4

FEA OF MACHINE TOOL STRUCTURE COMPONENT

4.1 Introduction

The methods adopted by researchers previously were model analysis and mathematical modeling of structures [1]. This method involves manufacture of a scale model of proposed design. With this method it is not possible to check different design variations in structure, because it requires every time modified model to be prepared. Thus, physical prototyping is an expensive, time-consuming way to do this, and the usual alternative – traditional numerical analysis – depends on highly trained specialists to get accurate results. FEA is more reliable, quick and efficient technique now days followed. Again it becomes easier as sufficiently large computers are available to solve element equations. Present work on analysis of a Turning Center is done using simulation package of Creo 1.0. For the investigation on turning centre, rigorous analysis pertaining to Bed, Head and Saddle will be carried out with the FEA software. Also sensitivity analysis and optimization is done for the machine tool component -Head in this chapter.

Following parameters will be considered according to shop floor data for FEA.

(a) Depth of cut will be taken 0.3, 0.6 ,0.9,1.2 mm
(b) Feed will be taken 0.1,0.14,0.15,0.2,0.3 mm/rev
(c) Cutting Speed will be taken 220 ,250 m/min
(d) Tool nose radius 0.4mm,0.8mm
(e) Materials will be AISI 1040 steel, AISI 410 steel, Mild steel and Aluminium

4.2 Load calculation and FEA for BED

Below given are the cutting parameters taken for the load calculation for turning of AISI 410 steel with different tool nose radius.

Material: AISI 410 Steel

Depth of cut (d): 0.3 mm

Feed (f): 0.1 mm/rev

Speed (N): 1600 rpm

Cutting speed (V): 220 m/min.

Efficiency (η): 80%

U = Unit power = 52×10^3 kW/ m^3/min

K_h = correction factor for flank wear = 1.19

K_y = correction factor for rake angle = 1.29

Q = material removal rate = d f v =$0.3 \times 0.1 \times 220 = 6.6 \text{ X } 10^{-6} \text{m}^3/\text{min}$

$$\text{Power at spindle (P)} = \frac{\text{U} \times \text{K}_\text{h} \times \text{K}_\text{y} \times \text{Q}}{\eta} = 0.66 \text{ KW}$$

$$\text{Tangential cutting force, P}_\text{Z} = \frac{6120 \text{ P}}{\text{V}} = 18.36 \text{ kg} = 183\text{N}$$

$$0.4 \text{ mm Tool nose Radius} \dots \dots \ \text{P}_\text{x} = 0.75 \text{ P}_2 = 13.77 \text{ kg} = 137\text{N}$$

$$\text{P}_\text{y} = 0.65 \text{ P}_2 = 11.93 \text{ kg} = 119\text{N}$$

$$0.8 \text{ mm Tool nose Radius} \dots \dots \ \text{P}_\text{x} = 0.65 \text{ P}_2 = 11.93 \text{ kg} = 119\text{N}$$

$$\text{P}_\text{y} = 0.70 \text{ P}_2 = 12.85 \text{ kg} = 128\text{N}$$ [10]

As a structure of turning centre, major parts include Bed, Head and Saddle. Fig.4.1 shows meshing with loading conditions of bed. Fig. 4.2 and 4.3 shows Von-Mises stress and displacement for the material AISI 410 steel, 0.3 mm depth of cut, 0.1 mm/rev feed 220 m/min cutting speed and 0.8mm tool radius. After applying loads and constraints, assigning material to part, analysis is performed. For Bed FEA report and result is given in Table 4.1. 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. The natural frequency of vibration is determined for the four basic modes of vibration, which are perpendicular to the plane by which the structure is fixed in assembly, for critical components. For mode shapes and natural frequency of vibrations are given in Fig.4.4.

