Interelation and Optimization of Surface Roughness and Frequency of En24 Steel Turning

Avijit Pramanik

Department of Mechanical Engineering, National Institute of Technical Teachers Training and Research, Kolkata, 700106, West Bengal, India

***Abstract*: - The success of the manufacturing process depends on upon the selection of appropriate process parameters. The selection of optimum process parameters plays a significant role to product quality, cost and productivity. This study investigated the multi – response optimization of the turning process for an optimal parametric combination to yield the minimum tool vibration frequency, surface roughness and maximization of metal removal rate using Genetic Algorithm (GA). A mathematical model of tool vibration frequency has been built up and modal analysis of the tool holder in ANSYS gives resonance frequency and it is used as a n useful for understanding the dynamic performance of any lathe –work piece system. The experiment s were designed and conducted on the lathe machine with high speed steel (AISI T42) as cutting tool and EN-24 Steel bar as work piece material The factors are chosen which influence the tool vibration, surface roughness and MRR of product in turning through design of experiment (DOE). Experimental results show that the tool vibration frequency and surface roughness of the work materials are co related with each other and influence of cutting parameters on frequency and surface roughness.**

***Keywords:* (HSM) High Speed Machining, (GA) Genetic Algorithm, (DOE) Design of experiment, Vibration Amplitude, Surface Roughness, ANOVA (Analysis of Variance).**

I. INTRODUCTION

Machining is a process in which a piece of raw material is converted into a desired final shape and size by controlled material –removal process. Many processes that have this common theme of controlled material removal are today collectively known as subtractive manufacturing. Now a day's most of the industries are sued CNC machining which changes the scenario of machining. According to the International Institution of Production Research, machining accounts for approximately half of all manufacturing techniques, which is a reflection of the achieved accuracy, productivity, reliability and energy consumption of this technique.

The advances in computational modeling, sensors, diagnostic equipment and analysis tools, surface metrology and manufacturing science particularly during the past decade have enabled academia and engineers to research machining dynamics from a new dimension and therefore to have the potential for great industrial benefits. Increasing demands on manufacturing precision products require the development of precision machines for engaging high value manufacturing. When designing precision machines, it is essential to consider the mechanical structures, control system dynamics, and machining process dynamics simultaneously.

On the basis of available research work it is considers chatter of a machine tool system consisting of a flexible work piece and a tool flexibility mounted on a guided bed and chatter are determines by using of finite element method, and the Laplace transformation technique [1, 2]. The stability limits that represented by curves with the rotational speeds which separate stable and unstable zones for maximum productivity and accepted surface roughness. Also it effect of feed rate upon the stability and the amplitude of vibration for constant depth of cut and rotational speed [3].

Machine tools chatter is one of the major constraints that limit productivity of the turning process. The self excited vibration is mainly caused by interaction between tool work piece structure and cutting process dynamics [4] .The model of the system is based on the predictive machine theory of shear zone model by analyzing the analytical solution of the governing equation three kinds of oscillatory motion are found [5,6].

The stock removal rate is highly affected by the phenomenon of instability analysis of machining process and a model is set up for machine tools structures for providing a finite element method and ANSYS software, so that the flexibility of machining structure, work piece and tool have been consider [7]. The reduction of self – excited vibration with controlled eliminators containing a piezoelectric actuator and an electromagnetic system. The results of numerical simulations and experimental investigations confirm the effectiveness of the eliminators. The simulations were conducted with MATLAB [8].

The derivation of statistical models to predict roughness parameters during machining process of PEEK composites using PCD and K10 tools, a nonlinear regression model and analysis of variance is used [13] and the application of ANOVA and ANN analysis for optimization of machining parameters in turning AlSiC composites and concluded that ANOVA and ANN modeling techniques provide a systematic and effective methodology for the optimization.

From above literature it is clear that substantial research work have been done on optimization of parameters of different types of machining, but there are few literatures available on experimental study and optimization of frequency of tool vibration, surface roughness and MRR of turning in conventional lathe on EN-24steel. In this context, the following objectives are made for the present study.

