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Multi Response Optimization of Process Parameters during Machining of Aluminium by Satisfaction Function

L R Bhandarkar, P P Mohanty, S K Sarangi, M Behara, S S Chakrabarti

Abstract*: Economical machining operation plays an important part in competitiveness in the industries therefore selection of optimum cutting parameters is of great concern in manufacturing environments. The current research is aimed at fixing the optimal process parameters for hard turning of aluminum in CNC lathe machine using carbide tool as per the machinability aspects. On the basis of three-factor-three-level L9 orthogonal array, trials are performed by varying the manageable process constraints which are spindle speed, depth of cut and feed rate. Performance of machining has been figured by several responses like Surface Roughness and Material Removal Rate. Towards optimization above mentioned performance factors are treated as purpose functions, assuming that it corresponds to Higher-is-better and Lower-is-Better requirement respectively. Satisfaction function approach is used in this paper to find out satisfactions of individual responses enabling gathering of multi-responses into a comparable sole index.

Keywords*: Cutting parameters, Material removal rate, Surface finish, Taguchi method.

I. INTRODUCTION

Turning operation is among the renowned and oldest methods of metal cutting using a single point cutting tool. Due to advancement in machining technology it has replaced some popular operations like grinding in many applications without hampering the surface quality and with reduced lead time. Considering process potential of any machining process, operational parameter optimization is of great importance. In industries the primary disadvantage is that, they are not operating the machine tool to their most favorable operating condition [1]. The cutting conditions are either chosen from handbook or from operator's experience. But this will not completely guarantee, that for a specific environment and machine, the selected cutting conditions provides optimal cutting performance. To select the cutting conditions appropriately, various mathematical models created on artificial neural network and regression analysis have been developed by various researchers to form the relationship between cutting conditions and cutting performance [2]. Material removal rate and Surface roughness are affected mainly by cutting conditions (depth of cut, feed rate, spindle speed), process parameters, tool geometry (tool nose radius, rake angle, edge geometry, etc.) and also upon the properties of work piece and tool. To improve surface finish and MRR it is very essential to know the significant influences of cutting parameters on MRR and Surface roughness [3]. Machined component's post machining condition will depend upon work material, cutting conditions and tool parameters. Machined surface work hardening being important aspect of machining may result into bend of thin sections of the component. For minimizing work hardening depth and variation of surface hardness average value, multi-response optimization can be used for identifying strong cutting conditions and tool parameters [4]. Response surface methodology can also be utilized for developing effective surface roughness mathematical model in relations to various cutting conditions. Response surface analytical model interfaced with optimization technique like Genetic algorithm can be too optimize cutting parameters for requisite surface roughness [5]. To get the combined effect of work material, machine tool and cutting tool, there is a need of considering a machining systems approach [6]. As per finishing operations are considered criteria like surface finish and chip breakability are considered for machining performance measures. Chip size and shape are two important factors covered under chip breakability [7]. Artificial neural network approach can also be used as multi-response technique for cutting condition optimization. A neural optimization algorithm can be developed by considering all significant turning parameters [8]. As per the criteria of minimum production cost, the cutting speed and tool life relationships are the important factors for proper cutting parameter optimization [9]. Considering maximum production rate as criteria, method is developed for calculating the optimum cutting conditions. Empirical models are used in this method for roughness, cutting force and tool life. Depending on the cutting speed, the feed relation to the surface finish can be explained [10].

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* Correspondence Author
L R Bhandarkar*, Mechanical department, Veer Surendra Sai University of Technology, Burla, Odisha, India. Email: lrbhandarkar@gmail.com
P P Mohanty, Mechanical department, Veer Surendra Sai University of Technology, Burla, Odisha, India. Email: pragyanmohanty.design@gmail.com
S K Sarangi, Mechanical department, Veer Surendra Sai University of Technology, Burla, Odisha, India. Email: sarojsarangi@gmail.com
S S Chakrabarti, Mechanical department, OP Jindal University, Raigarh, Chhattisgarh, India. Email: siddharth.chakrabarti@opju.ac.in

For improved productivity in mass production material removal rate plays a vital role. On the other hand, for greater productivity one should not compromise with the surface quality. Creep life or fatigue strength and frictional resistance of machined parts are influenced by surface roughness. As per turned parts are concerned, lesser surface roughness (better surface finish) is important as it can lessen or totally remove the need of additional machining. Even if surface roughness is so important as per life and utility of machined parts is concerned because of its dependency on various process parameters and several uncontainable factors, machining process does not have control over the surface quality achieved. Therefore, the scheme of controlling process parameters is a continuing procedure to produce best quality product by using different combinations of tools, materials and machining conditions.