Table 4.1 FEA report and Result for Bed of turning operation

Particulars	Details
Model description	Bed
Software used	Creo 1.0
Assumptions	• Only static loading is considered • Self weight of structure is ignored • Units of measurement for result parameters is: mm N s i.e. millimeter, Newton, Second
Material used	FE 20
Type of element used	3D solid elements
Loads	• Weight of ball screw and bracket(200N) • Head stock assy.(1500N) • Main motor(510 N), Turret et all.(3000N) • Z motor and bracket(120N), • Tail stock and others(800N), Cutting force
Constraints	Bottom face of bed is fixed with ground
Solution type	Standard Design Study, Static analysis

Results of Analysis

Parameters	Results
Displacement plot	Max. Displacement value: $1.474X\ 10^{-3}$mm
Von-Mises stress plot	Max. Von –Mises Stress value: 1.42 N/mm^2
Natural Frequency	Mode1:170 Hz, Mode2: 277 Hz Mode3:314 Hz , Mode4: 451 Hz

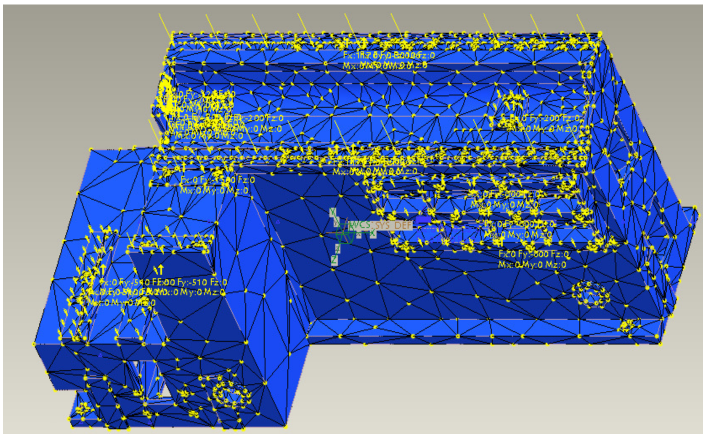

Fig. 4.1 Bed with meshing and load

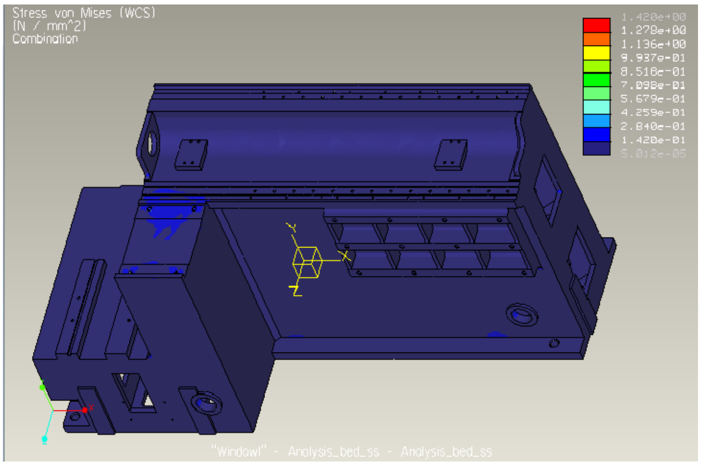

Fig 4.2 Bed with stress result

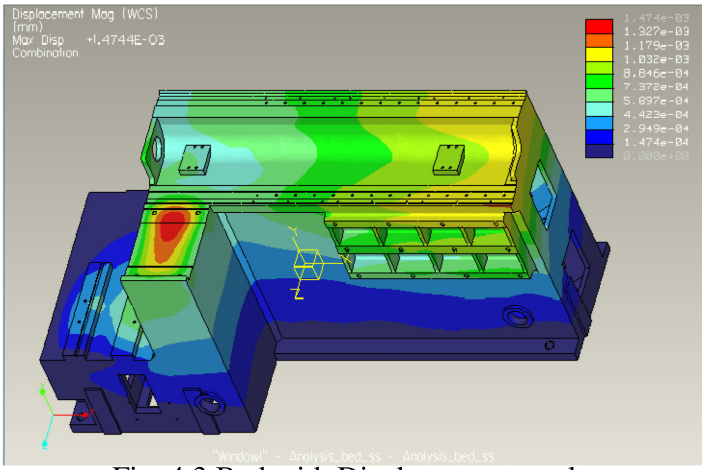

Fig. 4.3 Bed with Displacement result

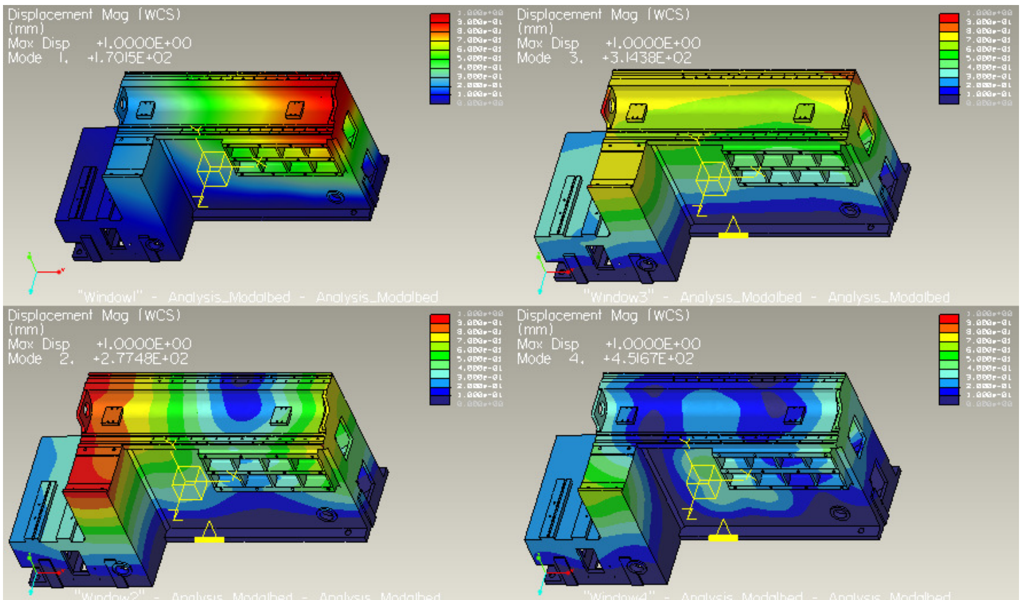

Fig. 4.4 Basic modes of vibration for Bed

Table 4.2 Deformation and stress (AISI 410 steel and r = 0.8mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3*	0.10	$1.474 x 10^{-3}$	1.420
