Analysis of Machining Environment on Performance of Turning Process For Al 6063

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Abstract**—** During the production of various mechanical components by the machining process of turning, there are various parameters taken into consideration during the process viz. depth of cut, spindle speed, environmental conditions, feed rate used, types of tools incorporated during the machining etc. This paper focuses on analysis of effects of these machining parameters on tool life and other supporting output parameters such as power consumed during the process, tool tip temperature generated, vibrations incorporated, noise levels produced and models for the same.

Keywords- *Taguchi, tool life, modelling, ANNOVA.*

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I. INTRODUCTION

In today's competitive world, every manufacturing industry strive to obtain maximum machining efficiency which is possible only when optimized values of input parameters like spindle speed, feed rate, depth of cut, tool type and cutting environments are fed to the machine. These optimized parameters only can result into minimum power consumption, maximum tool life, minimum tool wear, minimum vibrations, minimum noise levels and minimum tool tip temperature etc. This paper models the power consumption, tool life, noise levels generated, vibration levels generated and tool lip temperature. Turning process is widely used for machining of various components because of its reliability in industrial applications.

Bhateja et al. optimized different performance parameters with selection of different process parameters and concluded that tool life can be controlled by tool material, coatings used for tool, process parameters, and performance parameters [1]. Bhuiyan et al. analyzed techniques to measure tool wear from the frequency signals generated from vibrations during machining operation. When the cutting parameters change the dynamic elements of the process then its primary effect is the vibration signals. The evaluation of the frequency signals of these produced vibrations gives directly the tool wear [2]. Chaudhari et al. suggested that MQL method maximizes the material removal rate (MRR) along with reduction in surface roughness [3, 16].

Kompan and Somkiat compared the cutting parameters of turning operation the workpiece of medium carbon steel (AISI 1045) and optimized the tool life by Response Surface Methodology (RSM) [4]. Petkovic and Radovanovic used the genetic algorithms for the optimization of turning process [5, 13].

Patil et al. explained the effects of various parameters such as cutting tool geometry, tool materials, number of passes, depth of cut, feed rate, cutting speed and types of cutting fluids on the production cost, MRR, cutting forces and tool lives [6]. Motorcu et al. explained the effect of tool nose radius, depth of cut and feed rate on the surface roughness during turning operation. He concluded from the experimentations and analysis that the cutting speed was the insignificant factor [7, 15].

Ojolo et al. has investigated the effect of machining parameters on the tool life. They concluded that the cutting speed predominantly affects the tool life than feed rate and it has an inverse relationship with the tool life. They developed the multiple regression models which proved that this is an effective approach for optimization of cutting conditions [8, 17]. Rao et al. showed that the parameters like tool life, cutting forces and surface roughness are strongly correlated with cutting parameters like cutting speed, feed rate and depth of cut. They also concluded that the proper selection of cutting parameters can obtain a minimum cost, longer tool life, better surface roughness, maximum MRRs and lower cutting force [9, 14].

Das et al. optimized the process parameters for turning process using minimum quantity lubrication [10, 15]. Sahu et al. optimized the cutting parameters minimum tool wear, minimum work piece surface temperature and maximum material removal rate in turning of AISI D2 steel. The experimentation results showed that the Taguchi's method is the best method for optimizing process parameters for obtaining low tool wear, low work piece temperature and high MRR. They also constructed the multiple regression equation giving out relationship between cutting parameters and performance variables [11, 12].

Before going for experimentations, firstly the industrial data related to tool wear tare, tool life, tool replacement time is collected and then the experimentations were performed in dry environment and the tool wear rate and tool life was calculated.

The constructed model is helpful in the evaluation of optimum machining parameter like tool geometry, cutting speed, feed rate, depth of cut and tool material for cutting force for turning EN8 steel on conventional lathe machine. Taguchi's parameter optimization method evaluated the best possible combination for minimum cutting force during machining. The paper described the effects of various cutting parameters on the cutting forces.

II. TAGUCHI'S APPROACH

Design of experiments was firstly introduced by R.A. Fisher in England in 1920. He introduced this method to study the effect of multiple parameters simultaneously. Fisher applied this method to find out how much rainwater, fertilizer, sunshine are needed to obtain best quality crops. Many of the researchers studied this method and modified the same; Taguchi was one of those researchers. In electronic control laboratory in Japan, Dr. Genechi Taguchi carried out research in 1940. He took efforts to make Fisher's method more user friendly as well as effective. He finally introduced his approach in 1980 in USA.