In this paper, material removal rate and surface roughness of the work material, these two important responses which are extensively focused in turning operations are determined. The main focus is on seeing the effects on turning due to three process parameters viz., feed rate, depth of cut and spindle speed on MRR and surface quality. Optimum set of parameters are obtained using design of experiment method like Taguchi and Satisfaction function approach for better response.

II. EXPERIMENTATION

The experiments were performed on high precision CNC lathe machine (make: Sinewave Engineering) with Pentium III controller. The turning operation has been performed on the sample of Aluminum work piece having dimensions' diameter 25 mm and length as 100 mm using a carbide cutting tool. Specifications of tool are tabulated below:

Table I: Cutting tool specifications

Tool type	L.H.S. Single point cutting tool
Rake angle	Zero
Cutting type	Orthogonal cutting
Tool Material	Carbide

In the current article, three manageable process variables are selected on the basis of literature survey. Three parameters i.e. speed of spindle, tool feed and depth of cut has been taken as control factors. Each parameter has variation at three distinct levels as shown in Table II.

Table II: Machining process parameter

Control Parameters	Distinct Levels			
	Units	1	2	3
Spindle Speed	rpm	1300	1600	1900
Feed rate	millimeter/rev	0.42	0.84	1.25
Depth of cut	millimeter	0.25	0.5	0.75

The experimental design (DOE) selected is based on three-control factor-three-level orthogonal array shown in below table. For following nine factorial settings, experiments were conducted.

Table III: Taguchi design

Orthogonal Array L_9		
Spindle Speed	*Feed rate*	*Depth of cut*
1300	1.25	0.25
1300	0.82	0.5
1300	0.42	0.75
1600	1.25	0.75
1600	0.82	0.5
1600	0.42	0.25
1900	1.25	0.75
1900	0.82	0.5
1900	0.42	0.25

A. Surface Roughness Measurement

Elcometer surface roughness measurement instrument is used to acquire the Roughness value. Measurements of R_a values of the machined work-piece are done at four different locations and average of these four values has been considered for a particular set of trial.

Fig. 1. Experimental Setup

B. Material Removal Rate

For improved productivity in mass production material removal rate plays a vital role, following equation is used for determination of MRR (mm^3/sec)

$$MRR = (W_i - W_f) / (\rho \times t) \qquad (1)$$

where W_i – Work material initial weight, W_f - Work material final weight, ρ - Work material density, t - Machining time.

III. METHODOLOGY

A. Taguchi Method

Taguchi method uses a statistical technique of act called Signal-to-Noise (S/N ratio) in order to observe results. Both the mean and the variability of the output data is taken into account by S/N ratio. For estimating the comparative importance of various factors and for error variance computation after performing the statistical study of S/N ratio, Analysis of Variance (ANOVA) is applied.

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The obtained optimum experimental set need not be same as one of the rows of the orthogonal array in Taguchi design. Therefore, a confirmation test is required by using obtained optimum set for the parameters being experimented. If the optimum experimental set results match with the confirmation experiment results, the suggested optimum set of parameters will be adopted.

DOE was applied using Taguchi design to get an optimal number of experiments there by reducing the machining time and cost involved. Special set of arrays called orthogonal array is used in taguchi method. In general, according to orthogonal array, the degrees of freedom number are equal to the factor number multiplied by number of levels for that factor minus one. As we have considered three cutting parameters with three levels, degree of freedom will be six.

B. Material Removal Rate

Taguchi method has a disadvantage that it cannot do multi response optimization. Satisfaction function approach is one of powerful tool for obtaining collective result when there are multiple responses. The satisfaction function general shape is as shown in Fig. 2, where *F(x)* is the satisfaction function associated with deviation *x*, x_{id} is the difference limit, x_v is the veto limit and x_o is the dissatisfaction limit. When deviation is within interval $(0, x_{id})$ Decision Maker (DM) is fully pleased. Therefore, within the previously mentioned range, the deviations x is not penalized and the decision maker's satisfaction level will be at its highest value of 1. Within range (x_{id}, x_o) decision maker's satisfaction graph is decreasing tediously and some result may lead to deviation which overdoes the veto threshold x_v will be discarded. Satisfaction function each is used to change multi response characteristics to satisfaction values between 0 to 1. When preference of DM is unknown, the satisfaction function is assumed to be straight line. From the ideal point, the minimum distance *d* is obtained by following formula [11, 17].

$$d = [\sum_{i=1}^{n} (1 - S_i)^2]^{1/2} \quad (2)$$

where, *d* = deviation of the response from ideal point

Assume that there are *n* performance characteristics, S_i as i^{th} response satisfaction value.

