Investigation of the Effect of Machining Parameters on Surface Roughness and Power Consumption during the Machining of AISI 304 Stainless Steel by DOE Approach

Sourabh Waychal[1], Anand V. Kulkarni[2]

[1] *PG Student, Department of Mechanical Engineering, KLSGIT, Karnataka, India*
[2] *Associate Professor, Department of Mechanical Engineering, KLSGIT, Karnataka, India*

Abstract - ***This investigation is focused on the study of effect of various machining parameters on surface roughness and power consumption during machining of AISI 304 stainless steel in turning operation.***

AISI 304 is selected as the work material due to its wide commercial use in industries, high strength, high corrosion & oxidation resistance and availability. Machining is done using TiC coated carbide cutting tool and experiments have been carried out according to Taguchi's L9 array on conventional Kirloskar-Enterprise 1550 lathe. The surface roughness is measured using Taylor-Hobson Surtronic S128 instrument. The cutting force is measured using lathe tool dynamometer. 'Minitab' statistical analysis software is used to obtain design matrix, propose the regression equation and obtain graphs of interaction effect, main effect and perform Taguchi's S/N analysis.

The effects of different process parameters on the responses, namely surface finish and power consumption has been studied. It was observed that the speed and depth of cut were the main influencing factors on the surface roughness. It improved with increase in cutting speed. As expected, better surface finish was found at lower feed rates. Whereas, power consumption increases gradually with increase in all the input parameters.

Key Words: *Taguchi method, Machining, S/N ratio, ANOVA, surface roughness, power consumption*

1. INTRODUCTION

Experiments are performed by investigators in various fields. An experiment is nothing but a test. A designed experiment is a series of tests in which purposeful changes are made to the input variables of a process or system so that the reasons for the changes in the output responses can be observed & identified. The investigator sets various factors in these experiments simultaneously and changes the factor settings from experiment to experiment in a specified manner. This procedure yields maximum amount of information about the effect of input variables on the output response.

Design of Experiments is a problem solving quality tools which can be used for various investigations such as finding the significant factors in the processes, effect of each factor on the outcome, variance in process, screening the parameters, troubleshooting machine problem and modeling the processes.[1]

1.1 Objective of the Investigation

1. To study the effect of speed, feed and depth of cut on the surface roughness and power consumption during machining of AISI 304 steel under dry conditions.
2. To find low surface roughness and power consumption with the assumed input parameters in turning process using DOE approach.

2. TAGUCHI METHOD

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost [2]. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment [3]. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community [4-5]. The desired cutting parameters are determined based on experience or by hand book. Cutting parameters are reflected on surface roughness, surface texture and dimensional deviation turned product [5]. In a manufacturing process it is very important to achieve a consistence tolerance and surface finish [6]. Taguchi method is especially suitable for industrial use, but can also be used for scientific research [7].

Taguchi method is a statistical method developed by Dr.

Genichi Taguchi to improve the quality of manufactured goods and more recently it is also applied to Engineering, marketing, biotechnology and advertising.
Design process are of three stages, namely,

1. Systems Design
2. Parameter Design
3. Tolerance design.

The goal of a robust experimentation is to find the most satisfactory combination of control factor settings that achieve robustness against noise factors. Using various statistical softwares response tables, linear model results, generate main effects plots and interaction plots can be obtained for:

1. S/N ratios v/s control factors
2. Means or slopes v/s control factors
3. Standard deviation v/s control factors
4. Natural log of the standard deviation v/s control factors [8]

3. EXPERIMENTATION

Turning is the most commonly used machining process wherein the cutting tool removes material from the surface of a cylindrical rotating workpiece. A common method of assessing machining performance in a turning operation is based on surface roughness of the workpiece. Surface roughness is closely related to machining parameters.

The main objective of the experiment is to investigate the effect of various machining parameters on surface roughness and power consumption during the machining of AISI 304 stainless steel by DOE approach.

