
   The next step is to identify the noise factors that can have a negative impact on system performance and quality. Noise factors are those parameters which are either uncontrollable or are too expensive to control. Noise factors include variations in environmental operating conditions, deterioration of components with usage, and variation in response between products of same design with the same input.
iii. Identify the control parameters and their alternative levels
   The third step is to identify the control parameters thought to have significant effects n the quality characteristic. Control (test) parameters are those design factors that can be set and maintained. The levels (test values) for each test parameter must be chosen at this point. The number of levels, with associated test values, for each test parameter defines the experimental region.
iv. Design the matrix experiment and define the data analysis procedure
   The next step is to design the matrix experiment and define the data analysis procedure. First, the appropriate orthogonal arrays for the noise and control parameters to fit a specific study are

selected.

After selecting the appropriate orthogonal arrays, a procedure to simulate the variation in the quality characteristic due to the noise factors needs to be defined.

v. Conduct the matrix experiment

The next step is to conduct the matrix experiment and record the results. The Taguchi method can be used in any situation where there is a controllable process. The controllable process can be an actual hardware experiment, systems of mathematical equations, or computer models that can adequately model the response of many products and processes.

vi. Analyze the data and determine the optimum levels for control factors

After the experiments have been conducted, the optimal test parameter configuration within the experiment- design must be determined.

vii. Predict the performance at these levels

Using the Taguchi method for parameter design, the predicted optimum setting need not correspond to one of the rows of the matrix experiment. Therefore, as the final step, an experimental confirmation is run using the predicted optimum levels for the control parameters being studied.

The summary of steps applied for Taguchi optimization in the present study is presented in Fig.1.

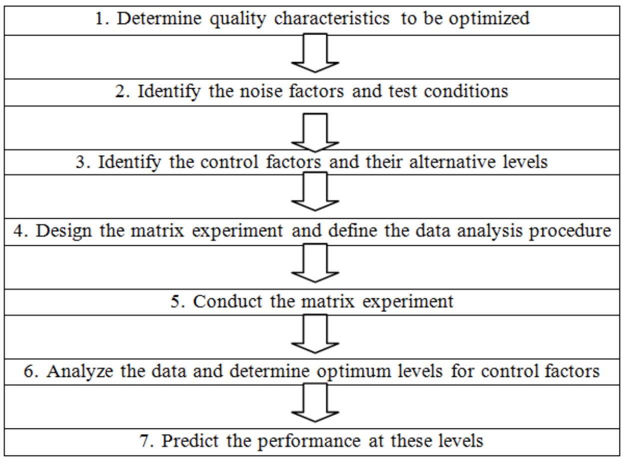

Fig. 1 Steps applied in Taguchi Optimization Method

5. Experimentation

5.1 Selection of cutting parameters

Surface quality and dimensional accuracy are the two important aspects of a product in any machining operation. Several factors influence the final surface roughness in a CNC milling operation. The theoretical surface roughness is generally dependent on many parameters such as the tool geometry (tool nose radius and flank width, run-out error), tool material, work material, machine-tool rigidity and various cutting conditions including feed rate, depth of cut and cutting speed (Boothroyd & Knight 1989; Alauddin *et al* 1995). However, factors such as tool wear, chip loads and chip formations, or material properties of both tool and work piece are uncontrollable during actual machining (Huynh & Fan 1992). The presence of chatter or vibration of the machine tool, defects in the surface of work material, wear in the tool or irregularities of chip formation contribute to the surface damage in practice during actual machining operations (Elbestawi & Sagherian 1991; Kline *et al* 1982). In any experimental study, it is difficult to consider all these factors that affect the surface finish. Available literature reveals that depth of cut, spindle speed and feed rate are the three primary machining parameters and thus these are considered as design factors in the present study.

