Journal of Engineering Sciences
Vol 11, Issue 2, FEB/2020
ISSN NO:0377-9254

OPTIMIZATION OF OPERATING PARAMETERS (ALUMINIUM) IN CNC TURNING

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ABSTRACT

In any machining process, apart from obtaining the accurate dimensions, achieving a good surface quality and improved metal removal rate are also of utmost importance. A machining process involves many process parameters which directly or indirectly influence the quality of the product. Metal Removal Rate and Surface Roughness in turning process are varied due to various parameters of which feed, speed, depth of cut are important ones. A precise knowledge of these optimum parameters would facilitate to reduce the machining costs and improve product quality. Extensive study has been conducted in the past to optimize the process parameters in any machining process to have the best product. Current investigation on turning process is a Response Surface Optimization technique applied on the most effective process parameters i.e. feed, cutting speed, depth of cut and type of material, while machining (Aluminium alloy and Resin) with high speed steel as cutting tool. Main effect plots are generated and analyzed to find out the relationship between them. The details of experimentation and analysis are given in the following context. Response Surface Design is a powerful and efficient method for optimizing quality and performance output of manufacturing processes, thus a powerful tool for meeting this challenge. The present study discusses an investigation into the use of Response Surface Design for optimizing the output parameters (Surface Roughness and Metal Removal rate) generated by a CNC turning operation. The present study utilizes a standard experimental design for determining the optimum turning parameters. Controlled factors include spindle speed, feed rate, depth of cut and material. After experimentally turning samples (Aluminium alloy and Resin), using the selected experimental design and parameters, this study produced a verified combination of controlled factors and a predictive equations for determining Metal Removal Rate and surface roughness for the selected materials with a given set of parameters.

In today's rapidly changing scenario of manufacturing industries, applications of optimization techniques in metal cutting processes was essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand of quality product in the market. Optimization methods in metal cutting processes, considered to be a vital tool for continual improvement of output quality in products.

This study focused in finding the optimum cutting speed that will produce the best surface finish and improved metal removal rate for different materials. Lathe machine was used to conduct the experiment. Selecting the wrong cutting parameter may lead to several negative effects. For example, high maintenance cost of the Lathe machine, poor surface finish, shorter tool life, low production rate, material waste and increase production cost. In order to find out the optimum cutting speed for each material, there were other cutting parameters needed to be constant, such as feed rate, depth of cut and diameter. In machining operation, the quality of surface finish was an important requirement for many turned parts. Thus, the choice of optimized cutting parameters is very important for controlling the required surface quality. The focus of this study is to find a correlation between the output parameters (Metal Removal Rate and Surface Roughness) and cutting speed, feed and depth of cut for the two different materials. Response Surface Methodology (RSM) has been applied to determine the optimum machining parameters leading to minimum surface

roughness and maximum Metal Removal Rate in turning process on Aluminium alloy and Resin.

INTRODUCTION TO TURNING PROCESS

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material. The turning process requires a turning machine or lathe, work piece, fixture, and cutting tool. The work piece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine, although some operations make use of multi-point tools. The cutting tool feeds into the rotating work piece and cuts away material in the form of small chips to create the desired shape.

Turning is used to produce rotational, typically axi-symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces. Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom designed shafts and fasteners. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed.

CUTTING PARAMETERS

In turning, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based upon the work material, tool material, tool size, and more.

CUTTING FEED - The distance that the cutting tool or advances during one revolution of the spindle, measured in inches per revolution (IPR). In some operations the tool feeds into the work piece and in others the feeds into the tool. For a multi-point tool, the cutting feed is also equal to the feed per tooth, measured in inches per tooth (IPT) multiplied by the number of teeth on the cutting tool.

FEED RATE - The speed of the cutting tool's movement relative to the work piece as the tool makes a cut. The feed rate is measured in inches per minute (IPM) and is the product of the cutting feed (IPR) and the spindle speed (RPM).

