Experimental Investigation of Machine Tool Condition during Machining of Ferrous Components

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***Abstract*—In an engineering manufacturing industry, the machine tool and its productivity is always considered as one of the main resources for manufacturing process to satisfy and meet the required demand on time. Keeping this as main focus of manufacturing system, it is desirable to operate the machine tool with an optimum combination of process parameters such as cutting speed, depth of cut, feed rate to maintain good operating condition and thereby enhancing its productivity. In the present study, an effort has been made to analyze the turning process with different combinations of process parameters and their influence on machine tool condition in terms of quality of surface finish and vibrations induced in the machine tool. Surface roughness of turned part and machine tool vibrations at a predetermined location were measured using Mitutoyo SJ-201 Talysurf and tri-axial accelerometers. After acquiring the experimental data, the analysis of variance was carried out to find the effect of process parameters on surface roughness and machine tool vibration. A multiple regression prediction model was built and predicted values of surface roughness and vibrations were compared with the experimental values, which were found to be in good agreement. Further, an artificial neural network (ANN) prediction model was developed to predict the surface roughness and machine tool vibration for given process parameters which predicted with good accuracy.**

***Index Terms*—productivity, vibration, analysis of variance, multiple regression, artificial neural network**

I. INTRODUCTION

Components to be assembled are always required on time and of acceptable quality to meet the required demand to sustain in the competitive world of manufacturing. Of several manufacturing processes, machining process is one such process of importance. In almost all the machining processes, selection of machining process parameters play a vital role in processing a required part with in the stipulated time and quality. Hence, it is necessary to select an optimum combination of process parameters to produce the component or the product with good quality without affecting the machine tool condition, so that there will not be any problem of quality of the part or delay in producing it. The present study focuses on quality of turning process in terms of surface roughness and machine tool vibration. Similar work carried out by various researchers is presented in the following paragraph. Reference [1], S. Saravanan, G.S. Yadavaand P.V. Rao, carried out an investigation to study the vibration characteristics of spindle bearing of a lathe using acoustic emission and shock pulse measurements. The variables influencing vibration considered were cutting speed, feed rate, depth of cut and grease contamination. The study revealed that the smaller contamination particles in the grease increase the wear of the bearing elements. Reference [2], Parikshit Mehta, Andrew Werner and Laine Mears, carried out a condition based maintenance system development which is an open architecture control, integrated on lathe to monitor the machine tool condition. Coolant temperatures and spindle vibration signals were acquired and processed using a high speed data acquisition system. The proposed system enhances machine monitoring by integrating the internal and external sensors aboard the machine tool. Reference [3], Li Zhang, Ruqiang Yan, Robert X. Gao and Kang Lee, carried out a study to design software for an automated spindle health monitoring system based on open system architecture as a contribution in developing smart machine tools. The analytic wavelet-based envelope spectrum algorithm was used to generate the software for extracting the spindle defect-related feature. The developed software was capable of identifying the spindle degradation, defect location and tracking of damage growth. Reference [4], A. Purushothamand G. Sravan Kumar, carried out an experimental investigation to study the influence of dynamic cutting force on chatter vibration of a lathe. The experiment was conducted with different combinations of process parameters such as cutting speed, depth of cut and feed rate on a hollow cylindrical work piece with single point cutting tool. Dynamometers, mounted in the tool post and accelerometer, mounted on the cutting tool were used to measure the cutting force and vibration with a time interval of 50 seconds. This study revealed the variations in the cutting force and vibration of the cutting tool. Reference [5], MironZapciu, Jean-Yves K'nevez, Alain Gérard, Olivier Cahuc and Claudiu F. Bisu, carried out an experiment to analyse the tool dynamic characterization