3.1 Cause-effect diagram of parameters affecting Surface roughness and Power Consumption

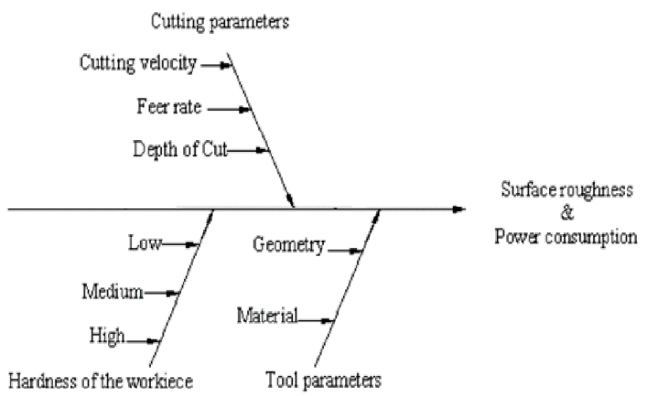

Fig -1: Factors affecting Surface Roughness and Power Consumption

From the literature survey it is evident that cutting velocity, feed rate, depth of cut and the other parameters mentioned in the above Fig-1 are important parameters that affect the surface roughness and power consumption and hence these parameters are chosen for experimentation.

3.2 Material used, Factors and their levels

In this study, cylindrical work pieces of stainless steel AISI 304 of dimensions □ 25 X 80 mm are used. The chemical composition of work pieces is given in the below Table 1. The machining was carried out on a Kirloskar lathe (Kirloskar Enterprise 1550) using single point TiC coated carbide cutting tool. The experiments were conducted in dry condition. The cutting parameters and their levels were obtained from manufacturer's handbook and are mentioned in Table 2.

Table -1: Chemical composition of AISI 304, % weight

C	Cr	Fe	Mn
0.04728	18.7228	70.5416	1.27437
Ni	**P**	**S**	**Si**
8.09020	0.03224	0.01003	0.41118

Table -2: Factors and their Levels

S.No.	Cutting parameter (Factor)	Level 1	Level 2	Level 3
1	Cutting Speed (m/min)/RPM	50/630	78/1000	100/1280
2	Feed rate(mm/rev)	0.05	0.072	0.09
3	Depth of Cut (mm)	0.5	1.0	1.5

3.3 Orthogonal array selection

In the study an L9 orthogonal array is used. Each cutting parameter is assigned to a column.

Table -3: Factors and their Levels

S. No.	Speed (RPM)	Feed (mm/rev)	DOC (mm)
1	630	0.05	0.5
2	630	0.072	1.0
3	630	0.09	1.5
4	1000	0.05	1.0
5	1000	0.072	1.5
6	1000	0.09	0.5
7	1280	0.05	1.5
8	1280	0.072	0.5
9	1280	0.09	1.0

3.4 Taylor-Hobson Surtronic S128, Surface roughness measuring instrument used

In this investigation, Taylor-Hobson Surtronic S128, Surface roughness measuring instrument is used to find the values of Ra.

Fig -2: Taylor-Hobson Surtronic S128

Specifications of the instrument is as given below.

Manufacturer	: Taylor-Hobson (UK)
Traverse unit	: Speed 1mm/sec
Cut-off values	: 0.25mm,0.80mm, 2.50mm
Evaluation length	: 0.25 mm - 25.0 mm
Parameters	: R_a, R_q, R_z(DIN), R_y
Measuring unit	: Metric/inch
Battery	: Li Poly 5V

3.5 Dynamometer used for experimentation

Fig -3: Dynamometer used for experimentation

The Lathe tool dynamometer used during experimentation is as shown in the fig. 3. Specification of the same is as given below.

Manufacturer	: Unitech Scales, Bangalore
Model	: UILD:15
Capacity	: 500Kgf in X,Y,Z direction

3.6 Lathe machine used for experimentation

The lathe machine used for experimentation is of medium duty conventional type. It is as shown in the fig. 4. Specifications of the same is as given below.