DEPTH OF CUT –

AXIAL DEPTH OF CUT - The depth of the tool along the axis of the work piece as it makes a cut, as in a facing operation. A large axial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is typically machined in several passes as the tool moves to the specified axial depth of cut for each pass.

RADIAL DEPTH OF CUT- The depth of the tool along the radius of the work piece as it makes a cut, as in a turning or boring operation. A large radial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is often machined in several steps as the tool moves over at the radial depth of cut.

LATEST TECHNIQUES

The latest techniques for optimization include fuzzy logic, scatter search technique, genetic algorithm, and Taguchi technique and Response surface Methodology.

FUZZY LOGIC

Fuzzy logic has great capability to capture human commonsense reasoning, decision-making and other aspects of human cognition. Kosko (1997) shows that it overcomes the limitations702 Aman Aggarwal and Hari Singh of classic logical systems, which impose inherent restrictions on representation of imprecise concepts. Vagueness in the coefficients and constraints may be naturally modelled by fuzzy logic. Modelling by fuzzy logic opens up a new way to optimize cutting conditions and also tool selection.

GENETIC ALGORITHM (GA)

These are the algorithms based on mechanics of natural selection and natural genetics, which are more robust and more likely to locate global optimum. It is because of this feature that GA goes through solution space starting from a group of points and not from a single point. The cutting conditions are encoded as genes by binary encoding to apply GA in optimization of machining parameters. A set of genes is combined together to form chromosomes, used to perform the basic mechanisms in GA, such as crossover and mutation. Crossover is the operation to exchange some part of two chromosomes to generate new offspring, which is important when exploring the whole search space rapidly. Mutation is applied after crossover to provide a small randomness to the new chromosomes. To evaluate each individual or chromosome, the encoded cutting conditions are decoded from the chromosomes and are used to predict machining performance measures.

SCATTER SEARCH TECHNIQUE (SS)

This technique originates from strategies for combining decision rules and surrogate constraints. SS is completely generalized and problem-independent since it has no restrictive assumptions about objective function, parameter set and constraint set. It can be easily modified to optimize machining operation under various economic criteria and numerous practical constraints. It can obtain near-optimal solutions within reasonable execution time on PC. Potentially, it can be extended as an on-line quality control strategy for optimizing machining parameters based on signals from sensors. Chen & Chen (2003) have done extensive work on this technique.

TAGUCHI TECHNIQUE Genichi Taguchi is a Japanese engineer who has been active in the improvement of Japan's industrial products and processes since the late 1940s. He has developed both the philosophy and methodology for process or product quality improvement that depends heavily on statistical concepts and tools, especially statistically designed experiments. Many Japanese firms have achieved great success by applying his methods. Wu (1982) has reported that thousands of engineers have performed tens of thousands of experiments based on his teachings. Sullivan (1987) reports that Taguchi has received some of Japan's most prestigious awards for quality achievement, including the Deming prize. In 1986, Taguchi received the most prestigious prize from the International Technology Institute – The Willard F. Rockwell Medal for Excellence in Technology. Taguchi's major contribution has involved combining engineering and statistical methods to achieve rapid improvements in cost and quality by optimizing product design and manufacturing processes.

OBJECTIVE OF THE THESIS

- To conduct experiments in dry turning process using Taguchi method.
- To perform statistical analysis using S/N and ANOVA technique.
- To develop a mathematical model using Response Surface Methodology.
- To determine the optimum machining parameters using evolutionary algorithms.
- To identify the best optimization method in finding the optimum machining parameters based on the minimum surface roughness.
- Make use of other published work in the literature in order to prove the effectiveness of the proposed algorithms.
- **MEASUREMENTS**

- High speed steel tool was used in this experiment. The surface roughness of the work piece was measured using a profilometer. The experiments were carried out using the machining parameters as given in Table 3.1.`