- Built up mathematical model for the frequency of tool vibration.
- CATIA, Modeling and further applying FEM for modal analysis.
- Determine the factor which influences the tool vibration, surface roughness and MRR of product in turning through design of experiments (DOE).
- Find out the predicted values using regression analysis method. Model equations are formed using coefficients obtain from Analysis of Variance (ANOVA).
- Find out the optimum process parameters for turning of EN-24 using Genetic Algorithm (GA).

II. EXPERIMENTAL PROCEDURE

A series of turning experiments were carried out in order to obtain experimental data in the different conditions. Accordingly the present work has been carried out through the following plan of experiment.

First of all checking and preparing the Lathe ready for performing the machining operation. Cutting the EN-24 bar by power saw and performing initial operation to get desired dimension of the work piece. Then performing the straight turning operation on specimens in various cutting conditions involving various combinations of process control parameters like: spindle speed, feed rate and depth of cut. Measuring surface roughness and tool vibration with the help of Mar Surf PS1 and Pico Scope respectively.

Table 1 Chemical composition of AISI T-42 cutting tool

Element	**Content (%)**
Carbon (C)	1.15 – 1.30
Molybdenum (Mo)	3.00 – 4.00
Vanadium (V)	-3.00 – 3.70
Chromium (Cr)	3.80 – 4.80
Tungsten (W)	9.00 – 11.00
Cobalt (Co)	9.00 – 11.00
Nickel (Ni)	0.00 – 0.40
Phosphorus (P)	0.35
Sulpher (S)	0.35
Manganese (Mn)	≤ 0.40
Silicon (Si)	≤ 0.40

Table 2 Machining parameters and their limits

Variables / Levels	1	2	3	4	5
Depth of cut (mm)	0.15	0.25	0.35	0.45	0.55
Feed (mm/rev.)	0.2	0.35	0.5	0.62	0.8
Rotational speed (rpm)	115	150	250	400	600

As an important subject in the statistical design of experiments, the response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and objective is to optimize this response (Montgomery 2005). In turning operation there is large no. of factors that can be considered as machining parameter. In present study these are selected as deign factors while the other parameters assumed constant over the experimental domain. Usable and popular RSM design which is largely applicable in any type of research area is Central Composite Design (CCD).

Table 3 Measured responses of Surface Roughness and Frequency

Parameter			**Reponses**	
Speed (rpm)	Feed (mm/rev.)	Depth of cut (mm)	Frequency (Hz)	Surface Roughness (μm)
250	0.5	0.35	2175	2.69
600	0.5	0.35	2780	6.85
150	0.62	0.45	2359	3.78
250	0.5	0.55	2580	5.89
150	0.62	0.25	2300	3.66
250	0.5	0.15	2250	3.32
250	0.8	0.35	2175	2.68
250	0.2	0.35	2589	5.70
150	0.35	0.25	2351	4.00
400	0.35	0.45	2752	6.91
400	0.35	0.25	2463	4.79
250	0.5	0.35	2176	2.73
400	0.62	0.25	1985	1.45
150	0.35	0.25	2344	3.98
250	0.5	0.35	2243	3.20
115	0.5	0.35	2436	4.57
400	0.62	0.45	1996	1.48
250	0.5	0.35	2299	3.63
250	0.5	0.35	2179	2.78
250	0.5	0.35	2219	3.06

III. RESULT AND DISCUSSION

The Figure 1 shows the main effect plot for frequency. It shows how cutting parameters (spindle speed, feed rate, depth of cut) impacts on frequency. If depth of cut increases frequency increased. If feed rate is increased, frequency decreases, and with spindle speed frequency changes abruptly, first decreases to a certain point and then decreases.

Whereas figure 2 shows the main effect plot of surface roughness.it shows how cutting parameters impacts on surface roughness.the impact is for individual. If depth of cut increases surface roughness increased. If feed rate is increased, surface roughness decreases, and with spindle speed surface roughness changes abruptly, first decreases to a certain point and then decreases.