Manufacturer	: The Mysore Kirloskar Ltd.
Model	: Enterprise 1550
Supply Volts	: 415
Coil Volts	: 110
Full load amps	: 8.6
Phase	: 3
H.P	: 5/3

3.7 Lathe machine used for experimentation

The experimental setup which was used during experimentation is as shown in the fig. 4

Fig -4: Experimental Setup

4. RESULTS & DISCUSSIONS

Table of experimental values of Surface Roughness and Power Consumption for AISI 304 are as shown below.

Table -4: Values of Surface Roughness and Power Consumption for AISI 304

Speed (RPM)	Feed (mm /rev)	DOC (mm)	Fx (N)	Fy (N)	Fz (N)	Resultant (N)	Power (kW)	Ra (μm)
630	0.05	0.5	29.41	68.65	78.45	108.315	0.08932403	3.5
630	0.072	1	58.84	117.68	98.07	164.099	0.13532711	6.3
630	0.09	1.5	107.87	137.29	196.13	262.586	0.21654632	3.5
1000	0.05	1	58.84	98.07	88.26	144.463	0.18910222	1.5
1000	0.072	1.5	117.68	176.52	137.3	252.704	0.33078836	5.0
1000	0.09	0.5	39.23	88.26	117.68	152.241	0.19928331	4.0
1280	0.05	1.5	127.48	205.94	137.29	278.408	0.46647687	5.8
1280	0.072	0.5	39.23	68.65	137.29	158.431	0.26545352	2.3
1280	0.09	1	78.45	117.68	205.94	249.828	0.41859155	5.3

The Taguchi experimental design is done for L9 Orthogonal array for three parameters which are spindle speed, feed rate and depth of cut.

MINITAB statistical software is used for the analysis of the experimental data and provide the calculated results of signal-to-noise ratio.

4.1 Plots for Surface Roughness

Main Effects plot for Ra is as shown in Fig 5

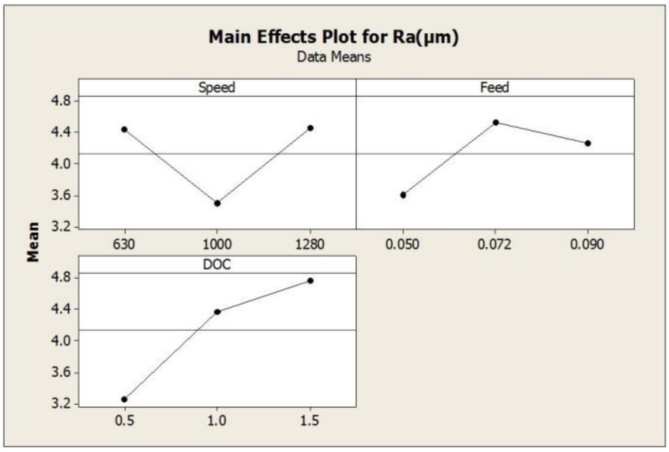

Fig -5: Main Effects plot for Surface roughness

Interaction Plot for Ra is as shown in Fig 6.

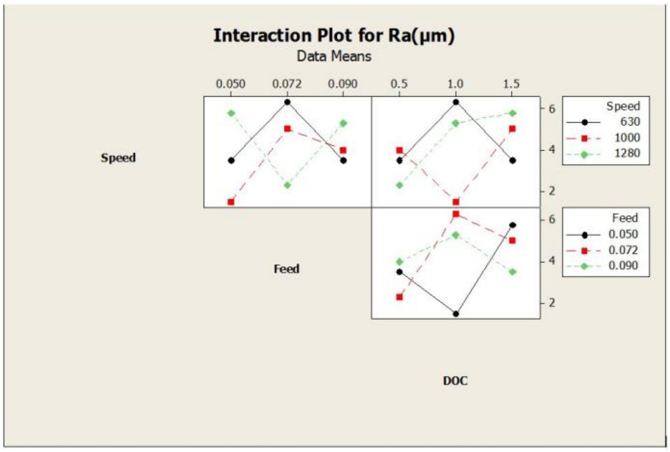

Fig -6: Interaction for Surface roughness

Main Effects Plot for S/N ratios (Ra) is as shown in Fig 7.