Taguchi's design of experiments can be highly effective when one wishes to study the effects of multiple variables on the performance and find solution for production problems.

III. METHODOLOGY

A. *Selection of input & output variables*

According to the literature survey, prime focus was put on process parameters viz. spindle speed, feed rate, depth of cut, type of tool used and cutting environment. Accordingly, the process variables were tabulated by use of L27 orthogonal array generated by Taguchi method for analysis.

B. *Experimental conditions and process parameters*

Fig.1 shows the process flow chart for the steps used in the study. The experimentations were performed on conventional lathe machine with varying capacity and motor power. The work piece used was primarily known as HE - 9 grade aluminum because of its wide engineering applications. Three types of tools viz. brazed tip ceramic tools; inserts with aluminum titanium nitride coating and titanium nitride coating cutting tools were used for machining process. The geometry of the work piece was kept constant throughout the experimentation. Table I shows the details of work piece material, tool used, cutting fluids etc.

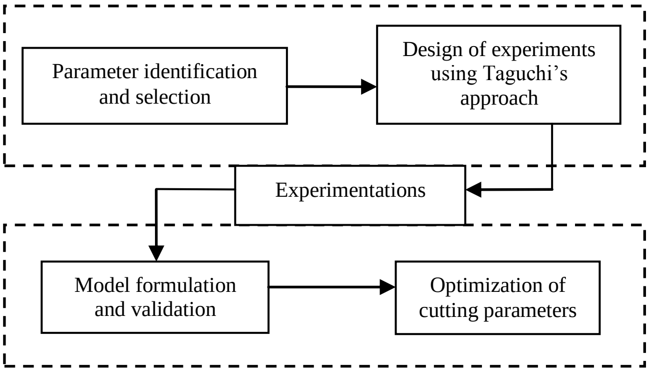

Figure 1. *Process flow chart for experimentations of turning process*

TABLE I. DETAILS OF CUTTING FLUID, MACHINE TOOLS, TOOL HOLDER, WORK PIECE.

Sr No.	Particular	Details
1	Work piece	HE 9 grade aluminum (size:70*120 mm round bars)
2	Cutting tool	Brazed tip ceramic tools CNMG 120412 TF (AlTiN coated) CNMG 120412 MP (TiN coated)
3	Tool holder	PCLNR/L 1616H 12-M SANDVIK
4	Cutting oil	Servocut-S(Manufactured by Indian Oil)
5	Coolant used during machining	5% cutting oil mixed with water and flow rate of 15lit/hr.
6	Compressed air pressure(MQL)	Air at 4 bar and 5% cutting fluid mixed with water and flow rate of 90ml/hr.

C. *Machining parameters*

The input parameters were varied at three different levels explained in Table II. The experiments were carried out in accordance with 3 Level L27 orthogonal array using Taguchi technique. The material composition is described in Table III.

TABLE II. MACHINING PARAMETERS

Parameters	Variables		
Spindle speed (rpm)	200	300	500
Feed rate (mm/rev.)	0.16	0.18	0.2
Depth of cut (mm)	0.5	0.75	1.0

Cutting tool	Brazed tip ceramic tool	CNMG 120412 TF (AlTiN coated)	CNMG 120412 MP (TiN coated)
Environment	Dry	Wet	MQL

TABLE III. WORKPIECE COMPOSITION

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Min.	0.2	-	-	-	0.45	-	-	-
Max.	0.6	0.35	0.1	0.1	0.9	0.1	0.1	0.1

IV. PREDICTION MODEL USING RSM

Response surface method (RSM) is a combination of statistical and mathematical techniques which is useful for the analysis and modeling of the problem. RSM is used for constructing models and is based on statistical design of variables and least squaring. RSM the functional relationship between the response (output variable) and independent variables (input variables). Before applying RSM for constructing models, using design of experiments method, small number of experiments are performed. The response function representing the tool life and independent variables (input variables) can be expressed as;

$$TL=F(S, F, D, Env, Tt, P, Vb, N) \quad (1)$$

A. RSM model for Power

Table IV shows ANOVA results for power consumed. The p-value for the input parameters except feed, cutting environment is less than 0.05 and it indicates that the input parameters spindle speed, depth of cut and tool type are having strong effect on the power consumption during machining of aluminum work piece. The values of R^2=96.02% and R^2(adj.)=91.37% proves close significance of the model. Equation 2 represents the model obtained for power using RSM.