5.2 Selection of response variable

From literature review it is found that, all the studies, whether experimental or analytical, mostly concentrate on the centre line average roughness value for surface quality. The surface quality is one of the most specified customer requirements and the major indicator of surface quality on machined parts is surface roughness. The surface roughness is mainly a result of various controllable or uncontrollable process parameters. So the present study thus aims at consideration of surface roughness as response variable.

5. 3 Work piece material used

The present study was carried out with medium leaded brass UNS C34000. The chemical composition and mechanical properties of the work piece materials are shown in table 1. It is available in material hand book. All the specimens were in the form of 100 mm × 75 mm ×25 mm blocks.

Table 1: Composition and Mechanical Properties of Work Piece Materials

Work material	Chemical composition (%Wt)	Mechanical properties
Brass	0·095%Fe,0·9%Pb, 34%Zn and balance Cu	Hardness-68 HRF, (UNS C34000) Density-8·47 g/cc, Tensile strength-340 MPa

5.4 Cutting tool used

Coated carbide tools have been found to perform better than uncoated carbide tools. Thus, commercially available CVD coated carbide tools have been used in this investigation. For each material a new cutter of same specification has been used. The details of the end milling cutters are given below:

Cutter diameter - 8 mm;
Overall length -108 mm;
Fluted length - 38 mm;
Helix angle – 30°;
Hardness - 1570 HV;
Density - 14·5 g/cc

5.5 Design of experiment

The design of experiments technique permits us to carry out the modeling and analysis of the influence of process variables (design factors) on the response variables. In the present study depth of cut (*d*, mm), spindle speed (*N*, rpm) and feed rate (f, mm/min) have been selected as design factors while other parameters have been assumed to be constant over the experimental domain.

The process variables (design factors) with their values on different levels are listed in table 2. The selection of the values of the variables is limited by the capacity of the machine used in the experimentation as well as the recommended specifications for different work piece and tool material combinations (Oberg *et al* 2000). Five levels, having nearly equal spacing, within the operating range of the parameters have been selected for each of the factors. In the present investigation, *L*25 Orthogonal Array (OA) design has been considered for experimentation. Interaction effect of process parameters has been assumed negligible.

Table 2: Process Parameters

Levels	N (rpm)- (x1)	f (mm/ min)- (x2)	d (mm)- (x3)
−1	1500	550	0·10
−0·5	1800	600	0·15
0	2100	650	0.20
+0·5	2400	700	0·25
+1	2700	750	0·30

6. Data Analysis

Experimental data regarding features of bead geometry corresponding to *L*25 Orthogonal Array (OA) design of experiment (table 3) have been explored to calculate the desired value. For all surface roughness parameters a Smaller the best criterion has been used. For all surface roughness parameters, the maximum of entries of table 3 has been considered as just acceptable value; whereas mix.- min. observed value has been treated as the best (desired) value. This is because all surface roughness characteristics follow Smaller-the-Best criteria. The objective is to improve surface finish; which means all types of roughness values should be as lower as possible.

The surface roughness parameters have been measured using the stylus-type profilometer, Talysurf. The measured roughness parameters along with design matrix have been shown in table 3. The S/N Ratio is calculated by Taguchi's Design of Experiments.

$$\frac{S}{N_{(\text{Smaller})}} = -10 \log\left(\frac{\sum y_i^2}{n}\right)$$

Table 3: Experimental Results

Exp. No	Speed(N)	Feed(F)	Depth Of Cut(D)	Ra	S/N Ratio
1	-1	-1	-1	1.427	-3.08848
2	-0.5	-0.5	-1	1.257	-1.98671
3	0	0	-1	1.237	-1.84739
4	0.5	0.5	-1	1.102	-0.84363
5	1	1	-1	1.185	-1.47437
6	-1	-0.5	-0.5	1.862	-5.39959
7	-0.5	0	-0.5	1.244	-1.89641
8	0	0.5	-0.5	1.167	-1.34142
9	0.5	1	-0.5	1.282	-2.15776
10	1	-1	-0.5	1.007	-0.06059
11	-1	0	0	1.21	-1.65571
12	-0.5	0.5	0	1.35	-2.60668
13	0	1	0	1.005	-0.04332
14	0.5	-1	0	0.837	1.545491
15	1	-0.5	0	0.881	1.100482
16	-1	0.5	0.5	1.267	-2.05553
17	-0.5	1	0.5	1.125	-1.02305
18	0	-1	0.5	0.758	2.406616
19	0.5	-0.5	0.5	0.799	1.949064
20	1	0	0.5	0.985	0.131275
21	-1	1	1	1.182	-1.45235
22	-0.5	-1	1	0.903	0.886245
23	0	-0.5	1	0.761	2.372307
24	0.5	0	1	0.745	2.556875
25	1	0.5	1	0.766	2.315425

