7

CONCLUDING REMARKS AND FUTURE SCOPE

7.1 Introduction

Turning centre is selected for this research work and following problems were considered for the investigation.

(1) Structure analysis for turning centre components
(2) Investigation of different cutting parameters for turning operations
- Regression Analysis
- Optimization of cutting parameters by RSM

For the investigation on turning centre Bed, Saddle and Head were carried out with the FEA software. By using Regression Analysis, Response Surface Methodology and (3^4) full factorial design of experiment quadratic models have been developed for different materials with 95% confidence level. This chapter describes the conclusions about the results and remarks. Also future scope suggested here to extend the project for further real time implementations.

7.2 Structure analysis for turning centre components

7.2.1 Rigidity and Strength Analysis

In present work, analysis of a turning centre was done using simulation package of Creo 1.0. For the investigation on turning centre, rigorous analysis pertaining to Bed, Head and Saddle have been carried out with the FEA software details have been discussed in Chapter No. 4 Section No. 4.2, 4.3 and 4.4. In turning operations, cutting forces were calculated based on the assumptions as given by machine tool manufacturer. These loads were imposed on the machine tool structure, considering assembly aspects and other conditions. Results obtained, using FEA software are given in Table 7.1 below.

Table 7.1 Results of rigidity and stress analysis

Part Name	Parameters Analyzed	Comparing results with permissible value	
		Results obtained using software	Permissible value
Bed	Displacement	1.474 µm	3 µm
	Stress	1.42 N/mm^2	30 N/mm^2
Head	Displacement	1.844 µm	3 µm
	Stress	0.732 N/mm^2	30 N/mm^2
Saddle	Displacement	1.259 µm	3 µm
	Stress	1.414 N/mm^2	30 N/mm^2

From the above results it can be seen that the deformation and stresses induced in the different machine tool structure are within the permissible limits specified for different cutting conditions.

7.2.2 Vibrational (Modal) Analysis

Modal analysis is nothing but finding natural frequencies for basic mode shapes of vibration. To remain on safe side from dynamic point of view, care should be taken so that excitation force frequency will not coincide with the natural frequency of vibration. For natural frequency of vibrations are given Table 7.2 below.

Table 7.2 Results of Modal analysis

Part name	Mode No.	Natural frequency of vibration
Bed	1	170 Hz
	2	277 Hz
	3	314 Hz
	4	451 Hz
Head	1	665 Hz
	2	876 Hz
	3	1102 Hz
	4	1599 Hz
Saddle	1	763 Hz
	2	783 Hz
	3	886 Hz
	4	889 Hz

From the above Table 7.2, it can be seen that for the four basic modes of vibration the values of natural frequency are comparatively higher. So there is no any chance for resonance, details have been discussed in Chapter No. 4 Section No. 4.2, 4.3 and 4.4. To make the structure free from any resonant vibration in the operating range, the high stiffness to weight ratio is desirable apart from economical reasons. Moreover, stiffness/weight ratio is a factor, which will decide the ribbing arrangement also.

7.2.3 Sensitivity Study and Optimization

In order to design Head and Bed optimally the effect of various parameters in the design can be viewed through sensitivity study. It was decided to vary the thickness of head between 15 to 20 mm. Figure 4.13 (Chapter 4 and Section No. 4.5.1) shows the different graphs for sensitivity analysis. From figure, as expected thickness increase total mass also increase and stress reduces. Also as thickness increases maximum displacement will reduces and no effect of bending as thickness increases. When reducing weight of Head, it must be seen that in the final design, displacement value for the structure must not exceed some specified value. In order to fulfill the requirement, reducing weight and limiting displacement value at a time optimization study is used. The results of optimization study is given in Table 7.3 below and also discussed in Chapter No. 4 and Section No. 4.6 in detail. For the optimization study objective function and constraints are as follows:

Objective function : Minimize total mass

Constraints : Max. Displacement Magnitude < 3.0 µm

Table 7.3 Optimization of Head, Bed and Saddle

Part name	Parameter Selected	Values of selected parameter(mm)			Total mass variation with selected parameter (Kg)		
		Initial	Final	Optimum	Initial	Final	Optimized
Head	Thickness	12	17	12	73.6	72.1	72.1
Bed	Thickness	15	30	15	1415	1405	1405
Saddle	Thickness	15	30	15	114	113	113

From the Table 7.3, it can be seen that for thickness 12 mm, the head deformation was within the specified limits (2.617×10^{-3} mm), satisfied the constraint of the optimization study, as well as it reduces the total weight by 1.5 kg (approx.) thus saving the material and ultimately the production cost.

For the optimization study of Bed objective function and constraints are as follows:

Objective function : Minimize total mass

Constraints : Max. Displacement Magnitude < 2.5 µm

From the Table 7.3, it can be seen that for thickness 15 mm, the Bed deformation was within the specified limits (1.486 x 10^{-3} mm), satisfied the constraint of the optimization study, as well as it reduces the total weight by 10 kg (approx.) thus saving the material and ultimately the production cost.