S.No.	Input factor	symbol	Range of factors	
			min	max
1	Speed (rpm)	s	2000	3000
2	Feed (mm/rev)	f	30	100
3	Depth of cut (mm)	d	0.6	1
4	Material (categoric)	m	Al	r

Table 3.1: Levels of independent control factors

- **MACHINING TRIAL**

- Experiments were conducted using the design of experiments (DOE) technique with standard experimental design of central composite design, and then followed by optimization of the results using Analysis of Variance (ANOVA) to find the maximum MRR and minimum surface roughness and maximum tool life. The twenty four of machining trials were as tabulated in Table 3.2

Table 3.2: Experimental Observations

	Spe ed	**Feed**	**Dept h of**	**Mate rial**	**Surfa ce**	**Meta l**
R	**A:s**	**B:f**	**C:d**	**D:m**	**R_a**	**MRR**
	rp	**Mm/**	**mm**		**micro**	**mm^3/**
1	250	56	1	Al	1.54	1461.
2	200	30	1	R	1.65	161.6
3	300	30	0.754	r	1.18	68.54
4	200	30	0.801	al	2.29	933.3
5	200	100	0.6	al	3.99	1413.
6	250	100	0.6	al	4	1415.
7	300	58	0.832	al	3	1542.
8	300	100	0.6	r	3.23	120.2
9	200	100	1	al	4.58	2447.
10	300	59	0.6	al	5.58	1166.
11	300	30	1	al	2	1406.
12	250	65	0.8	r	3.57	146.0
13	250	100	1	r	3.51	251.2
14	200	100	0.846	r	3.02	106.9
15	300	100	0.6	r	3.3	128.2

DEVELOPMENT AND INTERPRETATION OF EMPIRICAL MODELS

In the present study, Empirical models for the output responses, Surface roughness (Ra), Metal removal rate (MRR) in terms of input machining parameters in actual factors were developed by using the RSM. The developed models are further

used for optimization of the machining process. The regression coefficients of the developed model are determined from the regression analysis. The second order models were developed for output responses due to lower predictability of the first order model to the present problem.

Analysis of variance (ANOVA) is employed to test the significance of the developed models. The multiple regression coefficients of the second order model for surface roughness and metal removal rate were found 0.9325 and 0.9781 respectively. The R^2 values are very high, close to one, it indicates that the second order models were adequate to represent the machining process. The "Pred RSquared" of 0.8027 is in reasonable agreement with the "Adj R-Squared" of 0.8967 in case of surface roughness. The "Pred R-Squared" of 0.9498 is in reasonable agreement with the "Adj R-Squared" of 0.9666 in case of MRR. Similarly, The Model F-value of 26.09 for surface roughness and The Model F-value of 84.51 for metal removal rate implies the model is significant. The analysis of variance (ANOVA) of response surface quadratic model for surface roughness and metal removal rate were shown in Table 4.1 and Table 4.2 respectively. Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. S/N ratio of 18.415 &32.54 for surface roughness and MRR indicates an adequate signal. This model can be used to navigate the design space. The *P* value for both the models is lower than 0.05 (at 97% confidence level) indicates that the both the models were considered to be statistically significant. The Plot of Predicted versus actual response for surface roughness and MRR

TABLE 4.1 ANOVA for Response Surface Quadratic Model of Ra

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	26.35247	13	2.027113	4.072587	0.0161 significant
s	0.00343	1	0.003434	0.006899	0.9354
f	5.193041	1	5.193041	10.43311	0.009
d	3.743536	1	3.743536	7.52097	0.0207
M	1.694704	1	1.694705	3.40475	0.0948
sf	0.000667	1	0.000667	0.00134	0.9715