B. RSM model for Noise

Table V shows ANOVA results for noise generated. The p-value for almost the input parameters except tool type is less than 0.05 and it indicates that the input parameters spindle speed, feed, depth of cut and cutting environment are having strong effect on the noise levels generated. The values of R^2=98.87% and R^2(adj.)=97.55% proves the close significance of the model. Equation 3 represents the model obtained for noise using RSM.

TABLE IV. ANALYSIS OF VARIANCE RESULTS FOR POWER

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	14	19968.1	19968.1	1426.29	20.66	0.000
Linear	5	14911.9	4131.7	826.35	11.97	0.000
S	1	10847.2	1650.6	1650.60	23.91	0.000
D	1	1672.3	1564.1	1564.12	22.66	0.000
Tt	1	548.5	659.0	658.96	9.54	0.009
Square	5	2599.0	2599.0	519.79	7.53	0.002
S*S	1	1001.9	1004.9	1004.88	14.56	0.002
D*D	1	1480.5	1480.5	1480.53	21.44	0.001
Interaction	4	2457.3	2457.3	614.32	8.90	0.001
D*Tt	1	762.0	762.0	761.98	11.04	0.006
Env*Tt	1	1553.4	1553.4	1553.39	22.50	0.000
Residual error	12	828.5	828.5	69.04		
Total	26	20796.6				

Std deviation=8.90900 R-Sq=96.02%

PRESS=4698.41 R-Sq(pred)=77.41% R-Sq(adj)=91.37%

$$P=34.5517-71.0175S+6.4445F+69.1321D+31.2358Env+51.6956Tt+12.9414S^2-2.7298F^2-15.7084D^2-3.3424Env^2+0.5502Tt^2-2.6483(S*Tt)-2.1936(F*Tt)-7.9686(D*Tt)-11.3776(Env*Tt) \quad (2)$$

The correlation coefficient of 0.9798 justifies the trueness of the model. Fig. 2 shows that the experimental and calculated values are closely matching which proves that the model is sound and acceptable.

TABLE V. ANALYSIS OF VARIANCE RESULTS FOR NOISE

Source	DF	Seq SS	AdjSS	Adj MS	F	P
Regression	14	1451.94	1451.94	103.710	75.07	0.000
Linear	5	613.94	522.96	104.592	75.71	0.000
S	1	382.94	320.09	320.093	231.70	0.000
F	1	47.41	29.01	29.010	21.00	0.001
D	1	0.05	159.48	159.478	115.44	0.000
Env	1	108.38	11.48	11.475	8.31	0.014
Square	5	765.67	765.67	153.135	110.85	0.000
S*S	1	563.45	563.45	563.450	407.85	0.000
F*F	1	18.77	18.77	18.775	13.59	0.003
D*D	1	178.21	178.21	178.210	129.00	0.000
Interaction	4	72.32	72.32	18.081	13.09	0.000
S*Tt	1	24.82	24.82	24.816	17.96	0.001
F*Tt	1	47.10	47.10	47.098	34.09	0.000
Residual error	12	16.58	16.58	1.382		
Total	26	1468.51				

Std deviation=1.17537 R-Sq=98.87%

PRESS=90.6643 R-Sq(pred)=93.83% R-Sq(adj)=97.55%

$$N=80.4136+31.2740S-9.4150F-22.0747D+5.9214Env-2.7484Tt-9.6906S^2+1.7689F^2+5.4499D^2-0.7933Env^2-0.494Tt^2+1.4381(S*Tt)+1.9811(F*Tt)+0.1119(D*Tt)-0.1472(Env*Tt) \quad (3)$$

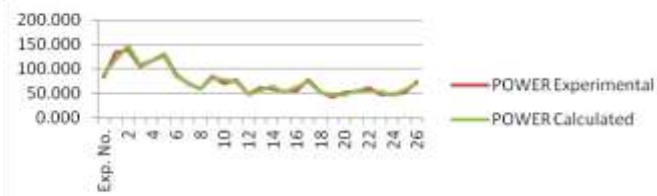

Figure 1. *Validation for power consumed during the process*

The correlation coefficient of 0.9943 justifies the trueness of the model. Fig 3 shows that the experimental and calculated values are closely matching which proves soundness of the model.