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in a lathe under different working conditions. The frequencies from the FFT spectrum and frequencies obtained from the finite element modal analysis were compared and a procedure was established for better performance of the machine tool. Reference [6], D. O'sullivan and M. Cotterell, conducted an experimental study to develop temperature measuring techniques for a turning process using thermocouples and infrared camera influenced by cutting speed, feed rate and depth of cut. The study revealed that increase in cutting speed results in decrease of cutting tool force and machined work piece surface temperature. Further it also revealed that there exists a tool wear with increased cutting force and machined work piece surface temperature. Reference [7], N. Kusuma, MeghaAgrwal and P. V. Shashikumar, performed an experimental work on a CNC milling machine to analyze the influence of cutting parameters on surface finish and machine tool vibration. Analysis of Variance (ANOVA), Artificial Neural Network (ANN) and Genetic Algorithm (GA) were used to carry out the analysis. The ANOVA analysis revealed that the vibration is influenced more by spindle speed and surface roughness is influenced by depth of cut. The prediction process carried out by using ANN model revealed that the model is capable of producing an acceptable level of prediction values for the surface roughness. The GA optimization model provided the required optimum cutting parameters for a given surface roughness value. Reference [8], O. B. Abouelatta, carried out an experimental investigation to develop an ANN prediction model to predict the machining process parameters such as cutting speed, depth of cut and feed rate for a defined surface roughness. The experimental work was carried out on turning, milling and surface grinding of machining AISI 1040. The developed ANN model was tested with the experimental values and the predicted surface roughness values compared well. Reference [9], JithinBabu R and A Ramesh Babu, investigated the influence of process parameters on surface roughness and cutting force during turning operation. The study focused on finding out the contribution of input parameters over output parameters using analysis of variance tool and building prediction models using multiple regression and ANN. The study revealed that the feed rate and depth of cut influence the surface roughness and cutting force respectively.

II. Design of Experiments and Experimental Setup Details

Experimental trials to analyse the influence of process parameters on surface roughness and machine tool vibrations during turning of mild steel are based on full factorial design with three levels and three factors. Table 1 provides the three levels and three factors considered in this experimental study. Based on full factorial design, 27 experimental trials with different combination of process parameters were carried out on HMTLT-20 engine lathe in dry run condition on a 20 mm diameter mild steel specimen using a carbide cutting tool insert of 0.2 mm nose radius. A tri-axial accelerometer was mounted on the spindle bearing housing at the front bearing area to capture the vibrations in axial (X-axis), tangential (Y-axis) and radial (Z-axis) directions respectively. The data from the accelerometer was obtained and processed in a 4 channel FFT analyzer. Surface roughness of the machined part was measured using Mitutoyo SJ-201 Talysurf.

TABLE I. Selected Process Parameters (Factors) and Levels for Experimental Trials.

Levels	Spindle speed (RPM)	Feed rate (mm/rev)	Depth of cut (mm)
1	250	0.05	0.50
2	420	0.11	0.75
3	710	0.22	1.00

III. Result Analysis

The experimental trials were carried out as per the design of experiments with different combination of process parameters. Surface roughness and spindle bearing housing vibration in axial, tangential and radial directions were measured and are tabulated in Table II.Variation of surface roughness and vibrations in all three axes with respect to process parameters are shown in Fig.1 to Fig.4.