2	0.3	0.15	$1.490 x 10^{-3}$	1.325
3	0.3	0.20	$1.497 x 10^{-3}$	1.291
4	0.3	0.30	$1.613 x 10^{-3}$	1.256
5	0.3	0.14	$1.489 x 10^{-3}$	1.333
6	0.6	0.14	$1.715 x 10^{-3}$	1.234
7	0.9	0.14	$1.866 x 10^{-3}$	1.201
8	1.2	0.14	$2.462 x 10^{-3}$	1.306

Table 4.3 Deformation and stress (AISI 410 steel and r = 0.4mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	$1.482 x 10^{-3}$	1.349
2	0.3	0.15	$1.485 x 10^{-3}$	1.318
3	0.3	0.20	$1.491 x 10^{-3}$	1.281
4	0.3	0.30	$1.575 x 10^{-3}$	1.243
5	0.3	0.14	$1.484 x 10^{-3}$	1.326
6	0.6	0.14	$1.668 x 10^{-3}$	1.223
7	0.9	0.14	$1.813 x 10^{-3}$	1.185
8	1.2	0.14	$2.549 x 10^{-3}$	1.009

Table 4.4 Deformation and stress (AISI 1040 steel and r = 0.8mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	$1.483 x 10^{-3}$	1.382
2	0.3	0.15	$1.485 x 10^{-3}$	1.358
3	0.3	0.20	$1.489 x 10^{-3}$	1.332
4	0.3	0.30	$1.499 x 10^{-3}$	1.283
5	0.3	0.14	$1.485 x 10^{-3}$	1.362
6	0.6	0.14	$1.497 x 10^{-3}$	1.292
7	0.9	0.14	$1.760 x 10^{-3}$	1.224
8	1.2	0.14	$2..080 x 10^{-3}$	1.155

Table 4.5 Deformation and stress (AISI 1040 steel and r = 0.4mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	$1.481x10^{-3}$	1.379
2	0.3	0.15	$1.482x10^{-3}$	1.352
3	0.3	0.20	$1.484x10^{-3}$	1.325
4	0.3	0.30	$1.492x10^{-3}$	1.273
5	0.3	0.14	$1.482x10^{-3}$	1.357
6	0.6	0.14	$1.490x10^{-3}$	1.283
7	0.9	0.14	$1.713x10^{-3}$	1.209
8	1.2	0.14	$2.016x10^{-3}$	1.136