It is understood from Fig. 2 that how satisfaction function can be used in case where highest satisfaction can be obtained from the lowermost value of the response curve. From Fig. 3 it is clear that maximum satisfaction is achieved at maximum value of response characteristics.

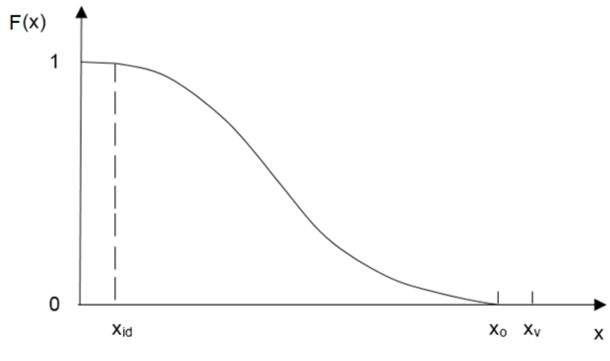

Fig. 2. Shape of satisfaction Function for HB type

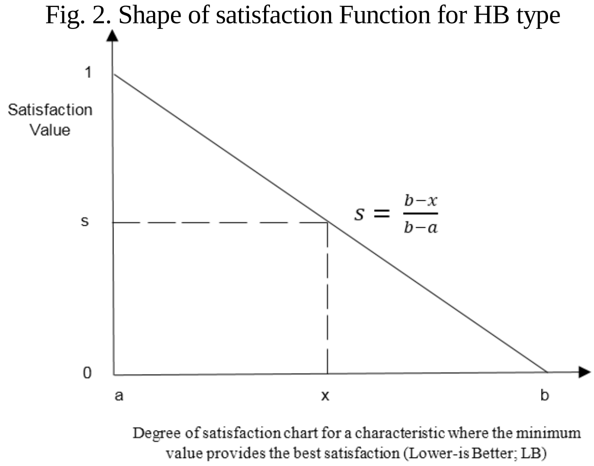

Fig. 3. Shape of satisfaction Function for LB type

IV. RESULTS AND DISCUSSION

After performing the turning operation at different cutting parameters sets, the following data shown in Table IV are obtained by experimentation for Material Removal Rate and Surface Roughness. The corresponding S/N ratio values for MRR and R_a are tabulated below.

Table IV: Experimental data - S/N ratio values for MRR and Surface roughness

Spindle Speed	Feed rate	Depth of cut	Ra	MRR	SNRA	SNMRR
1300	1.25	0.5	0.377	11.4	8.473173	21.1381
1300	0.84	0.25	0.302	5.5	10.39986	14.80725
1300	0.42	0.75	0.244	6.64	12.2522	16.44336
1600	1.25	0.25	0.355	9.35	8.995433	19.41623
1600	0.84	0.75	0.363	9.68	8.801867	19.71751
1600	0.42	0.5	0.268	2.24	11.4373	7.00496
1900	1.25	0.75	0.304	15.31	10.34253	23.6995
1900	0.84	0.5	0.297	5.26	10.54487	14.41971
1900	0.42	0.25	0.171	2.27	15.34008	7.120517

A. Parameter optimization by Taguchi method

MINITAB 17 software was used for carrying out Taguchi design analysis, which is statistical tool in the Design of Experiment (DOE) application. The response data for Signal to Noise (S/N) ratio is shown in Fig. 4 and Fig. 5 for R_a and MRR.

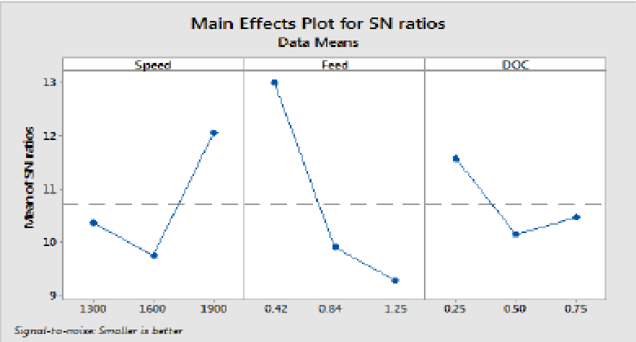

Fig. 4. Prediction of optimal set for better surface finish (Speed =1600 rpm, Depth of cut = 0.5 mm, Feed rate = 1.25 mm/rev)