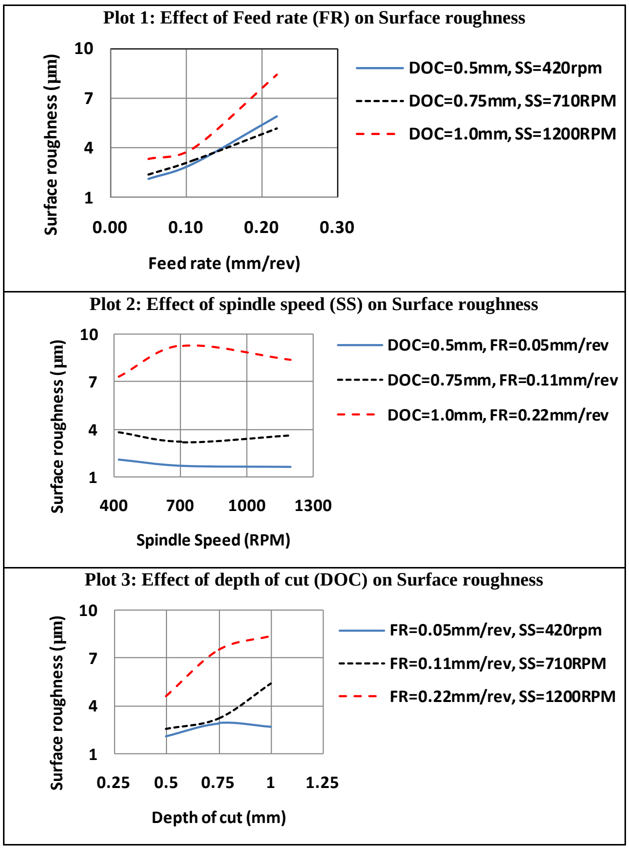


Figure 1. Effect of process parameters on surface roughness

From Fig.1, it is observed that the surface roughness is more affected by feed rate signifying that feed rate is directly related to the surface roughness as suggested in theory that the surface roughness is function of square of feed rate. Plot 2 of Fig. 1 shows the trend of decrease of surface roughness with the increase of spindle speed. From Fig.2, the vibration in axial direction increases as the spindle speed increases. From Fig.3, the vibration along the tangential direction is more due to the direct contact of the cutting edge of the tool with the work piece, where increasing the spindle speed increases the vibration. From Fig. 4, it is observed that the radial vibrations increase as the spindle speed increases.

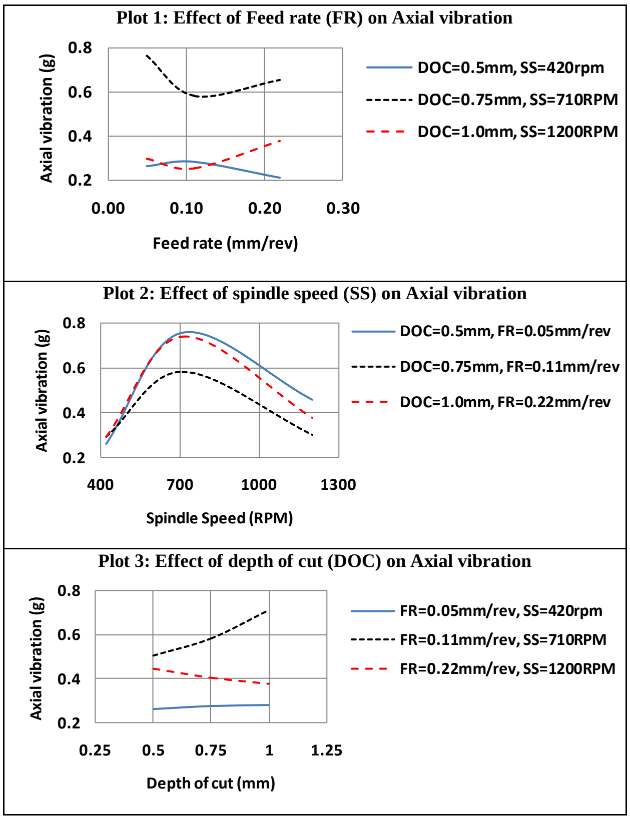
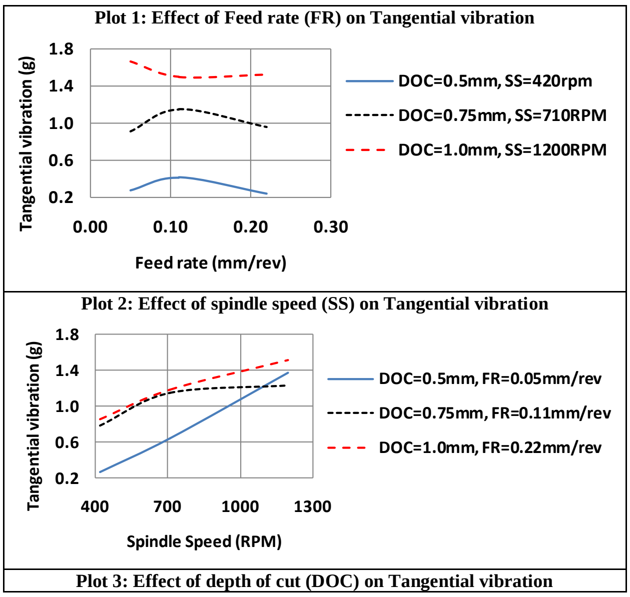