Table 4.6 Deformation and stress (Aluminium and r = 0.8mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	$1.482x10^{-3}$	1.404
2	0.3	0.15	$1.483x10^{-3}$	1.391
3	0.3	0.20	$1.483x10^{-3}$	1.383
4	0.3	0.30	$1.484x10^{-3}$	1.368
6	0.3	0.14	$1.483x10^{-3}$	1.393
7	0.6	0.14	$1.486x10^{-3}$	1.356
8	0.9	0.14	$1.491x10^{-3}$	1.319
9	1.2	0.14	$1.502x10^{-3}$	1.281

Table 4.7 Deformation and stress (Aluminium and r = 0.4mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm2)
1	0.3	0.10	1.481x10-3	1.402
2	0.3	0.15	1.481x10-3	1.387
3	0.3	0.20	1.481x10-3	1.381
4	0.3	0.30	1.482x10-3	1.364
6	0.3	0.14	1.481x10-3	1.391
7	0.6	0.14	1.482x10-3	1.351
8	0.9	0.14	1.486x10-3	1.311
9	1.2	0.14	1.492x10-3	1.271

4.2.1 Result analysis

Table 4.2 - 4.5 shows deformation and Von-Mises stress results for tool nose radius 0.8 mm and 0.4 mm for different values of depth of cut and feed for turning of AISI 410 steel and AISI 1040 steel. It has been seen that for constant depth of cut and

increasing the feed, deformation not much vary for tool radius o.8mm and 0.4mm. Now, for constant feed and increasing the depth of cut, deformation Increases compare with previous result. Also Von Mises stress results remains same for different tool nose radius. From Table 4.6 and 4.7, it has been asserted that deformation values not much vary by changing depth of cut or feed. For the combination of different cutting parameters and different materials only one red spot (Deformation 1.473x 10^{-3}mm) appears at the location of head which can be reduced by providing more ribs in casting.

4.3 Load calculation and FEA for HEAD

Below given are the cutting parameters taken for the load calculation for turning of AISI 1040 steel with different tool nose radius.

Material: AISI 1040 Steel

Depth of cut (d): 1.2 mm

Feed (f): 0.14 mm/rev

Speed (N): 1600 rpm

Cutting speed (V): 250 m/min.

Efficiency (η): 80%

U = Unit power = 37×10^{3} kW/ m^3/min

K_h = correction factor for flank wear = 1.08

K_y = correction factor for rake angle = 1.29

Q = material removal rate = d f v = $1.2 \times 0.14 \times 250 = 42 \text{ X } 10^{-6} \text{m}^3/\text{min}$

$$\text{Power at spindle (P)} = \frac{\text{U} \times \text{K}_\text{h} \times \text{K}_\text{y} \times \text{Q}}{\eta} = 2.7 \text{ KW}$$

$$\text{Tangential cutting force}, \text{P}_\text{Z} = \frac{6120 \text{ P}}{\text{V}} = 66.09 \text{ kg} = 660\text{N}$$

$$0.4 \text{ mm Tool nose Radius} \ldots \ldots \text{P}_\text{x} = 0.75 \text{ P}_2 = 49.56 \text{ kg} = 495\text{N}$$

$$\text{P}_\text{y} = 0.65 \text{ P}_2 = 42.95 \text{ kg} = 429\text{N}$$

$$0.8 \text{ mm Tool nose Radius} \ldots \ldots \text{P}_\text{x} = 0.65 \text{ P}_2 = 42.95 \text{ kg} = 429\text{N}$$

$$\text{P}_\text{y} = 0.70 \text{ P}_2 = 46.26 \text{ kg} = 462\text{N}$$ [10]

Fig.4.5 shows meshing with loading conditions of Head. Fig. 4.6 and 4.7 shows displacement and Von-Mises stress for the material AISI 1040 steel, 1.2 mm depth of cut, 0.14 mm/rev feed, 250 m/min cutting speed and 0.8 mm tool radius. After applying loads constraints, assigning material to part and analysis is performed. For Head FEA analysis report is given in Table 4.8.

For mode shapes and natural frequency of vibrations are given in Fig. 4.8. The natural frequency of vibration is determined for the four basic modes of vibration, which are perpendicular to the plane by which the structure is fixed in assembly, for critical components. For analysis of Head, four mode shape of natural frequency are given as: Mode: 1 665 Hz, Mode: 2 876 Hz, Mode: 3 1102Hz and Mode: 4 1599Hz.