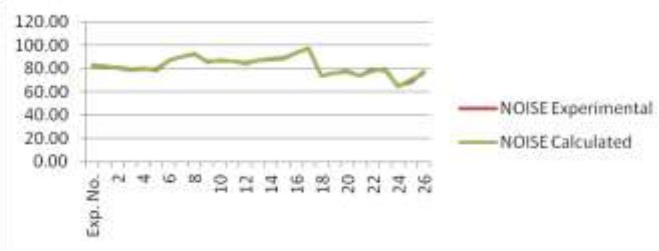

Figure 2. *Validation of noise levels produced during experimentation*

C. *RSM model for Tool Tip Temperature*

Table VI shows ANOVA results for tool tip temperature. The p-value for the input parameters except spindle speed is less than 0.05 and it indicates that the input parameters feed rate, depth of cut, cutting environment and tool type are having strong effect on the temperature at the tool tip temperature. The values of R^2=95.78% and R^2(adj.)=90.85% proves the close significance of the model. Equation 4 represents the model obtained for tip temperature using RSM.

TABLE VI. ANALYSIS OF VARIANCE RESULTS FOR TOOL TIP TEMPERATURE

Source	DF	Seq SS	AdjSS	Adj MS	F	P
Regression	14	8794.19	8794.19	628.16	19.44	0.000
Linear	5	6058.53	3307.16	661.43	20.46	0.000
F	1	3040.53	2453.28	2453.28	75.91	0.000
D	1	887.47	240.73	240.73	7.45	0.018
Env	1	631.15	513.72	513.72	15.89	0.002
Tt	1	1446.62	325.31	325.31	10.07	0.008
Square	5	1882.10	1882.10	376.42	11.65	0.000
F*F	1	1598.16	1598.16	1598.16	49.45	0.000
Env*Env	1	181.28	181.28	181.28	5.61	0.036
Interaction	4	853.56	853.56	213.39	6.60	0.005
S*Tt	1	158.39	158.39	158.39	4.90	0.047
F*Tt	1	206.73	206.73	206.73	6.40	0.026
Env*Tt	1	411.45	411.45	411.45	12.73	0.004
Residual error	12	387.84	387.84	32.32		
Total	26	9182.04				

Std deviation=5.68510 R-Sq=95.78%

PRESS=2780.61 R-Sq(pred)=69.72% R-Sq(adj)=90.85%

$$T=258.158-4.194S-86.58F-27.121D-39.619Env-36.323Tt-1.196S^2+16.321F^2+3.758D^2+5.497Env^2-1.247Tt^2+3.633(S*Tt)+4.151(F*Tt)+2.533(D*Tt)+5.856(Env*Tt) \quad (4)$$

The correlation coefficient of 0.9786 justified the trueness of the model. Fig 4 shows that the experimental and calculated values are closely matching which proves suitability of the model.

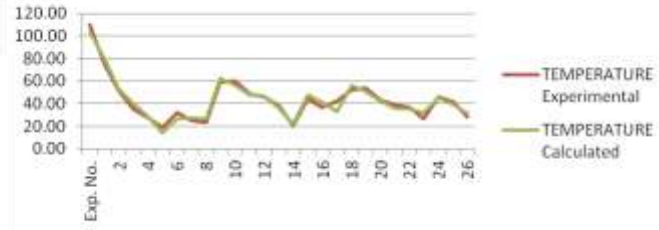

Figure 3. *Validation for tool tip temperature generated*

D. *RSM model for Tool Life*

Table VII shows ANOVA results for tool life. The p-value for input parameters except depth of cut is less than 0.05 and it indicates that the input parameters spindle speed, feed, cutting environment and tool type are having strong effect on the tool life. The values of R^2=94.88% and R^2(adj.)=88.90% proves the close significance of the model. Equation 5 represents the model obtained for tool life using RSM.

TABLE VII. *ANALYSIS OF VARIANCE RESULTS FOR TOOL LIFE*

Source	DF	Seq SS	AdjSS	Adj MS	F	P
Regression	14	52740.4	52740.4	3767.17	15.87	0.000
Linear	5	41460.9	15680.7	3136.15	13.21	0.000
S	1	27611.2	6448.4	6448.43	27.16	0.000
F	1	8879.1	6919.4	6919.42	29.15	0.000
Env	1	1849.9	1268.5	1268.51	5.34	0.039
Tt	1	752.1	1168.0	1168.00	4.92	0.047
Square	5	9368.4	9368.4	1873.68	7389	0.002
S*S	1	3102.4	3102.4	3102.39	13.07	0.004
F*F	1	4003.4	4003.4	4003.36	16.86	0.001
Tt*Tt	1	1428.7	1428.7	1428.75	6.02	0.030
F*Tt	1	1184.7	1184.7	1184.72	4.99	0.045
Residual error	12	2848.7	2848.7	237.39		
Total	26	55589.1				

Std deviation=15.4075 R-Sq=94.88%

PRESS=13641.9 R-Sq(pred)=75.46% R-Sq(adj)=88.90%

$$TL=-185.672+140.369S+145.405F-36.825D-62.258Env+68.825Tt-22.739S^2-25.831F^2+4.223D^2+11.007Env^2-15.431Tt^2-5.124(S*Tt)-9.936(F*Tt)+4.232(D*Tt)+4.046(Env*Tt) \quad (5)$$

The correlation coefficient of 0.9941 justifies the trueness of the model. Fig 5 shows that the experimental and calculated values are closely matching and hence it proves the soundness of the model.

