DEVELOPMENT OF EMPIRICAL MODEL FOR PREDICTION OF SURFACE ROUGHNESS IN TURNING OPERATION

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Abstract

In present days, the important goal in the modern industries to manufacture high quality and low cost products in just in time. The quality of the product depends upon the surface roughness and hence the surface roughness placed an important role in product manufacturing. Hence, an Empirical model is proposed for prediction of surface roughness in machining processes at given cutting conditions (speed, feed, depth of cut).For a given work-tool combination, the range of cutting conditions are selected from different cutting condition variables. These cutting conditions are applied for Factorial design of experiments (DOE) method. After conducting experiments, surface roughness values are measured. Then these experimental results are used to develop an Empirical model for prediction of surface roughness by using Multiple Regression method.

Keywords: Surface Roughness, Factorial Design of Experiments (DOE), Prediction Models, Multiple Regression method.

I. INTRODUCTION

Surface Roughness is one of the important attributes of job quality in machining process. The controlled surface roughness of machined component is necessary to improve its tribological properties, fatigue strength, corrosion resistance and aesthetic appearance. In addition to tolerances, surface roughness imposes one of the most critical constraints for the selection of machines and cutting parameters in process planning. A good-quality machined surface significantly improves the fatigue strength, corrosion resistance, and creep life of the component. Therefore, the desired finish surface is usually specified and the appropriate processes are selected to reach the desired quality.

Turning is the most common metal removal operation and is widely used in a variety of manufacturing industries, including aerospace and automotive sectors, where quality is an important factor in the production of cylindrical, cone shaped and taper surfaces etc. Several factors influence the final surface roughness in a Turning operation. This surface roughness might be considered as the sum of two independent effects. **K. Taraman et.al.,** developed **[1]** a mathematical model for the surface roughness in a turning operation was developed in terms of the cutting speed, feed and depth of cut. Utilizing PL1 language and an IBM 360/50 computer, the model was used to generate contours of surface roughness in planes containing the cutting speed and feed at different levels of depth of cut. The surface roughness contours were used to select the machining conditions at which an increase in the rate of metal removal was achieved without sacrifice in surface finish.

II. LITERATURE SURVEY

R. M. Sunderam et. al., [2] has presented the experimental development of mathematical models for predicting the surface finish of AISI 4140steel in fine turning operation using TiC coated tungsten carbide throw away tools. presented a novel experimental design called the rotatable design was used for the experimental procedures. Variables included in the model are: cutting speed, feed, depth of cut and time of cut of the tool. Statistical coding was used for the experimental variables. First order (log transformed) models were developed. For tools that exhibited lack of fit for the first-order models, a second-order model was developed. Multiple regression analysis was used in developing these prediction models. **Mike S.Lou and co-workers [3,4]** developed a new technology for surface prediction, literature reviews of the surface texture, surface finish parameters, and multiple regression analysis have been carried out. **M.S. Chua [5] et. al.,** developed a process planning or NC part programming, optimal cutting conditions are to be determined using reliable mathematical models representing the machining conditions of a particular work-tool combination. The development of such mathematical models requires detailed planning and proper analysis of experiments. In this paper, the mathematical models for TiN-coated carbide tools and Röchling T4 medium carbon steel were developed based on the design and analysis of machining experiments. The models developed were then used in the formulation of objective and constraint functions for the optimization of a multipass turning operation with such work-tool combinations. This is the base for my project work by considering three parameters spindle speed, feed, depth of cut for achieving good surface values with less percentage deviation from actual.

From the above literature survey it is evident that, there is a need to develop a technique to predict the surface roughness of the final product, without carrying out the turning operation, for a given set of values for the process parameters. This would be very handy in determining the requirement of machining parameters such as feed rate and spindle speed for obtaining a desired surface roughness and increasing product quality.

III. RESULTS AND DISCUSSION

In order to establish the correlation between the cutting parameters and the surface roughness in the mathematical model form, machining issues were incorporated with different cutting conditions, aiming at simulating them for the surface roughness.

A. *Design of Experiments:*

The experiments program was planned using a multiple variable factorial design [3*4*4]. The factors considered were Spindle Speed, Feed Rate, Depth of Cut. The range of values of each factor was set at the mixed levels, as shown in Table1. Based on this setting a total of 48 experiments, each having a combination of different levels of factors were carried out. The experiments are conducted on Lathe and selected work piece material is Mild Steel (C-0.18 to 0.25, P-0.035, Si-0.04, Cu-0.2, Mn-0.6 to 1.25). The cutting tool with High Speed Steel (W-18%, Cr-55%, C-0.7)is used to machine the work piece material. The response of surface roughness was measured by using Taylor Hobson Talysurf instrument and tabulated (Table 1 & 2).