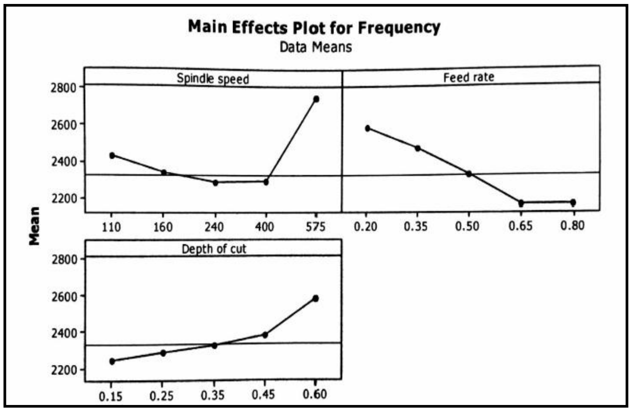

Fig. 1: Main Effects Plot of Frequency

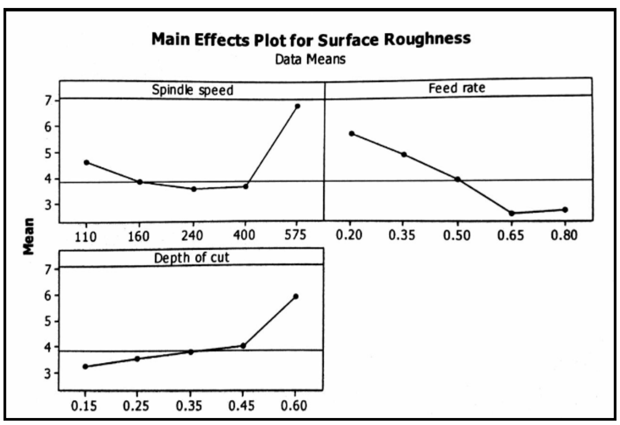

Fig. 2: Main Effects Plot of Roughness (Ra)

From the generated model, combination of factors, which gives the best response, is established. These mathematical models are useful not only for predicting machining quality but also process optimization. The adequacy of the model is tested using the sequential F-test, lack-of-fit, test and the Analysis of Variance (ANOVA) technique using the same software to obtain the best fit model.

From ANOVA summery table it I clear that the analysis of variance shows the main effect of the spindle speed (A), feed rate (B), depth of cut (C), the quadratic effect of the spindle speed (A^2), feed rate (B^2), depth of cut (C^2), along with the interaction effect of spindle speed and feed rate (A*B), spindle speed and depth of cut (A*C, feed rate and depth of cut (B*C) are the most significant terms associated with respectively for Frequency and Surface Roughness. The ANOVA table of the quadratic model show that the p value isles than 0.005 which indicates that the model terms is statistically significant.

Table 4 Analysis of Variance for Frequency

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	848253	848253	94251	25.66	0.00
Linear	3	361324	32376	10793	2.94	0.08
A	1	42532	30767	30767	8.37	0.01
B	1	228321	437	437	0.12	0.73
C	1	90390	2786	2786	0.75	0.40
Square	3	329743	236444	236444	21.43	0.00
A*A	1	169956	181154	181154	49.31	0.00
	1	117776	93409	93409	25.43	0.00
C*C	1	42013	40217	40217	10.93	0.00
Interaction	3	157376	157276	52425	14.27	0.00
A*B	1	139108	113268	113268	30.83	0.00
A*C	1	134	25	25	0.01	0.93
B*C	1	18139	18139	18139	4.91	0.05
Residual Error	10	36734	36734	3673		
Lack–of–Fit	4	24124	25125	6032	2.86	0.12
Pure Error	6	12611	12614	2101		
Total	19	884999				

Through the backward elimination process, the final quadratic models of response equation in terms of actual factors are presented as follows:

Frequency = [2437.81-2.52*A-50.19*B-832.27*C+ 0.01*A*A+18.62*B*B+3136.56*C*C–0.54*A*B– 259.59*B*C]

Where, R–Sq. = 98.49%, R–Sq. (pred.) = 91.36%, R–Sq. (adj.) = 97.11%

Surface Roughness (Ra) = [6.5583-0.0192*A-0.1408*B- 6.9569*C+0.1405*B*B+24.9822*C*C- 0.0035*A*B=0.0036*A*C-2.359*B*C]

Where, R–Sq. =97.08%, R–Sq. (pred.) = 92.27%, R–Sq.(adj.) = 96.32%

Table 5 Analysis of Variance for Surface Roughness (Ra)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	43.8617	43.8617	4.87352	37.11	0.00
Linear	3	19.551	1.8844	0.62815	4.78	0.02
A	1	2.4177	1.7831	1.7831	13.58	0.00
B	1	12.4481	0.0262	0.0262	0.20	0.66
C	1	4.6853	0.1947	0.1947	1.48	0.25