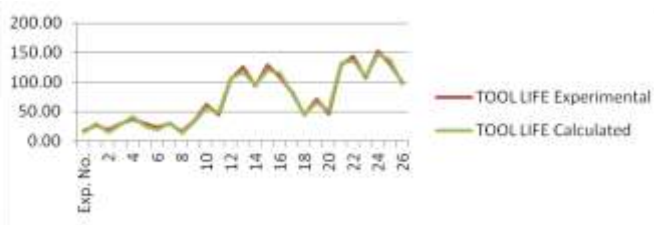

Figure 4. *Validation for tool life*

E. *RSM model for Vibrations*

Table VIII shows ANOVA results for vibrations produced. The p-value for input parameters except cutting environment, depth of cut and tool type is less than 0.05 and it indicates that the input parameters spindle speed and feed are having strong effect on the vibrations generated. The values of R^2=91.24% and R^2(adj.)=81.02% proves the close significance of the model. Equation 6 represents the model obtained for vibrations using RSM.

TABLE VIII. *ANALYSIS OF VARIANCE RESULTS FOR VIBRATIONS*

Source	DF	Seq SS	AdjSS	Adj MS	F	P
Regression	14	919001	919001	65643	8.93	0.000
Linear	5	83719	191701	38340	5.22	0.009

S	1	15689	106843	106843	14.53	0.002
F	1	8754	60893	60893	8.28	0.014
Square	5	169642	169642	33928	4.62	0.014
Tt*Tt	1	126608	126608	126608	17.22	0.001
Interaction	4	665640	665640	166410	22.64	0.000
S*Tt	1	463486	463486	463486	63.04	0.000
F*Tt	1	188725	188725	188725	25.67	0.000
Residual error	12	88220	88220	7532		
Total	26	1007221				

Std deviation=85.7419 R-Sq=91.24%

PRESS=532623 R-Sq(pred)=47.12% R-Sq(adj)=81.02%

$$Vb= 1201.81-571.37S-431.35F+ 174.98D+ 181.41Env+ 40.92Tt+51.96S^2+ 39.62F^2-48.62D^2-23.21Env^2-145.26Tt^2+196.53(S*Tt)+125.41(F*Tt)+ 6.96(D*Tt)-32.72(Env*Tt) \quad (6)$$

The correlation coefficient of 0.9552 justifies the model. Fig 6 shows that the experimental and calculated values are closely matching which proves soundness of the model.

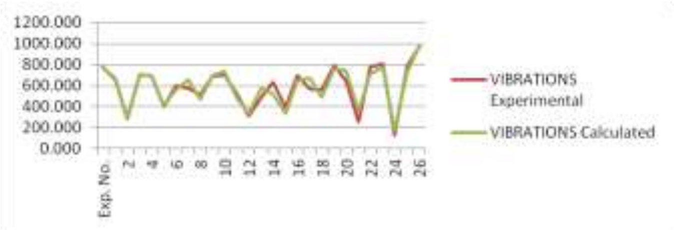

Figure 5. *Validation for vibrations produced during experimentations*

V. CONCLUSION

The objective of the experimentation was to develop a models for power consumed, noise generated, tool tip temperature, tool life and vibrations involving various input parameters like spindle speed, feed rate, depth of cut, cutting environment and tool type. The conventional lathe machine was selected to perform these experimentations. Taguchi's method was used to bring out different combinations of 3 levels of the mentioned 5 input parameters and RSM is used to develop the models. ANOVA results were also studied for understanding the significance of the model.

Study revealed that parameters spindle speed, depth of cut and tool type are having strong effect on the power consumption; spindle speed, feed, depth of cut and cutting environment are having strong effect on the noise levels generated; feed rate, depth of cut, cutting environment and tool type are having strong effect on the temperature at the tool tip temperature; spindle speed, feed, cutting environment and tool type are having strong effect on the tool life; spindle speed and feed are having strong effect on the vibrations generated.

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