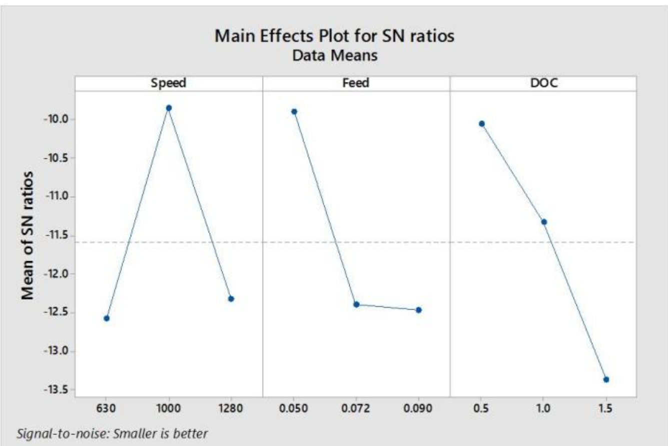

Fig -7: Main Effects Plot for S/N ratios (Ra)

Regression Equation obtained for Ra:
Ra = 1.47 - 0.00008 * Speed + 17.6 * Feed + 1.50 * DOC

4.1.1 Regression Analysis: Ra versus Speed, Feed, DOC

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	44.441	14.814	6.77	0.033
Speed	1	9.281	9.281	4.24	0.095
Feed	1	13.118	13.118	5.99	0.058
DOC	1	22.042	22.042	10.07	0.025
Error	5	10.948	2.190		
Total	8	55.389			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.47971	90.23%	68.38%	24.78%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-.044	3.08	-0.14	0.892	
Speed	-0.00381	0.00185	-2.06	0.095	1
Feed	73.8	30.2	2.45	0.058	1
DOC	3.83	1.21	3.17	0.025	1

4.1.2 Taguchi Analysis: Ra versus Speed, Feed, DOC

Response Table for Signal to Noise Ratio

Smaller is better

Level	Speed	Feed	DOC
1	-9.891	-12.583	-10.052
2	-12.4	-9.847	-11.331
3	-12.469	-12.33	-13.376
Delta	2.579	2.736	3.324
Rank	3	2	1

4.2 Plots for Power Consumption

Main Effects plot for Power Consumption is as shown in Fig 8.

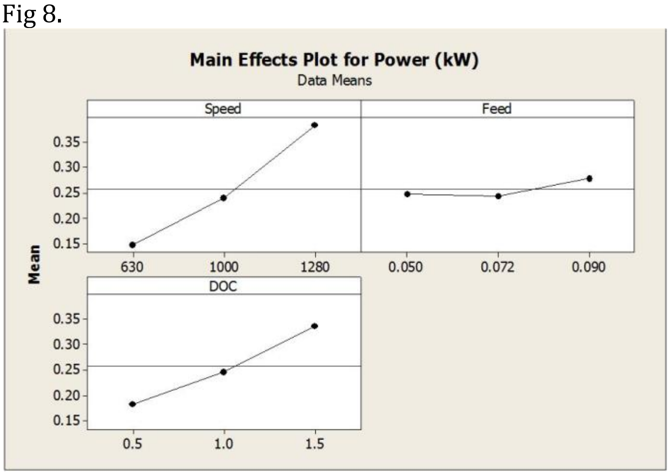

Fig -8: Main Effects plot for Power Consumption

Interaction Plot for Power Consumption is as shown in Fig 9.