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ISSN NO:0377-9254

sd	0.005508	1	0.005508	0.011066	0.9183
sm	0.187601	1	0.187601	0.376901	0.553
fd	5.774464	1	5.774465	11.60123	0.0067
fm	0.009111	1	0.009112	0.018306	0.8951
dm	1.565137	1	1.565137	3.14445	0.1066
s2	1.433995	1	1.433996	2.88098	0.1205
f2	0.781212	1	0.781213	1.569501	0.2388
d2	2.594529	1	2.594529	5.212558	0.0455
Residual	4.977458	10	0.497746		
Lack of Fit	4.838108	6	0.806351	23.14607	0.0045 significant
Pure Error	0.13935	4	0.034838		
Cor Total	31.32993	23			

R-Squared results for validating the model (Surface Roughness)

Std. Dev.	0.705511041	R-Squared	0.841127709
Mean	2.878333333	Adj R-Squared	0.634593731
C.V. %	24.5110958	Pred R-Squared	-0.688073219
PRESS	52.88722142	Adeq Precision	8.136479813

OBSERVATIONS

- A negative "Pred R-Squared" implies that the overall mean is a better predictor of your response than the current model.
- "Adeq Precision" measures the signal to noise ratio.
- A ratio greater than 4 is desirable.
- The ratio of 8.136 indicates an adequate signal.
- This model can be used to navigate the design space.

Table : R-Squared results for validating the model (Metal Removal Rate)

Std. Dev.	90.56661796	R-Squared	0.99114161
Mean	767.0818572	Adj R-Squared	0.984327463
C.V. %	11.8066432	Pred R-Squared	0.942969312
PRESS	686488.7762	Adeq Precision	36.73484898

OBSERVATIONS

- The "Pred R-Squared" of 0.9430 is in reasonable agreement with the "Adj R-Squared" of 0.9843.
- "Adeq Precision" measures the signal to noise ratio.
- A ratio greater than 4 is desirable.
- The ratio of 36.735 indicates an adequate signal.
- This model can be used to navigate the design space.

The following equations were obtained in terms of actual factors individually for aluminium alloy and resin.

MODEL OF EQUATIONS

4.4.1 SURFACE ROUGHNESS

For aluminium alloy,

$\mathbf{R_a}$ = 35.32134822 - 0.011385648s - 0.019427137f - 41.93268705d + 4.67811 E-7sf-0.000254967s d + 0.108362292fd + 2.3633 E-06s^2 - 0.000398249f^2 +19.48317581d^2

For resin,

$\mathbf{R_a}$ = 33.08948639 - 0.011833057s - 0.018043056f - 38.56288148d + 4.67811 E-07sf - 0.000254967sd +0.10836229f d + 2.3633 E-06 s^2 - 0.000398249 f^2 +19.48317581 d^2

4.4.2 METAL REMOVAL RATE

For aluminium alloy,

MRR = -1850.976709+0.594459933 s+7.533431572 f+2481.309721 d-0.000694198 s f-0.49934073 s d +8.93648226 f d

For resin,

MRR =-737.3687931+0.464291611 s-4.961102928 f+856.649045 d **-** 0.000694198 s f - 0.499340729 s d + 8.93648226 f d

EFFECT OF PROCESS PARAMETERS ON SURFACE ROUGHNESS (Ra)

The effect of process parameters on output response, surface roughness is shown in fig.4.3 to 4.6. From Fig. 4.3, it is observed that increase in wheel speed tends to improve the finish. With carbide tools particularly, slow speed is not at all desirable since it means wastage of time and money and tools wear out faster. Fig. 4.4 shows the effect of feed on roughness. As the table speed increases, finish gets poorest because the tool marks show on the work piece. The effect of depth of cut on surface roughness is shown in Fig. 4.5. It is noted that the increase in depth of cut makes the finish poor. Hence smaller values of table speed and depth of cut and larger value of wheel speed must be selected in order to achieve better surface roughness during the process.