Figure 2. Effect of process parameters on axial vibration



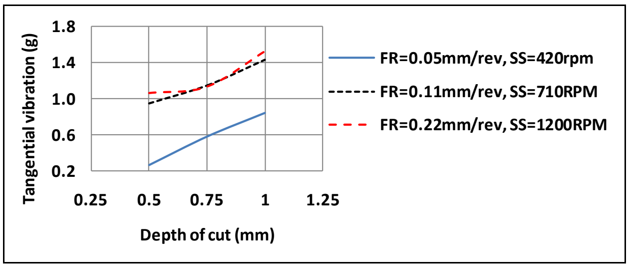


Figure 3. Effect of process parameters on tangential vibration

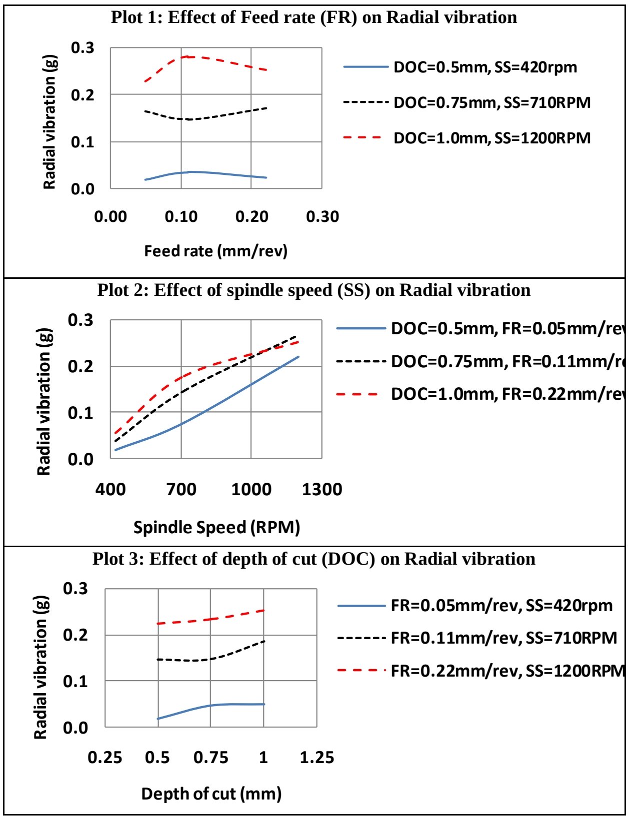


Figure 4. Effect of process parameters on radial vibration

A. Contribution of Process Parameters by Anova

The analysis of variance which is frequently referred to as ANOVA is a statistical technique which is specially designed to test whether the means of two or more quantitative populations are equal. Reference [10], S.P.Gupta, suggests F-test of ANOVA in determining the degree of factors affecting the output of the experiment.

IV. Multiple Regression Based Prediction Model

The experimental data presented in the Table 2 has been used to develop the multiple regression prediction model using multiple regression module in MS Office Excel application. The input data was prepared in an Excel spread sheet as per the required format and the prediction model was developed for surface roughness and vibrations along the axial, tangential and radial directions. The regression prediction models were developed with 95% confidence level and according to the second order fit as in equations 1 to 4.