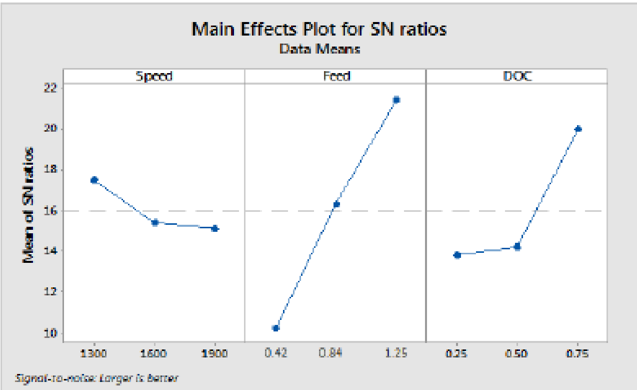

Fig. 5. Prediction of optimal set for maximum MRR (Speed =1300 rpm, Depth of cut = 0.75 mm, Feed rate = 1.25 mm/rev)

Rank analysis of the cutting parameter is shown in Table V and Table 6 for R_a and MRR. Rank analysis gives significant contribution of parameter to the response.

Table V: Response table of Signal to Noise Ratio for R_a

Smaller is better			
Level	Spindle Speed	Feed rate	Depth of cut
1	10.375	13.01	11.578
2	9.745	9.916	10.152
3	12.076	9.27	10.466
Delta	2.331	3.739	1.427
Rank	2	1	3

Table VI: Signal to Noise Ratio response table for MRR

Larger is better			
Level	Spindle Speed	Feed rate	Depth of cut
1	17.46	10.19	13.78
2	15.38	16.31	14.19
3	15.08	21.42	19.95
Delta	2.38	11.23	6.17
Rank	3	1	2

B. Multi response optimization by Satisfaction function

The drawback of Taguchi method is that; it is only used for single response optimization. By using satisfaction function approach, we can optimize the multi responses. In this work we have two responses MRR and Surface roughness. By the satisfaction approach we can get a single optimized set which will give minimum R_a and maximum MMR. In this method the satisfaction value S is calculated separately for MRR and R_a. The satisfaction value varies from 0 to 1. Satisfaction value S for R_a,

$$S_{R_a} = \frac{b - x_i}{b - a} \quad (3)$$

Satisfaction value S for MRR,

$$S_{MRR} = \frac{x_i - a}{b - a} \quad (4)$$

where, b = Maximum S/N ratio, a = Minimum S/N ratio, x_i = corresponds to S/N ratio for set of parameters

$$d = \sqrt{(1 - S_{R_a})^2 + (1 - S_{MRR})^2} \quad (5)$$

where, d = deviation from ideal point

Following Table VII shows the calculated satisfaction values for each experimental set, total deviation from ideal point and corresponding S/N ratio. Fig. 6 shows Prediction of optimal set for maximum MRR and minimum R_a.

Table VII: Calculated satisfaction values, total measured deviation and conforming S/N ratio

Speed (RPM)	Feed (mm/rev)	DOC (mm)	MMR (mm^3/s)	R_a (mm)	S(R_a)	S(MRR)	d	S/N
1300	1.25	0.5	11.4	0.377	0	0.7008416	1.043789	-0.3722553
1300	0.84	0.25	5.5	0.302	0.3640777	0.2494262	0.983747	0.142331
1300	0.42	0.75	6.64	0.244	0.6456311	0.3366488	0.752072	2.47481281
1600	1.25	0.25	9.35	0.355	0.1067961	0.5439939	1.002873	-0.024921
1600	0.84	0.75	9.68	0.363	0.0679612	0.5692425	1.026766	-0.2294294
1600	0.42	0.5	2.24	0.268	0.5291262	0	1.105315	-0.8697244
1900	1.25	0.75	15.31	0.304	0.3543689	1	0.645631	3.80031159
1900	0.84	0.5	5.26	0.297	0.3883494	0.2310635	0.982537	0.1530186
1900	0.42	0.25	2.27	0.171	1	0.0022953	0.997705	0.01995992