Table 4: Mean Response Table for S/N Ratio

Parameters	Level 1 (- 1)	Level 2 (- 0.5)	Level3 (0)	Level4 (0.5)	Level5 (1)	Max.-Min.
Speed(N)	-2.73033	-1.32532	0.309358	0.610007*	0.402445	3.34034
Feed(f)	0.337857*	-0.39289	-0.54227	-0.90637	-1.23017	1.568026
Depth of cut(d)	-1.84812	-2.17115	-0.33195	0.281675	1.3357*	3.506854

*Optimized level of parameters

Table 5: ANOVA Table

Parameter	Column Sum of Square	Degree of freedom	Variance	F Value	P%
Speed(N)	41.73091	4	10.43273	15.31509	**0.00012**
Feed(f)	7.013042	4	1.753261	2.573761	**0.09168**
DC(d)	43.04143	4	10.76036	15.79605	**0.00009**
Error(e)	8.174467	12	0.681206	-	-
TOTAL	99.95985	24	-	-	-

6.1 Analysis of Variance

The data obtained from the experiments has been analyzed in a series of standard steps when they change from one level to another level are calculated and plotted as response curves. The response curves are the average value of the characteristic and average S/N values versus level of process parameters. The response curves are used as an aid to visualize the parametric effect on selected quality characteristics. Although the important control factors are identified in the analysis of the full range of the max. – min. value in the response table, the method does not identify experimental error.

The ANOVA identifies the significant parameters and quantifies their effect on the selected quality characteristics. Associated with each response curve is the S/N response curve, which is used to keep in the selection of optimal level of response process parameters for individual quality characteristics.

6.2 Regression Analysis

Regression analysis is a statistical tool for the investigation of relationships between variables. Regression techniques have long been central to the field of economic statistics (“econometrics”).

Regression analysis with a single explanatory variable is termed as simple regression.

Multiple regressions is a technique that allows additional factors to enter the analysis separately so that the effect of each can be estimated.

In linear regression, the model specification is that the dependent variable y_i is a linear combination of the parameter. For example, in simple linear regression for modeling n data points there is one independent variable: x_i, and two parameters, β_0 and β_1:

Straight line:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i, \quad i = 1, \ldots, n.$$

In multiple linear regressions, there are several independent variables or functions of independent variables. Multiple linear regression equation were modelled for a relationship between process parameters in a bid to evaluate surface finish for any combinations of factor levels in a range specified.

In the more general multiple regression model, there are *p* independent variables:

$$y_i = \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_p x_{ip} + \varepsilon_i,$$

The least squares parameter estimates are obtained from *p* normal equations. The residual can be written as

$$e_i = y_i - \hat{\beta}_1 x_{i1} - \cdots - \hat{\beta}_p x_{ip}.$$

6.3 Results

From the ANOVA shown in Table 5, P value of speed is significantly contributing towards machining performance. Moreover, the variance due to noise factors is only 0.681206, indicative that the selection and arrangement of the control factors is adequate and logical and the results are highly reliable.

Best performance for finish machining are found from the Mean response table of S/N Ratio(Table 4) with machining parameters for surface roughness (Table 4) [Speed – 2400 rpm, Feed – 550 mm/min., Depth of Cut - 0.3 mm .]