EFFECT OF PROCESS PARAMETERS ON MRR

The effect of process parameters on output response, surface roughness is shown in Fig 4.7 to 4.10. From Fig. 4.7, it is observed that increase in wheel speed tends to increase the MRR; where as the other two machining parameters are kept at its mid value. It is observed from the direct effects, depth of cut plays more vital role on MRR than other two parameters. Material removal rate in machining process is an important factor because of its vital effect on the industrial economy. Increasing the feed, wheel speed and depth of cut leads to an increase in the amount of Material removal rate. But the most influential factors are table speed, and depth of cut. The highest value of MRR is obtained at the extreme range of the input parameters in all the interaction plots. Also the MRR increases gradually with the depth of cut. Fig 4.1 to 4.2 shows the comparision of experimental and model values of R_a and MRR respectively.

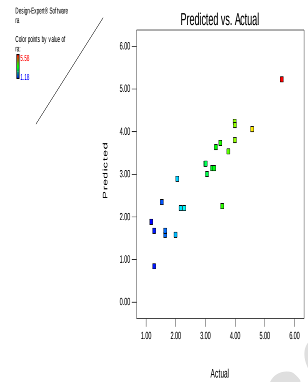

Fig 4.1: Predicted Versus Actual values of Surface Roughness

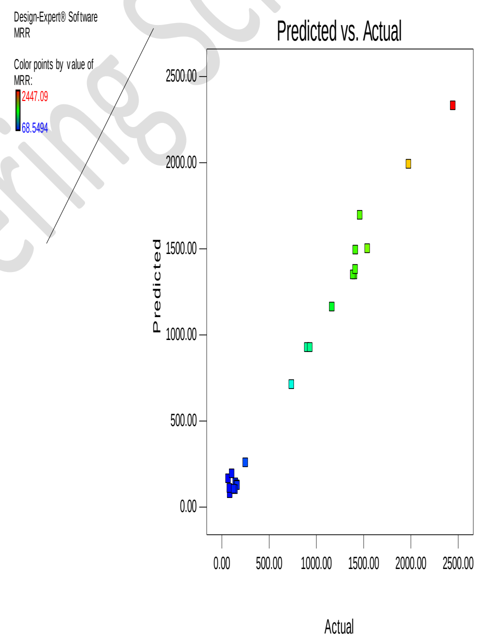

Fig 4.2: Predicted Versus Actual values of Surface Roughness

RESULTS AND DISCUSSION

OPTIMIZATION OF THE PROBLEM

Optimization of machining parameters increases the utility for machining economics; a Response Surface Optimization is attempted using DESIGN EXPERT software for individual machining parameters in turning. Table 5.1 shows the RSM optimization results for the surface roughness and MRR parameters in turning. It also includes the

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ISSN NO:0377-9254

results from confirmation experiments conducted with the optimum conditions individually in case of Aluminium alloy and resin. The desirability values for the two combinations show the conformity to the optimality (desirability should be nearer to 1).

RESULTS

The optimum results for the output responses namely surface roughness and Metal removal rate in terms of machining parameters namely speed, feed, depth of cut and material type on CNC lathe machine using DESIGN EXPERT software were determined and presented in Table 5.1.The confirmation experiments were conducted and there is in good agreement between predicted and experimental values. It is found that the error in prediction of the optimum conditions is about 3 to8%. Thus the response optimization predicts the optimum conditions fairly well.

s	f	D`	m	Ra	Ra exp	MRR	MRR exp	Desirability
2525	34.47	1	al	1.18	1.2	1377.8	1371.6	0.74
3000	30	0.7	r	2.295	2.35	182.9	180.1	0.73

TABLE5.1 : RSM optimization for output responses

CONCLUSIONS

In this study an experimental investigation performed to evaluate the surface roughness and MRR parameters of Aluminium alloy and resin in turning operation has been presented. A plan of experiments has been prepared in order to test the influence of cutting speed, feed rate, depth of cut and material type on the output parameters. The obtained data have been statistically processed using Response Surface Method. The empirical models of output parameters are established and tested through the analysis of variance to validate the adequacy of the models. It is found that the surface roughness and MRR parameters greatly depend on work piece materials. A response surface optimization is attempted using DESIGN EXPERT software for output responses in turning.