Square	3	16.6578	12.4826	4.16087	31.69	0.00
A*A	1	7.8066	8.9507	8.95069	68.16	0.00
B*B	1	6.1764	5.3197	5.31969	40.51	0.00
C*C	1	2.6747	2.5513	2.55130	19.43	0.00
Interaction	3	7.6528	7.6528	2.55094	19.43	0.00
A*B	1	6.1319	4.7973	4.79726	36.53	0.00
A*C	1	0.0313	0.0139	0.01388	0.11	0.75
B*C	1	1.4896	1.4896	1.48965	11.34	0.00
Residual Error	10	1.3131	1.3131	0.13131		
Lack–of–Fit	4	0.6871	0.6871	0.17178	1.65	0.27
Pure Error	6	0.6260	0.6260	0.10433		
Total	19	45.174				

Table 6 for error calculation

Output	Actual value	Predicted value	Difference	% Error
Frequency	2589	2535	54	2.08
Surface Roughness	3.94	4.085	-0.1452	3.7

According to the investigation individual response optimization is performed. It has been observed that the result of experiments conducted for response is approximately in accepted region. Thus the response optimization predicts for optimum condition. A comparison is made between measured and calculated results, which are much good to agreement. It is indicating that the final developed models can predict the response within the limits of machining parameters being used.

Genetic algorithm process and procedure is used to optimize the result obtained from experimentation. For this method we need the fitness equation which is already modeled previously by using RM. Following the algorithm procedure, a genetic algorithm program is written for multi objective optimization i.e. to get optimum cutting parameters for two outputs or objective which is respectively Tool vibration frequency and Surface roughness. In this way we will obtain the minimum set of considering cutting parameters for minimizing both tool vibration and surface roughness at the same time. After executing the program with given input values the optimum cutting parameters are obtained. The detailed optimized result is given in the table below.

Table 6 for GA optimized input variables

Speed (rpm)	Feed (mm/min)	DOC (mm)	Frequency (Hz)	Surface Roughness (μm)
150	0.8	0.25	2110	1.89

In the present work response surface equation I derived from quadratic regression fit, so to verify taking the independent variable values within the range for which the formula was derived and also to verify the result obtained from optimization. So one conformation experiment is performed for tool vibration frequency and surface roughness considering the input parameters obtained from GA optimization.

Table 7 for conformation Experimentation

Speed (rpm)	Feed (mm/min)	DOC (mm)	Frequency (Hz)	Surface Roughness (μm)
150	0.8	0.25	2180	1.94

IV. CONCLUSION

Experiments were designed and conducted on lathe machine with High speed steel (AISIT42) as cutting tool and EN-24 steel bar as work material. Mathematical model for frequency of tool vibration and surface roughness were generated through Response Surface Methodology (RSM). Based on the experimental result presented and discussed, the following conclusions are drawn

- Tool vibration frequency and surface roughness of the work material are co related with each other and influence of cutting parameters, figure 1 and 2 show that both the responses are affected as same manner.
- The Figure 1 shows the main effect plot for frequency. It shows how cutting parameters (spindle speed, feed rate, depth of cut) impacts on frequency. If depth of cut increases frequency increased. If feed rate is increased, frequency decreases, and with spindle speed frequency changes abruptly, first decreases to a certain point and then decreases.
- The main effect plot of surface roughness shows how cutting parameters impacts on surface roughness. If depth of cut increases surface roughness increased. If feed rate is increased, surface roughness decreases, and with spindle speed surface roughness changes abruptly, first decreases to a certain point and then decreases.
- The result of the confirmation test shows that the tool vibration frequency is 2180 Hz, surface roughness is 1.94 micrometer when the optimum cutting parameters were chosen to be spindle speed 150 rpm, feed rate 0.8 and depth of cut is 0.25 mm. the percentage of errors in each case is within 5%.

REFERENCES

[1]. Zhanchen Wang, 'Chatter Analysis of Machine Tool System in Turning Processes', International Journal of Machine Tool Design Research, Vol.1, pp.325-335.