TABLE II. MEASURED VALUES OF VIBRATION AND SURFACE ROUGHNESS

Trial No.	Spindle speed (RPM)	Feed rate (mm/rev)	Depth of cut (mm)	Vibration(g)			Surface roughness (microns)
				Axi.	Tang.	Rad.	
1	420	0.05	0.50	0.264	0.269	0.018	2.10
2	420	0.05	0.75	0.276	0.580	0.046	2.93
3	420	0.05	1.00	0.281	0.844	0.049	2.67
4	420	0.11	0.50	0.284	0.412	0.035	3.03
5	420	0.11	0.75	0.292	0.781	0.039	3.81
6	420	0.11	1.00	0.321	0.910	0.043	4.01
7	420	0.22	0.50	0.211	0.234	0.024	5.87
8	420	0.22	0.75	0.251	0.454	0.042	6.12
9	420	0.22	1.00	0.295	0.860	0.055	7.31
10	710	0.05	0.50	0.757	0.647	0.077	1.73
11	710	0.05	0.75	0.762	0.910	0.164	2.39
12	710	0.05	1.00	0.771	1.066	0.190	2.98
13	710	0.11	0.50	0.504	0.947	0.147	2.58
14	710	0.11	0.75	0.582	1.150	0.148	3.22
15	710	0.11	1.00	0.712	1.432	0.187	5.40
16	710	0.22	0.50	0.508	0.850	0.148	4.87
17	710	0.22	0.75	0.655	0.957	0.171	5.14
18	710	0.22	1.00	0.740	1.192	0.180	9.31
19	1200	0.05	0.50	0.457	1.380	0.222	1.66
20	1200	0.05	0.75	0.382	1.391	0.234	2.17
21	1200	0.05	1.00	0.295	1.660	0.229	3.31
22	1200	0.11	0.50	0.317	1.222	0.195	1.87
23	1200	0.11	0.75	0.300	1.238	0.269	3.64
24	1200	0.11	1.00	0.252	1.493	0.281	4.00
25	1200	0.22	0.50	0.448	1.065	0.225	4.61
26	1200	0.22	0.75	0.407	1.133	0.233	7.54
27	1200	0.22	1.00	0.377	1.522	0.254	8.42

TABLE III. ANOVA RESULTS FOR PROCESS PARAMETERS CONTRIBUTION ON SURFACE ROUGHNESS AND VIBRATION

Effect	Sum of square (SS)	Degree of freedom (DOF)	Mean of square (MS)	Frequency (F)	Percentage of contribution (p)
Surface roughness					
Spindle speed	0.02306	2	0.0115	0.00714	0.992891
Feed rate	83.1241	2	41.562	25.7259	0.000003
Depth of cut	0.21857	2	0.1092	0.06764	0.934805
Residual	32.3114	20	1.6155		
Vibration in axial direction					
Spindle speed	0.76079	2	0.3803	104.757	0.000000
Feed rate	0.02580	2	0.0129	3.5526	0.047839
Depth of cut	0.04530	2	0.0226	6.2381	0.007846
Residual	0.07262	20	0.0036		
Vibration in tangential direction					
Spindle speed	2.55202	2	1.276013	23.2065	0.000006
Feed rate	0.09884	2	0.0494	0.89879	0.422879
Depth of cut	0.07086	2	0.0354	0.64441	0.535532
Residual	1.09970	20	0.0549		
Vibration in radial direction					
Spindle speed	0.18031	2	0.0901	123.509	0.000000
Feed rate	0.00087	2	0.0004	0.6008	0.557994
Depth of cut	0.00055	2	0.0002	0.3814	0.687771
Residual	0.01459	20	0.0007		

$$\text{Surface roughness} = 4.4044 - 0.0033*SS - 13.9659*FR - 3.8890*DOC - 7.3012e^{-9}*SS^2 + 59.3098*FR^2 + 1.6198*DOC^2 + 0.0053*SS*FR + 24.1838*FR*DOC + 0.0034*DOC*SS \quad (1)$$

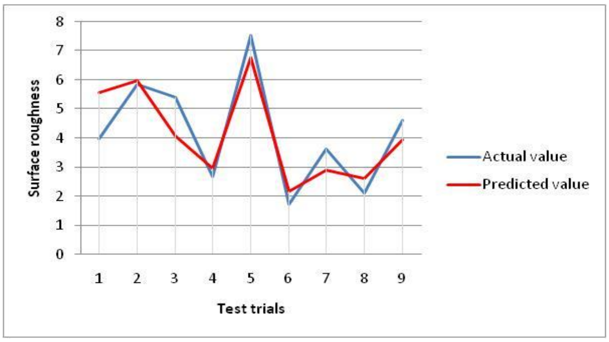
$$\text{Axial vibration} = -1.0077 + 0.0044*SS - 4.3349*FR + 0.2646*DOC - 2.5000e^{-6}*SS^2 + 9.3663*FR^2 - 0.0176*DOC^2 + 0.0007*SS*FR + 1.3404*FR*DOC - 0.0004*DOC*SS \quad (2)$$