Table 4.8 FEA report and Result for Head of turning operation

Particulars	Details
Model description	Head
Software used	Creo 1.0
Assumptions	• Only static loading is considered • Self weight of structure is ignored • Units of measurement for result parameters is: mm N s i.e. millimeter, Newton, Second
Material used	FE 20
Type of element used	3D solid elements
Loads	• Encoder and others Assy. (50N) • Spindle Assy.(700N) • Cutting force
Constraints	Bottom face Head is fixed on Bed
Solution type	Standard Design Study, Static analysis

Results of Analysis

Parameters	Results
Displacement plot	Max. Displacement value: $1.844X\ 10^{-3}$ mm
Von-Mises stress plot	Max. Von –Mises Stress value: 0.732 N/mm^2
Natural Frequency	Mode1: 665Hz, Mode2: 876 Hz Mode3: 1102 Hz, Mode4: 1599Hz

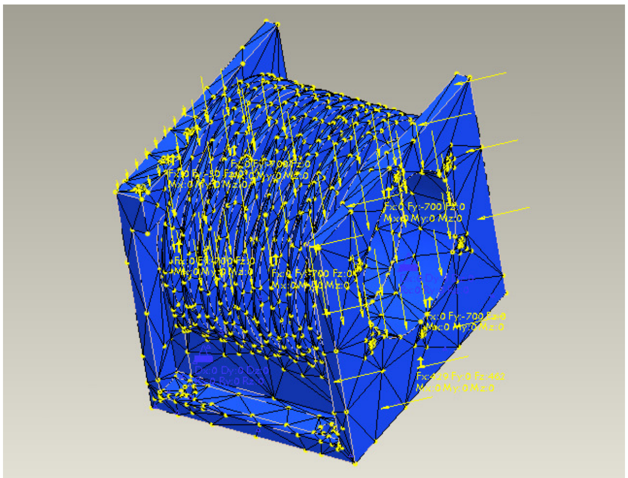

Fig. 4.5 Head with meshing and load

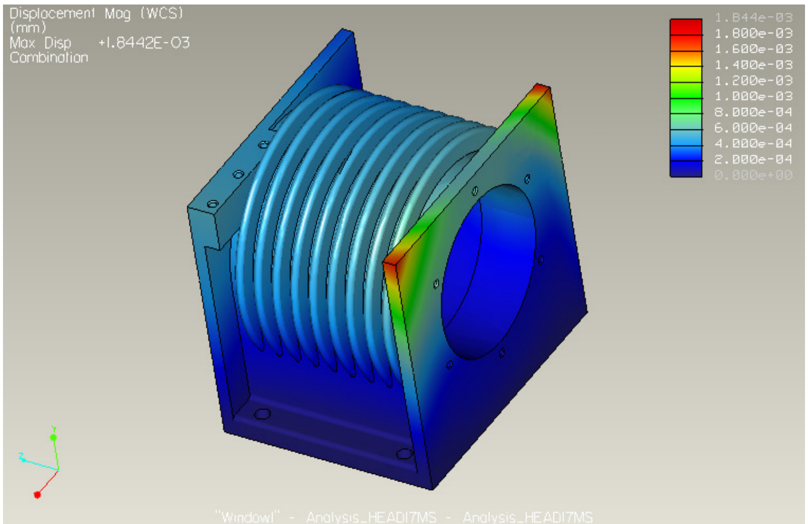

Fig 4.6 Head with Displacement result

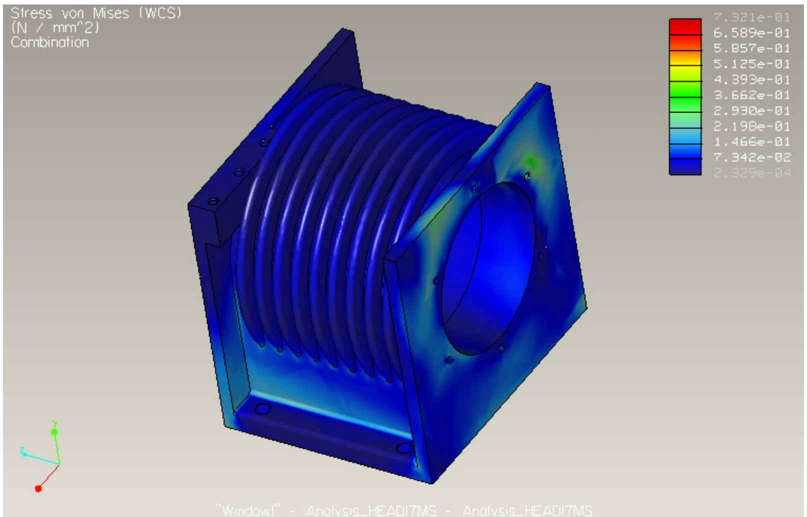

Fig.4.7 Head with Stress result

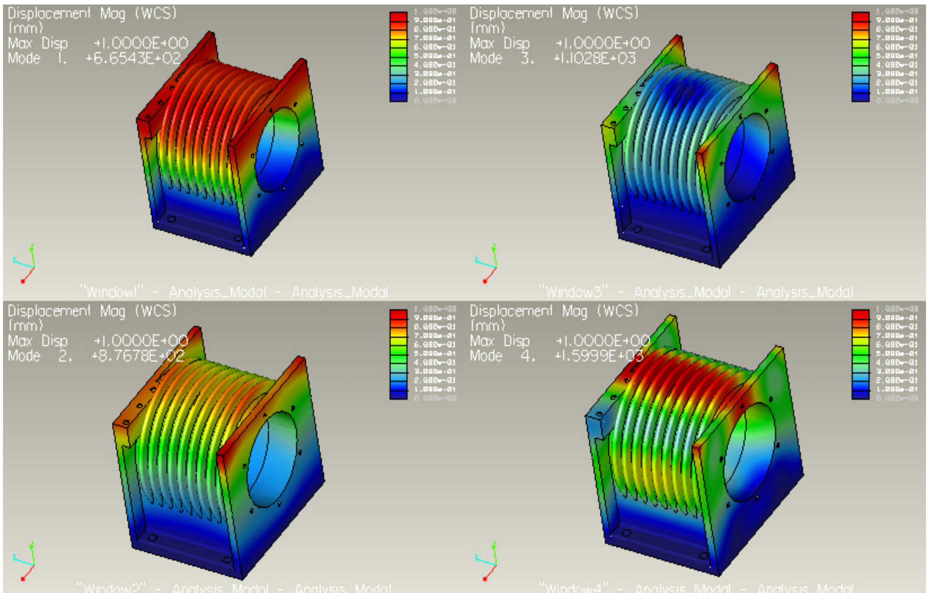

Fig. 4.8 Basic modes of vibration for Head