Table 1: Values of Test Variables

VARIABLES DESIGNATION	*DESCRIPTION*	*VALUES OF DIFFERENT LEVELS*
s	Spindle Speed(rpm)	680, 395, 225
f	Feed rate (mm/min)	90, 78, 72, 60
d	Depth of cut(mm)	1.0, 0.75, 0.5, 0.25

Table 2: Experimental Results (Train Data)

TEST No.	*SPINDLE SPEED,V (rpm)*	*FEED, F(mm/rev)*	*DEPTH OF CUT, D (mm)*	*SURFACE ROUGHNESS, Ra (µm)*
1	680	90	1	5.56
2	680	90	0.75	6.286
3	680	90	0.5	6.99
4	680	90	0.25	7.542
5	680	78	1	5.52
6	680	78	0.75	5.964
7	680	78	0.5	6.224
8	680	78	0.25	6.322
9	680	72	1	5.862
10	680	72	0.75	5.128
11	680	72	0.5	5.96
12	680	72	0.25	5.168
13	680	60	1	5.428
14	680	60	0.75	5.423
15	680	60	0.5	4.914
16	680	60	0.25	4.857
17	395	90	1	4.68
18	395	90	0.75	5.462
19	395	90	0.5	5.784
20	395	90	0.25	6.992
21	395	78	1	5.176
22	395	78	0.75	5.186
23	395	78	0.5	6.384
24	395	78	0.25	6.678
25	395	72	1	5.868

26	395	72	0.75	6.184
27	395	72	0.5	6.65
28	395	72	0.25	6.562
29	395	60	1	6.678
30	395	60	0.75	6.549
31	395	60	0.5	5.674
32	395	60	0.25	6.342
33	225	90	1	4.557
34	225	90	0.75	5.743
35	225	90	0.5	6.642
36	225	90	0.25	7.682
37	225	78	1	5.576
38	225	78	0.75	6.528
39	225	78	0.5	6.243
40	225	78	0.25	7.868
41	225	72	1	6.436
42	225	72	0.75	6.84
43	225	72	0.5	7.264
44	225	72	0.25	7.501
45	225	60	1	7.2
46	225	60	0.75	7.54
47	225	60	0.5	7.642
48	225	60	0.25	7.523

B Surface Roughness Model:

The purpose of developing the mathematical models relating the machining responses and their machining factors is to facilitate a functional relationship between surface roughness and the independent variables (v, f, d). The following models are considered in this section.

I. Multiple Regression Model:

The multiple regression models were developed by using the independent variables (v, f, d) and the dependent variable (Ra). The experimental results were modeled using multiple regression methodology and respective models excluding and including interaction terms were developed. The equation excluding interaction terms using independent variables. For simplicity, equation is re-written as algebraic representation of regression line can be represented by

$$Ra = b_0+b_1s+b_2f+b_3d \quad \ldots\ldots\ldots\ldots (1)$$

Where, Ra is surface roughness; s,f,d are predictors and b_0,b_1,b_2,b_3 are the regression coefficients. Using the experimental data, the analysis consisted of estimating these three variables first for first order model. If the first order model demonstrates any statistical evidence of lack of fit, a second order model can then be developed using additional data, this model is an algebraic model with interaction terms are considered. The Multiple regression equation of second order model with interaction terms can be represented by the fallowing equation

$$Ra=b_0+b_1s+b_2f+b_3d+b_4sf+b_5ds+b_6fd+b_7s^2+b_8f^2+b_9d^2 \quad \ldots\ldots (2)$$

Where Ra is surface roughness; s,f,d are predictors and $b_0,b_1,b_2,b_3,b_4,b_5,b_6,b_7,b_8,b_9$ are the multiple regression coefficients.

C. Development of Surface Roughness Prediction Model:

The experimental results as shown in the Table 2 are used to develop the surface roughness prediction model. The criterion to judge the efficiency and the ability of the model to predict surface roughness values is taken as percentage deviation(Δ) which is defined in equation(3). With this criterion it would be much easier to see how the proposed model fit and how the predicted values are close to the actual ones.

Percentage Deviation = ((Predicted Ra – Experimental Ra)/Experimental Ra)*100 ……… (3)

I. Multiple Regression Model:

Regression analysis is conducted with MINITAB using above experimental data to establish the surface roughness prediction model.

First Order Multiple Regression Model:

The First Order Multiple Regression Model for the prediction of surface roughness is postulated by the equation(1) and the fallowing equation is found

$$Ra = 8.39 - 0.00201\, s - 0.00588\, f - 1.37\, d \quad \ldots\ldots\ldots (4)$$

Referring to the regression analysis results in Table 3, for 3-degrees of freedom for regression and 44 degrees of freedom for residual error, F-ratio from the regression analysis is 4.54, which is greater than F-ratio (2.41) from the statistical tables. Its P-value corresponding to F-ratio is 0.002, which is significant for 95% confidence interval. All the independent variables are not significant as their p-value are less than 0.05. The R2 value is 39%, which indicates 35.1 variability in predicting Ra with independent variables. Hence, the first order multiple regression model cannot be considered. In order to improve the prediction accuracy and for further comparison, another model called second order multiple regression model is considered.