[2]. Vipul Shah, 'Experimental Investigation of chatter and critical cutting conditions in turning', International Journal of Machine Tools and Manufacturer, Vol. 39, 1999, pp. 1631-1654.

[3]. Ramiz Saeed Matty Samarjy, 'Estimating the Limits of Stability under Several Working Conditions at Experimental Turning', Journal of Engineering for Industry ASME. Vol. 107/ 96 May 1985.

[4]. Prof. Dr. M.J. Ostad – Ahmad – Ghorabi, "Comprehensive dynamic cutting force model and its application to wave removing

process", Journal of Engineering for Industry AME, Vol. 110, pp. 153-161.
[5]. Ivana Kovacic, "Natural Frequencies and Normal modes of a Spinning Timoshenko Beam with General Boundary Conditions", Journal of Applied Mechanics, Vol. 59, pp. 197-203.
[6]. Mung Chen, "An Integrated Approach toward the Dynamic Analysis of High Speed Spindles, Part 1: system Model", Journal of Vibration and ACOU~ CVSo, 1.116, pp.506-513.
[7]. R.A Mahdavinejad, 'A step forward to chatter analysis in turning machines'.
[8]. Arkadiusz Parus, D. W. Wu & C. R. Liu, "Self –Excited Vibrations in Metal Cutting", Journal of Engineering for Industry, Vol. 81, pp.183-186.
[9]. Mr. Ashirbad Swain, 'Evaluation of Cutting Forces and Prediction of Chatter Vibrations in Milling', Journal of Braz. Soc. Of Mech. Sci. & Eng., January – March 2004, Vol. xxvi, No. 1/81.
[10]. Vinay Babu Gada, "The Dynamic Interaction of Cutting Process, Work piece, and Lathe's structures in Facing", Journal of Manufacturing Science and Engineering, Vol. 118, pp. 348-358.
[11]. Jui P. Hung, Keneko T., Sato R., Tani Y. and O-hori M.,'Self excited chatter and its marks in turning', ASME, Journal of Engineering for industry, Vol. 106, pp. 222-228.
[12]. M. Ramesh, R.P Elvin, K. Palanikumar and K. Hemachandra Reddy, ' Surface Roughness Opyimization of Machining Parameters in Machining of Composite Material', international Journal of Applied Research in Mechanical Engineering, Vol. 1, pp.26-32, 2011.
[13]. Francisco Mata, Issam Hanafi, Abdellatif Khamlichi, Abdallah Jabbouri and Mohammed Bezzazi, 'Derivation of statistical models to predict roughness parameters during machining process of PEEK composites using PCD and K10 tools', International Journal of Physical Science , Vol. 22 (1),pp. 21-32, 1999.
[14]. Muthukrishnan, 'Optimization of machining parameter of Al/sic-MMC with ANOVA and ANN analysis', J. Mater. Process. Tech, Vol. 209, pp.225-232, 2008.

AUTHOR PROFILE

Avijit Pramanik completed 3 years Full time Diploma Courses in Mechanical Engineering in the year of 2005, from Hooghly Institute of Technology, Govt. of West Bengal. After that complete my B. Tech. Degree from Haldia Intitute of Technology, Haldia West Bengal in Year of 2010. Author also received the M. Tech. Degree in Manufacturing Technology from National Institute of Technical Teachers Training and Research Kolkata, under MHRD Govt. of India, in the year of 2016. After competition of Diploma I joined as a Supervisor in Factory Mechanical Department at Howrah Mills Company Limited, Howrah West Bengal. During 2010 -2013 work as a Lecturer in Department of Mechanical Engineering at GSM Polytechnic Burdwan West Bengal. In the year of 2013 to 2014 work as a Lecturer in Department of Mechanical Engineering at BIETP Birbhum, West Bengal. During 2012-2014, I work as a Part - Time Contractual Lecturer in Department of Mechanical Engineering at Hooghly Institute of Technology Hooghly, Govt. of West Bengal. I also worked as a Guest faculty in Department of Mechanical Engineering at Elite Polytechnic Institute in the year of 2014-2015. Now I work as a Lecturer in Department of Mechanical Engineering, Baghmundi Govt. Polytechnic, Purulia West Bengal.