For the optimization study of Saddle objective function and constraints are as follows:

Objective function : Minimize total mass

Constraints : Max. Displacement Magnitude < 1.5 µm

From the Table 7.3, it can be seen that for thickness 15 mm, the Saddle deformation was within the specified limits (1.332 x 10^{-3} mm), satisfied the constraint of the optimization study, as well as it reduces the total weight by 1 kg (approx.) thus saving the material and ultimately the production cost.

7.3 Investigation on Cutting Parameters for Turning Operations

7.3.1 Regression Analysis

To establish the prediction model, Regression analysis was conducted with Minitab using the experimental data given in Chapter No. 5 (Table 5.4, 5.5) for different set of materials. Here we assume that the three, four, and five-factor interactions are negligible, because these higher-order interactions are normally assumed to be almost impossible in practice. Therefore, a 2^{5-1} fractional design was selected. This resolution V design leads to 16 runs of the experiments. To consider system variations, such as tool wear and vibration in particular, the cutting time and a replicate number of three are selected, respectively and average is taken and presented in Table 5.6 and 5.7.

Figures 5.14 and 5.15 compares the relative percentage error among the fitted values considering the cutting time, the fitted values without considering the cutting time, and the computed values from Eq. $\mathrm{Ra} = \frac{0.032\,f^2}{r}$. It shows that the fitted values have the highest precision, which shows that it represents the surface roughness better than Eq. $\mathrm{Ra} = \frac{0.032\,f^2}{r}$. Predicted equations for different set of materials are given as below:

$\mathrm{Ra} = 1.35 - 0.245 * \mathrm{Material(A)} + 0.225 * \mathrm{Feed(B)} - 0.224 * \mathrm{Tool\ radius(C)} - 0.233 * \mathrm{Speed(D)} - 0.0214 * \mathrm{Time(t)} + 0.0612 * A * B - 0.0424 * A * C + 0.090 * A * D - 0.020 * A * E - 0.188 * B * C + 0.0488 * C * D$ (AISI 1040 steel and Aluminium)

$\mathrm{Ra} = 0.817 - 0.0769 * \mathrm{Material(A)} + 0.427 * \mathrm{Feed(B)} - 0.317 * \mathrm{Tool\ rdius(C)} - 0.0602 * \mathrm{Speed(D)} + 0.00522 * \mathrm{Time(t)} + 0.0467 * A * C + 0.0316 * A * E - 0.179 * B * C - 0.0560 * B * D$ (AISI 410 steel and Aluminium)

Also confirmation test reveals that the predicted values are very close to each other and hence, the developed models are suitable for predicting the surface roughness in machining with 4 % error within range, details have been discussed in Chapter No. 5, Table 5.10, 5.11 and Section No. 5.11.

7.3.2 Optimization of cutting parameters by RSM

Response surface methodology 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 the objective is to optimize this response.

The aim of the present study was, therefore to develop the surface roughness prediction model of different materials like AISI 1040 steel, AISI 410 steel, Mild steel and Aluminium with the aid of statistical method and Response Surface Optimization under various cutting conditions. By using RSM and (3^4) full factorial design of experiment, quadratic model has been developed with 95% confidence level. For different materials like AISI 1040 steel, AISI 410 steel, Mild steel and Aluminium detailed conclusions are given below.

7.3.2.1 Material: AISI 1040 Steel

The surface roughness in the turning process has been investigated according to the 3^4 full factorial and RSM in experiments. Based on the experimental and analytical results, the following conclusions are drawn for the material AISI 1040 steel.

- For the surface roughness, feed rate is the main influencing factor on the roughness, followed by the tool nose radius and cutting speed. Depths of cut have no significant effect on the surface roughness. This has been explained in Chapter No. 6, Equation No. 6.6 and Fig. 6.8.
- It can be seen that (feed x tool nose radius) and (cutting speed x nose radius) have highest influence on surface roughness. This has been given in Table 6.8 and Page No. 161.
- 3D surface counter plots are useful in determining the optimum condition to obtain particular values of surface roughness. This has been given in Figs. 6.16-6.18, Page No. 164-165.
- Response surface optimization shows that the optimal combinations of machining parameters are (270.30 m/min, 0.1 mm, 0.3 mm and 0.91 mm) for cutting speed, feed rate, depth of cut and tool nose radius respectively. This has been given in Fig. 6.20, Table 6.10 and Page No. 166-167.
- Verification experiments carried out show that the empirical models developed can be used for turning of AISI 1040 steel within 5.3 % error. This has been explained in Section No. 6.3.3**,** Table 6.9 and Page No. 165.