Table 3: Regression Analysis: In Ra vs s, f, d.

PREDICTOR	*COEF*	*SE COEF*	*T*	*P*
Constant	8.3918	0.7853	10.69	0.00
s	-0.0020105	0.0005428	-3.7	0.01
f	-0.005884	0.009419	0.62	0.535
d	-1.3676	0.3645	-3.75	
R-Sq=39 %		*R-Sq(adj)=34.9%*		
Regression Analysis without interaction terms *Ra = 8.39 - 0.00201 s – 0.00588 f – 1.37 d.*				

Analysis of Variance:

Source	*DF*	*SS*	*MS*	*F*	*P*
REGRESSION	3	14.0448	4.6816	9.4	0.00
RESIDUAL ERROR	44	21.9147	0.4983		

Second Order Multiple Regression Model:

The Second Order Multiple regression model for the prediction of surface roughness is postulated by equation (2) and the following equation is found.

In Ra = 12.4 – 0.0273 s -0.0369 f + 6.38 d +0.000212 sf – 0.125 fd +0.00338 ds +0.000008 s^2 +0.000115 f^2 +0.123 d^2 ………… (5)

If the purpose is to determine the factors and factor interaction are statistically significant in predicting Ra based on 95% confidence interval, the p-value of all the independent variables must be below 0.05. The regression analysis results are shown in Table 4.

Table 4: Regression Analysis: In Ra Vs s, f ,nf ,vnf ,vol ,fol, nfol.

PREDICTOR	*COEF*	*SE COEF*	*T*	*P*
Constant	12.399	2.388	5.19	0.000
S	-0.027252	0.002362	-11.54	0.000
F	-0.03691	0.05943	-0.62	0.538
D	6.378	1.382	4.61	0.000
SF	0.00021172	0.00002056	10.3	0.000
FD	-0.12486	0.01381	-9.04	0.000
SD	0.0033786	0.0007958	4.25	0.000
S^2	0.00000786	0.00000185	4.25	0.000
F^2	0.0001154	0.0003866	0.3	0.767
D^2	0.1235	0.6681	0.18	0.854
R-Sq=91.2 %		*R-Sq(adj)=89.1%*		
Modified Regression Analysis with interaction terms Ra = 12.4 – 0.0273 s -0.0369 f + 6.38 d +0.000212 sf – 0.125 fd +0.00338 ds +0.000008 s^2 +0.000115 f^2 +0.123 d^2				

Analysis of Variance:

Source	*DF*	*SS*	*MS*	*F*	*P*
REGRESSION	9	32.7888	3.643	43.53	0.00
RESIDUAL ERROR	38	3.1801	0.0832		
TOTAL	47	35.9689			

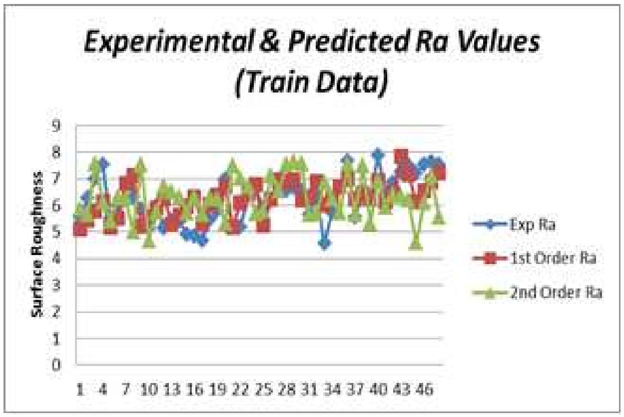
In Table 4, for 9 degree of freedom of regression and 38 degree of freedom for residual error, the F-ratio from the regression analysis is 43.53, which is greater than F-ratio from the statistical tables (2.02) and the corresponding p-value is less than 0.05 i.e. 0.000. Hence the model is significant. All the independent variables are significant since their p-value are less than 0.05 for 95% confidence interval. The R2 value is 91.2, which indicates 91.2% variability in predicting Ra with independent variables. The values predicted by first order and second order multiple regression models are tabulated in Table 5. The percentage deviation is computed between the experimental values and predicted values for the train data and results are tabulated in Table 6.