The first-order and second order linear equation used to predict the regression constants and exponents and the regression equation of surface roughness generated as:

$$\mathbf{y = 2.733627112\cdot10^{-3}\, x_1 - 7.299059698\cdot10^{-3}\, x_2 + 17.64091996\, x_3 - 5.071180242} \qquad \text{[Eqn. 1]}$$

The established regression equation indicates that the depth of cut affects the surface roughness the most, but other parameters like spindle speed and the feed had a slight effect on surface roughness values. Using this equation, the results may be validated.

The graphs shows that the effect of surface roughness with their machining variables of spindle speed, feed and depth of cut individually.

7. Conclusion

An overview of the Taguchi method has been presented and the steps involved in the method were briefly described. Overall, the Taguchi method is a powerful tool, which can offer simultaneous improvements in quality and cost. Furthermore, the method can aid in integrating cost and engineering functions through the concurrent engineering approach required to evaluate cost over the experimental design. The Taguchi method emphasizes pushing quality back to the design stage, seeking to design a product/process, which is insensitive or robust to causes of quality problems. It is a systematic and efficient approach for determining the optimum experimental configuration of design parameters for performance, quality, and cost. Principal benefits include considerable time and resource savings; determination of important factors affecting operation, performance and cost; and quantitative recommendations for design parameters, which achieve lowest cost, high quality solutions.

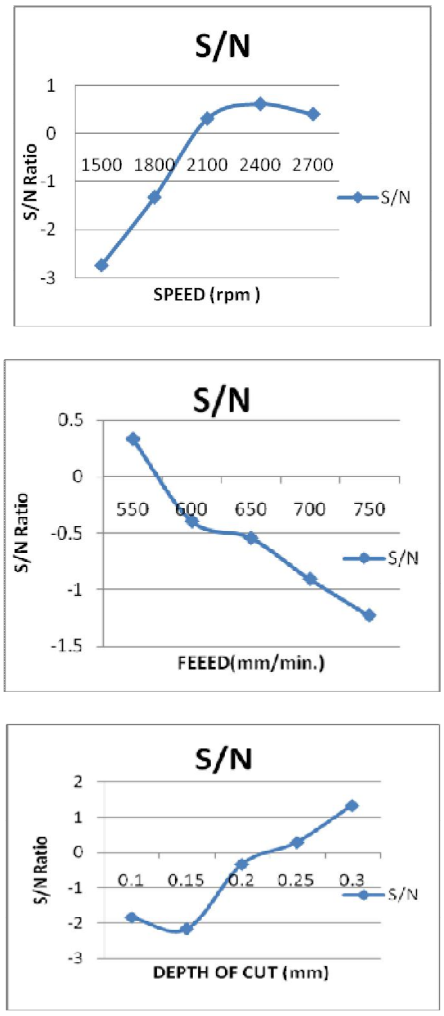

Fig. 2 Effect of S/N Ratio of Ra with Machining Variables

From the analysis of the result in end milling using conceptual S/N ratio and ANOVA approaches, the following conclusions can be drawn from the present study:

i. Taguchi's robust design method is suitable to analyze the metal cutting problem as described in the present work.

ii. The optimized levels of parameters are recommended to obtained better surface finish for the specific test range in a specified material. Similar experiments can be conducted to choose the best combination of speed, feed and depth of cut in order to improve product quality and productivity.

The detailed study and optimization procedure would help in real practice milling job order companies which deals mostly with precision and variety of orders and requirements. The basic idea to provide a decision making tool to the operator is achieved for CNC milling machine of any kind and the developed software can be made interactive. In our advanced machining laboratory, every operator found the technique is useful and they asked for user friendly and interfacing capability. We assure as the research is on for the objective and could be completed in a short period.

The future prospects on this study are plenty but the plan is to complete the following in phased manner

i. Simulation of results using Mat lab simulations model.

ii. Extending the study to high speed milling process.

iii. Fitting the values in to high speed milling and turning of precision components

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