7.3.2.2 Material: AISI 410 steel

Using 3^4 full factorial design and Response surface methodology, the process parameters influencing the surface roughness on the machining of AISI 410 steel has been assessed. The analytical results are summarized as follows:

- The effect of machining parameters on the surface roughness is evaluated with the help of Response surface methodology. Feed rate is dominant parameters for surface roughness followed by nose radius and cutting speed. This has been explained in Chapter No. 6, Equation No. 6.8 and Fig. 6.22.

- It can be seen that (feed x nose radius) have highest influence on surface roughness. This has been given in Table 6.17 and Page No. 172.
- 3D surface counter plots are useful in determining the optimum condition to obtain particular values of surface roughness. This has been given in Figs. 6.30-6.32, Page No. 175.
- Response surface optimization shows that the optimal combinations of machining parameters are (255.7 m/min, 0.1 mm, 0.3 mm and 1.2 mm) for cutting speed, feed rate, depth of cut and tool nose radius respectively. This has been given in Fig. 6.34, Table 6.19 and Page No. 177.
- Verification results reveal that the second order response surface model is suitable for predicting the surface roughness in machining of AISI 410 steel within the ranges of machining parameters studied within 3 % error. This has been explained in Section No. 6.4.3**,** Table 6.18 and Page No. 176.

7.3.3.3 Material: Mild Steel

This research work presented a full factorial design and RSM experimentation approach to study the impact of turning parameters on surface roughness for Mild Steel. It featured the following contributions:

- Depth of cut does not impact the surface roughness in the studied range, which could be used to improve productivity. Second, in addition to feed, nose radius and cutting speed has a significant impact on the observed surface roughness. This has been explained in Chapter No. 6, Equation No. 6.10 and Fig. 6.36.
- Feed x Nose radius was observed most significant interaction for the above turning parameters. This has been given in Table 6.26 and Page No. 183.
- 3D surface counter plots are useful in determining the optimum condition to obtain particular values of surface roughness. This has been given in Figs. 6.44-6.46, Page No. 186.
- Response surface optimization shows that the optimal combinations of machining parameters are (280 m/min, 0.1 mm, 0.3 mm and 0.80 mm) for cutting speed, feed rate, depth of cut and tool nose radius respectively. This has been given in Fig. 6.49, Table 6.28 and Page No. 188.

- Verification results shows that the second order response surface model is suitable for predicting the surface roughness in machining of Mild Steel within the ranges of machining parameters studied within 4 % error. This has been given in Section 6.5.3, Table 6.27 and Page No.187.

7.3.3.4 Material: Aluminium

Full Factorial design and Response surface methodology of an experiment can be successfully employed using carbide cutting tools in machining Aluminium. The following conclusions have been drawn:

- First-order and second-order model predicting equations for surface roughness have been developed using response surface methodology for machining Aluminium with coated tools. This has been explained in Chapter No. 6, Equations No.11and 12, Fig. 6.51 and Page No. 194.
- The established equations clearly show that the feed rate was main influencing factor on the surface roughness. It increased with increasing the feed rate but decreased with increasing the cutting speed and tool nose radius. Among the other parameter, depth of cut was found to be insignificant. This has been given in Figs. 6.56-6.58, Page No. 196-197.
- The variance analysis for the second-order model shows most significant interactions were found to between cutting speed, feed and nose radius. This has been given in Table 6.35 and Page No. 193.
- 3D surface counter plots are useful in determining the optimum condition to obtain particular values of surface roughness. This has been given in Figs. 6.59-6.61 Page No. 197.
- Response surface optimization shows that the optimal combinations of machining parameters are (280 m/min, 0.1 mm, 0.3 mm and 0.94 mm) for cutting speed, feed rate, depth of cut and tool nose radius respectively. This has been given in Fig. 6.63, Table 6.37 and Page No. 199.
- Verification results shows that the second order response surface model is suitable for predicting the surface roughness in machining of Aluminium within the ranges of

machining parameters studied within 5 % error. This has been given in Section 6.6.3 Table 6.36 and Page No.198.

7.4 Future Scope

An investigation on turning center was done in present research work based on Structure analysis of turning centre components and Response surface methodology. It can be used to estimate the value of surface roughness for given turning parameter or to aid the selection of working parameters given a required surface finish. It has been shown that the predicted results are better for different materials used here. Further research will concentrate on the following issues:

- Comparison of FEA will be done by other software with different loading conditions.
- Some additional variables such as approach angle, rake angle, coating material and effect of cooling as well as lubrication conditions can be used in this work.
- Comparison can be done by using conventional and wiper inserts for surface finish for different materials in this work.
- Noncontact type roughness measurement system can be used using machine vision system.
- An artificial neural network (ANN) and genetic algorithm will be used to develop and hopefully improve the empirical model.
- The models developed by the full factorial design and RSM will be compared with those from ANN method.