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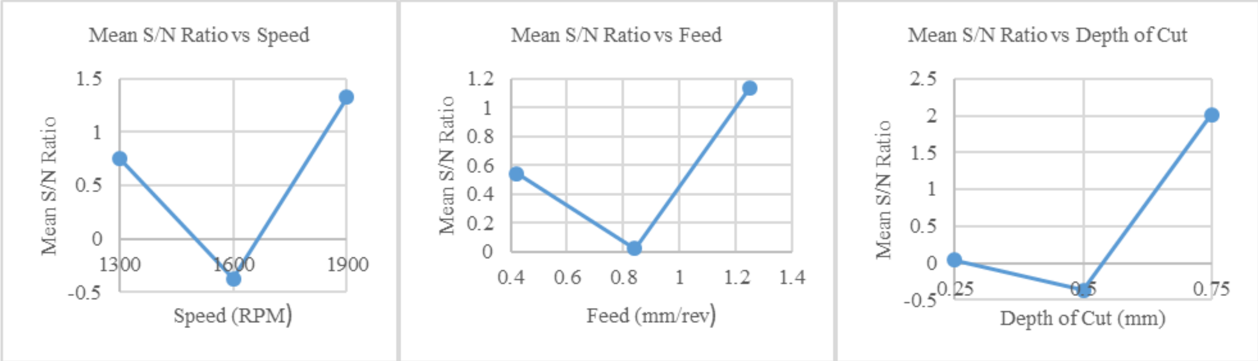

Fig. 6. Prediction of optimal set for maximum MRR and minimum R_a (Depth of cut = 0.75 mm, Speed =1900 rpm, Feed rate = 1.25 mm/rev)

V. RESULTS AND DISCUSSION

After conducting the experiments for all nine sets, Material removal rate by Taguchi method is found out to be maximum for following optimum parameters: Spindle Speed =1300 rpm, Depth of cut = 0.75 mm, Feed rate = 1.25 mm/rev and for least Surface roughness following optimum parameters were obtained: Spindle Speed = 1600 rpm, Depth of Cut = 0.5 mm, Feed rate = 1.25 mm/rev.

The optimized parameter found out for maximum Material removal rate and minimum Surface roughness by Satisfaction function approach were: Spindle Speed = 1900 rpm, Depth of cut = 0.75 mm, Feed rate =1.25 mm/rev.

Confirmation test were also conducted which showed similar trends as obtained by the optimization techniques used. From the considered control parameters, it was found that feed rate is the most significant factor for Surface Roughness and Material Removal rate. After feed rate, spindle speed is noteworthy factor which is then followed by depth of cut for better surface finish. For Material Removal Rate after feed rate, depth of cut is substantial parameter followed by spindle speed.

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AUTHORS PROFILE

Laxminarayan R. Bhandarkar is Assistant Director (Diploma Engineering Program) and Assistant Professor (Sr.) of Mechanical Engineering department at O P Jindal University, Raigarh, Chhattisgarh, India. Bhandarkar has published papers in areas of Vibration, Noise, Manufacturing, etc. His research interest are Coated tools, Optimization of manufacturing operations, Vibration and Noise, Finite element Analysis, Vehicle dynamics. He is perusing PhD in Mechanical from Veer Surendra Sai University of Technology, Burla, Odisha, India.

Dr. Pragyan Paramita Mohanty is presently working as Assistant Professor, Dept. of Mechanical Engg. VSSUT Burla, Odisha, India since 2014. She has 10 years of teaching and research experience. She got Ph.D. degree in the year 2015 from NIT Rourkela in the field of Industrial Design. Her area of research is Manufacturing, Friction Stir Welding, Ergonomic Design.

Dr. Saroj Kumar Sarangi is working as Associate Professor in Mechanical Engineering department of VSSUT Burla , Odisha, India. He had done Post Doctoral Research from NCKU Taiwan, Ph.D from IIT Kharagpur, M.Tech. from NIFFT Ranchi, B. E. from UCE Burla. He is Specialized in CVD Diamond Coating, High Speed Machining, Joining metal-Ceramics. His areas of Research are High Sped Machining, CVD Diamond Coating, UBMS PVD hard coatings, Ceramic-metal brazing, Thermal conductivity measurement techniques in Nano coatings, CVD Graphene Growth. He is having 13 years experience in teaching. He has many research publications to his account published in various Journal of repute. He has written book titled “Development of HFCVD Diamond Tool for machining non-ferrous materials” by LAMBERT Academic Publishing on 11th August 2016. He is also Reviewer of four journal papers for international journal “Applied Surface Science” and one international journal “Surface and Coating Technology” published from Elsevier Science.

Dr. Siddharth S Chakrabarti, Professor & Head-Mechanical Engineering Department, O P Jindal University, Raigarh. His research focuses on the evaporative heat transfer, flow and heat transfer in porous media, Solar Global Radiations, Solar thermal applications, nanomaterials, heat transfer with change of phase and others. He has more than 19 years of teaching, research and industry experience. He has visited countries such as the US, China and published around 75 papers in renowned international journals with five filed patents. Dr Siddharth has obtained his Ph.D. from Indian Institute of Technology, Kharagpur and M Tech from National Institute of Technology, Warangal.