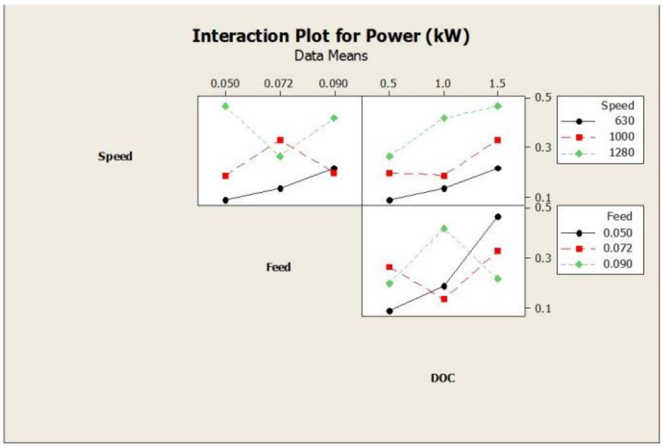

Fig -9: Interaction for Power Consumption

Main Effects Plot for S/N ratios (Power consumption) is as shown in Fig 10.

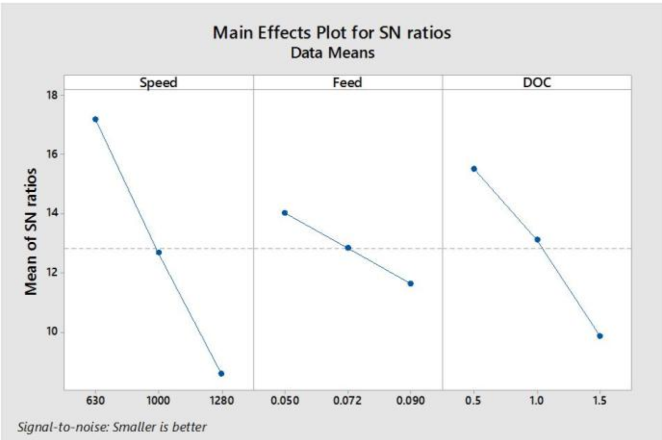

Fig -10: Main Effects Plot for S/N ratios (Power)

Regression Equation obtained for Power:
Power (kW) = -0.2939 + 0.000358 * Speed + 0.711 * Feed + 0.1533 * DOC

4.2.1 Regression Analysis: Power (kW) versus Speed, Feed, DOC

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.118117	0.039372	19.91	0.003
Speed	1	0.081670	0.081670	41.29	0.001
Feed	1	0.001218	0.001218	0.620	0.468
DOC	1	0.035228	0.035228	17.81	0.008
Error	5	0.009889	0.001978		
Total	8	0.128005			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0444723	92.27%	87.64%	68.96%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-0.2939	0.0925	-3.18	0.025	
Speed	0.000358	0.000056	6.43	0.001	1
Feed	0.711	0.906	0.78	0.468	1
DOC	0.1533	0.0363	4.22	0.008	1

4.2.2 Taguchi Analysis: Ra versus Speed, Feed, DOC

Response Table for Signal to Noise Ratio

Smaller is better

Level	Speed	Feed	DOC
1	17.214	14.023	15.504
2	12.695	12.834	13.134
3	8.569	11.621	9.84
Delta	8.645	2.402	5.663
Rank	1	3	2

5. CONFIRMATION TESTS

Confirmation tests are conducted with different values of process parameters to confirm if the regression model developed stands valid.

Table -5: Trials performed at different process parameters values for confirmation

Sl. No	Speed (RPM)	Feed (mm /rev)	DOC (mm)	Fx (N)	Fy (N)	Fz (N)	Resultant (N)	Power (expt) (kW)	Ra (expt) (μm)
1	840	0.065	0.75	78.45	88.26	88.26	147.4247	0.162167	3.60
2	1000	0.08	1.25	107.87	147.10	137.29	228.3037	0.303022	4.80

To find the predicted value of Ra, the values of process parameters are substituted in the regression model obtained for surface roughness.