$$\text{Tangential vibration} = -1.1845 + 0.0032*SS + 4.834*FR + 0.1436*DOC - 1.0000e^{-6}*SS^2 - 16.9580*FR^2 + 0.7265*DOC^2 - 0.0014*SS*FR + 0.6457*FR*DOC - 0.0006*DOC*SS \quad (3)$$

$$\text{Radial vibration} = -0.3779 + 0.0007*SS + 0.5947*FR + 0.2658*DOC - 3.1000e^{-7}*SS^2 - 1.3161*FR^2 - 0.1174*DOC^2 + 1.5800e^{-6}*SS*FR - 0.23136*FR*DOC + 3.0300e^{-5}*DOC*SS \quad (4)$$

V. ANN BASED PREDICTION MODEL

One of the objectives of present study was to develop an ANN based prediction model which establishes a relationship between process parameters and surface roughness and vibration along three axes.



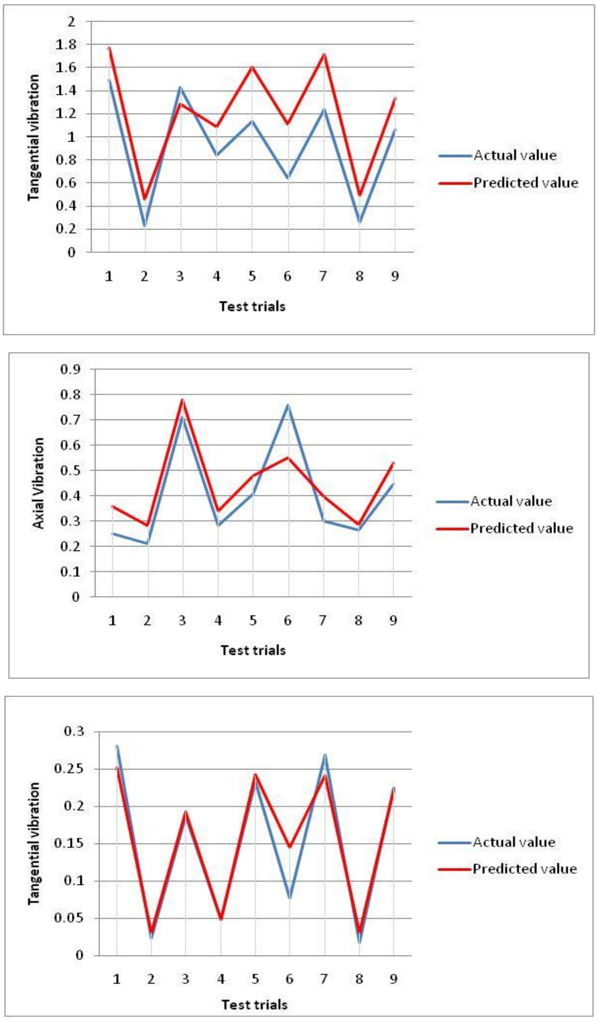


Figure 5.Comparison of actual experimental values with the predicted values from ANN prediction model.

Reference [11], Simon Haykin, has suggested use of multilayer perceptron for using the back-propagation algorithm for training the network. In the present work the ANN model developed has input, hidden and output layers. Number of neurons in the input layer is based on the number of input independent variables. In the present work the input layer consists of three neurons, the hidden layer consists of five neurons and output layer has one neuron. ANN model was built by using a soft computing tool, WEKA 3.8 for which 18 (66%) sets of the data were used to train the neural network and 9 trial sets were tested for the prediction from the trained network. The comparison of the actual and predicted values from the developed ANN model is as shown in the Fig. 5.

VI. CONCLUSIONS

An experimental investigation was carried on dry turning operation of mild steel specimen with 0.2 mm nose radius cutting tool insert under different combinations of process parameters. From the results of the investigation it is proposed to operate the machine tool under lower feed rate for better surface roughness and lower spindle speed for minimum vibration of spindle bearing housing which also relates with the common practice. The proposed approach provides a proven technique to improve quality of the component produced and also maintains the machine tool's spindle bearing in good condition. The prediction models developed with the help of soft computing tools, especially with ANN, provide predicted values which are in good agreement with the experimental values as compared to predicted values obtained from Multiple Regression model.

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