Table 4.9 Deformation and stress (AISI 1040 steel and r = 0.8 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	0.332 x 10^{-3}	0.316
2	0.3	0.15	0.494 x 10^{-3}	0.352
3	0.3	0.20	0.665 x10^{-3}	0.392
4	0.3	0.30	0.991 x 10^{-3}	0.472
5	0.1	0.14	0.230 x 10^{-3}	0.280
6	0.3	0.14	0.466 x10^{-3}	0.346
7	0.6	0.14	0.931 x10^{-3}	0.457
8	0.9	0.14	1.387 x10^{-3}	0.573
9	1.2*	0.14	1.844 x 10^{-3}	0.732

Table 4.10 Deformation and stress (AISI 1040 steel and r = 0.4 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	0.324 x 10^{-3}	0.316
2	0.3	0.15	0.480 x10^{-3}	0.351
3	0.3	0.20	0.646 x10^{-3}	0.391
4	0.3	0.30	0.961 x10^{-3}	0.476
5	0.1	0.14	0.229 x10^{-3}	0.280
6	0.3	0.14	0.455 x10^{-3}	0.345
7	0.6	0.14	0.903 x10^{-3}	0.456
8	0.9	0.14	1.347 x10^{-3}	0.586
9	1.2	0.14	1.781 x 10^{-3}	0.739

Table 4.11 Deformation and stress (Mild steel and r = 0.8 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	0.359×10^{-3}	0.325
2	0.3	0.15	0.534×10^{-3}	0.361
3	0.3	0.20	0.712×10^{-3}	0.403
4	0.3	0.30	1.067×10^{-3}	0.491
5	0.1	0.14	0.231×10^{-3}	0.283
6	0.3	0.14	0.502×10^{-3}	0.354
7	0.6	0.14	1.003×10^{-3}	0.475
8	0.9	0.14	1.502×10^{-3}	0.603
9	1.2	0.14	2.000×10^{-3}	0.798