Table -6: Confirmation experiments of Surface roughness for AISI 304

Sl. No	Speed (RPM)	Feed (mm/rev)	DOC (mm)	Ra (pred) (μm)	Ra (expt) (μm)	Error (μm)	% Error
1	840	0.065	0.75	3.6718	3.60	0.0718	1.955
2	1000	0.08	1.25	4.673	4.80	-0.127	-2.717

Table -7: Confirmation experiments of Power Consumption for AISI 304

Sl. No	Speed (RPM)	Feed (mm/rev)	DOC (mm)	Power (pred) (kW)	Power (expt) (kW)	Error (kW)	% Error
1	840	0.06	0.75	0.168010	0.162167	0.005843	3.4777
2	1000	0.08	1.25	0.312605	0.303022	0.009583	3.0655

6. DISCUSSIONS

6.1 Discussion on Surface roughness for AISI 304 in dry condition

Main Effects Plot

Effect of speed: Surface roughness improves as the speed increases. With the same parameters used in this investigation, R. A. Mahdavinejad [9] and Rangilal. Bhukyal

[10] also found that surface roughness improves with the increase in speed.

Effect of Feed: Surface roughness worsens as the feed increases, Atul P. Kulkarni [11] conducted experiments and found that surface roughness increases in increase of feed.

Effect of DOC: As expected, Surface roughness worsens gradually as there is increase in DOC. Surface roughness improves on reducing DOC.

Interaction Plot

Speed v/s Feed

With the lowest speed chosen at 630rpm, it is observed that surface roughness degrades with increase in feed. With further increase in feed, surface roughness is improved.

With increased speed of 1000rpm, it was observed that surface roughness degrades at minimum feed. As the feed increases, surface roughness degrades. With further increase of feed, surface roughness is improved.

With highest speed of 1280rpm, surface roughness was improved at minimum feed. As the feed increases, surface roughness degrades. With further increase of feed, surface roughness is improved.

Speed v/s DOC

At the lowest speed 630rpm, it is observed that surface roughness degrades with increase in depth of cut. With further increase in depth of cut, surface roughness is improved.

With increased speed of 1000rpm, it was observed that surface roughness improves with increase in depth of cut. As the depth of cut is further increased, surface roughness degrades.

At highest speed of 1280rpm, surface roughness drastically changes for DOC between 1.0 and 1.5mm whereas the unit variation in surface roughness is very less with DOC range from 1.0 to 1.5.

Lowest surface roughness is obtained at DOC 1mm and speed 1000rpm.

Feed v/s DOC

Surface finish is improved with increase in depth of cut. As depth of cut is further increased, degrades the surface roughness.

With increased feed of 0.72, it was observed that surface roughness degrades with increase in depth of cut. Surface roughness improves with further increase in depth of cut.

At highest feed rate, surface roughness degrades with increase of depth of cut. With further increase in depth of cut, surface roughness is improved.

S/N Ratio plot

The S/N ratio indicates that surface roughness is affected most by DOC followed by speed and feed. This is based on the delta values obtained in the response table for S/N ratio.

Order of importance of factors for Surface Roughness

1. Depth of cut
2. Speed
3. Feed

6.2 Discussion on Power Consumption for AISI 304 in dry condition

Main Effects Plot

Power consumption gradually increases with increase in speed and depth of cut. It was observed that with the increase in feed to 0.072, power consumption slightly decreases with further increase in feed, power consumption again increases.

Harsh Y Valera [12] carried out experiments on EN 31 Alloy Steel and found that power consumption increases with increase in speed, feed and DOC.

Interaction Plot

Speed v/s Feed

At lower speeds, power consumption gradually increases with increase in feed. Power consumption is increased with increase in speed. The lowest power consumption is observed at low speed and low feed as expected.

Speed v/s DOC

The power consumption is observed to increase with increase in speed and DOC. Lowest power consumption is obtained at low speed and low DOC and highest power consumption is obtained at high speed and high DOC as expected.