Table 5: Experimental & Regression Model Values (Train Data)

S.No	Experimental Ra	First Order Multiple Regression Ra	Second Order Multiple Regression Ra
1	5.56	5.1206	5.86663
2	6.286	5.4631	5.65254
3	6.99	5.8056	7.57907
4	7.542	6.1481	6.15056
5	5.52	5.1966	5.42981
6	5.964	*5.533*	6.31662
7	6.224	6.823	6.27510
8	6.322	7.112	5.00475
9	5.862	5.226	7.54631
10	5.128	5.568	4.68709
11	5.96	5.911	5.76089
12	5.168	6.253	6.71082
13	5.428	5.297	6.51980
14	5.423	5.6395	6.29976
15	4.914	5.982	5.72403
16	4.857	6.3245	6.31961
17	4.68	5.32	5.67150
18	5.462	6.0373	6.26059
19	5.784	6.3798	6.23118
20	6.992	6.7223	5.33779
21	5.176	5.176	7.48489
22	5.186	6.1079	7.01248
23	6.384	6.4504	6.71684
24	6.678	6.7929	5.68620
25	5.868	5.242	5.78137
26	6.184	6.232	7.13576
27	6.65	6.95	6.54200
28	6.562	6.8782	7.52406
29	6.678	6.945	7.64231
30	6.549	6.2132	7.57550
31	5.674	6.324	5.65548
32	6.342	6.8982	5.68207
33	4.557	6.0374	6.86505
34	5.743	6.24	6.22740
35	6.642	6.7224	5.71806
36	7.682	7.0049	7.55987
37	5.576	6.242	5.67144
38	6.528	6.4504	7.48800
39	6.243	6.245	5.30598
40	7.868	6.92	6.93056
41	6.436	6.1432	5.93885
42	6.84	6.4857	6.42720
43	7.264	7.824	6.34093
44	7.501	7.1707	6.22164
45	7.2	6.124	4.59990
46	7.54	6.556	6.09609
47	7.642	6.898	7.13726
48	7.523	7.241	5.55306
%	**Deviation**	**15.236**	**3.4265**

Fig 1. Experimental and predicted Ra Values (Train Data) for model

1 & 2

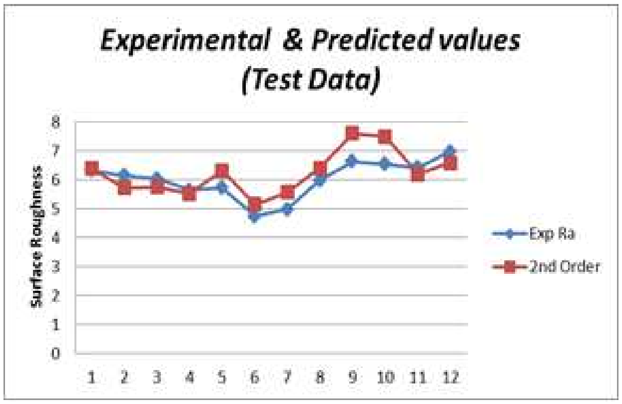


After the development of prediction models, the models are validated with new experimental values which are not used in training set. The test data contains 12 new experimental values. For all these input values, the response of surface roughness values are predicted and compared with experimental surface roughness values and are shown in Table 6. Further, the percentage deviation is also computed and displayed in Table 6. The Fig 3 shows the difference between experimental Ra values and the values predicted by both the models for test data.

Table 6: Experimental values and Predicted values (Test Data)

Exp No.	V (rpm)	F (mm/min)	D (mm)	Ra (mea)	Second Order Multiple Regression Ra
1	680	84	0.55	6.326	6.39181
2	680	81	0.95	6.147	5.71451
3	680	73.2	0.65	6.042	5.74826
4	680	69	0.35	5.642	5.51741
5	395	64.8	0.20	5.725	6.31076
6	395	85.2	90	4.742	5.14848
7	395	81	0.8	4.984	5.56406
8	395	76.2	0.4	5.974	6.40603
9	225	63	0.3	6.625	7.59006
10	225	71.2	0.3	6.542	7.49767
11	225	88.8	0.6	6.415	6.19695
12	225	80	0.6	6.971	6.59108
%	**Deviation**				**7.585**

Fig 2. Experimental values and Predicted values (Test Data)



IV. CONCLUSION

The first order regression model is predicting the surface roughness with the independent variables of Speed(v),Feed(f),Depth of Cut(d) and the percentage deviation of the model is 15.236% in train data. It is observed that the first order regression model is insignificant as its F ratio from the regression analysis is less than the value from statistical tables and all the independent variables are found insignificant in the first order regression model. The reason of high percentage deviation this model cannot be used.The second order regression model is predicting the surface roughness with independent variables in s,f,d. The percentage deviation of the model is 3.4265% in train data and 7.585% in test data. Hence, it is concluded that the Multiple Regression Model has good capabilities of predicting high accuracy surface roughness for given input conditions.

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