Feed v/s DOC

The power consumption is observed to increase with increase in feed and DOC. At lower and higher feed, power consumption was found to be almost the same but at medium feed, it is increased. As expected, power consumed is lowest at lowest feed and depth of cut.

S/N Ratio plot

The S/N ratio indicates that surface roughness is affected most by speed followed by DOC and feed. This is based on the delta values obtained in the response table for S/N ratio.

Order of importance of factors for Power Consumption:

1. Speed
2. Depth of cut
3. Feed

7. CONCLUSION

In this study, the Taguchi's methodology was utilized to find the optimal process parameters, which minimizes the surface roughness during the dry turning of AISI 304 Stainless Steel. A Taguchi orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) were used for the optimization of cutting parameters.

It was observed that the depth of cut and speed were the main influencing factors on the surface roughness. It improved with increase in cutting speed. As expected, better surface finish was found at lower feed rates. Low surface roughness was observed at speed of 1000rpm, feed rate of 0.05mm/rev and depth of cut of 1mm.

The predicted values and measured values are fairly close which indicates that the developed surface roughness and power consumption prediction models can be effectively used to predict the surface roughness and power consumption

REFERENCES

[1] http://www.weibull.com/hotwire/issue84/hottopics 84.htm
[2] W.H. Yang, Y.S. Tang, "Design optimization of cutting parameters for turning operations based on Taguchi method, Journal of Materials Processing Technology", 84 (1998) 122-129
[3] Ersan Aslan, Necip Camuscu Burak Bingoren, "Design of optimization of cutting parameters when turning hardened AISI 4140 steel (63 HRC) with Al 2 O3 + TiCN mixed ceramic tool, Materials and Design", date received 21.07.2005 and date accepted 06.01.2006.
[4] D.C. Montgometry, "Design and analysis of experiments", 4th edition, New York: Wiley; 1997.
[5] N. Nalbant, H. Gokkaya, G. Sur, "Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning, Materials and Design", date received 21.07.2006 and date accepted 06.01.2006.
[6] I.A. Choudhury, M.A. El-Baradie, "Surface roughness prediction in the turning of high strength steel by factorial design of experiments", Journal of Materials Processing technology, 67 (1997) 55-67.
[7] B. Erginc, Z. Kampu, B. Sustarsic, "The use of the Taguchi approach to determine the influence of injection –molding parameters on the properties of green parts", Journal of achievement in Materials and Manufacturing Engineering, 15, 2006.
[8] http://www.imsproductivity.com/page.cfm/content/ Taguchi-Methods/
[9] R. A. Mahdavinejad and S. Saeedy, "Investigation of the influential parameters of machining of AISI 304 stainless steel", Indian Academy of Sciences, Sadhana Vol. 36, Part 6, December 2011, pp. 963–970
[10] Rangilal. Bhukyal, CSP Rao2, G.V.Rao, "Evaluation and comparison of Machinability characteristics of Maraging Steel and AISI 304 Steels", 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014
[11] Atul P. Kulkarni, Girish G. Joshi, Vikas G Sargade,"Dry turning of AlSI 304 austenitic stainless steel using AlTiCrN coated insert produced by HPPMS Technique", Procedia Engineering 64 (2013) 737 – 746
[12] Harsh Y Valera, Sanket N Bhavsar, "Experimental Investigation of Surface Roughness and Power Consumption in Turning Operation of EN 31 Alloy Steel", 2nd International Conference on Innovations in Automation and Mechatronics Engineering, ICIAME 2014, Procedia Technology 14 (2014) 528 – 534

BIOGRAPHIES

Mr. Sourabh Waychal
Post Graduate Student at Mechanical Engineering Department, Gogte Institute of Technology, Belagavi

Mr. Anand V. Kulkarni
Associate Professor at Mechanical Engineering Department, Gogte Institute of Technology, Belagavi