Table 4.12 Deformation and stress (Mild steel and r = 0.4 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.30	0.10	0.348×10^{-3}	0.321
2	0.30	0.15	0.521×10^{-3}	0.361
3	0.30	0.20	0.691×10^{-3}	0.402
4	0.30	0.30	1.036×10^{-3}	0.490
5	0.10	0.14	0.231×10^{-3}	0.282
6	0.30	0.14	0.488×10^{-3}	0.353
7	0.60	0.14	0.973×10^{-3}	0.474
8	0.90	0.14	1.459×10^{-3}	0.624
9	1.20	0.14	1.946×10^{-3}	0.794

Table 4.13 Deformation and stress (Aluminium and r = 0.8 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	0.233×10^{-3}	0.287
2	0.3	0.15	0.277×10^{-3}	0.304
3	0.3	0.20	0.324×10^{-3}	0.314
4	0.3	0.30	0.426×10^{-3}	0.337
6	0.3	0.14	0.257×10^{-3}	0.300
7	0.6	0.14	0.506×10^{-3}	0.355
8	0.9	0.14	0.753×10^{-3}	0.413
9	1.2	0.14	1.003×10^{-3}	0.475

Table 4.14 Deformation and stress (Aluminium and r = 0.4 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	0.232×10^{-3}	0.286
2	0.3	0.15	0.270×10^{-3}	0.304
3	0.3	0.20	0.316×10^{-3}	0.314
4	0.3	0.30	0.414×10^{-3}	0.336
6	0.3	0.14	0.251×10^{-3}	0.300
7	0.6	0.14	0.492×10^{-3}	0.354
8	0.9	0.14	0.733×10^{-3}	0.413
9	1.2	0.14	0.973×10^{-3}	0.474

4.3.1 Result Analysis

Table 4.9 to 4.12 shows deformation and Von-Mises stress results for head with 0.8 mm and 0.4 mm tool nose radius for different values of depth of cut and feed for turning of AISI 1040 steel and Mild steel. It has been seen that for constant depth of cut and increasing the feed, deformation also increases. Now, for constant feed and increasing the depth of cut, deformation also increases. From Table 4.9 to 4.14, Von Mises stress results are remains same for different tool nose radius. From Table 4.13 and 4.14, it has been asserted that deformation values somewhat vary by changing depth of cut or feed. For the combinations of different cutting parameters and different materials only two very small spot (Deformation 1.844×10^{-3}mm) appears at the location of head thickness which is not risky for the strength point of view.

4.4 Load calculation and FEA for Saddle

Below given are the cutting parameters taken for the load calculation for turning of Mild Steel with different tool nose radius.

Material: Mild steel

Depth of cut (d): 0.3 mm

Feed (f): 0.3 mm/rev

Speed (N): 1600 rpm

Cutting speed (V): 250 m/min.

Efficiency (η): 80%

U = Unit power = 40×10^3 kW/ m^3/min

K_h = correction factor for flank wear = 1.08

K_y = correction factor for rake angle = 1.29

Q = material removal rate = d f v = $0.3 \times 0.3 \times 250 = 22.5 \text{ X } 10^{-6} m^3/min$

$$\text{Power at spindle (P)} = \frac{U \times K_h \times K_y \times Q}{\eta} = 1.56 \text{ KW}$$

$$\text{Tangential cutting force}, P_Z = \frac{6120 \text{ P}}{V} = 38.18 \text{ kg} = 381\text{N}$$

$$0.4 \text{ mm Tool nose Radius} \dots\dots P_x = 0.75 \ P_2 = 28.63 \text{ kg} = 286\text{N}$$

$$P_y = 0.65 \ P_2 = 24.81 \text{ kg} = 248\text{N}$$

$$0.8 \text{ mm Tool nose Radius} \dots\dots P_x = 0.65 \ P_2 = 24.81 \text{ kg} = 248\text{N}$$

$$P_y = 0.70 \ P_2 = 26.72 \text{ kg} = 267\text{N}$$ [10]

Fig.4.9 shows meshing with loading conditions of Saddle. Fig. 4.10 and 4.11 shows displacement and Von-Mises stress for material Mild steel, 0.3 mm depth of cut, 0.3 mm/rev feed, 250 m/min cutting speed and 0.8 mm tool radius. After applying loads, constraints, assigning material to part and analysis is performed. For Saddle, FEA analysis report is given in Table 4.15.

The natural frequency of vibration is determined for the four basic modes of vibration, which are perpendicular to the plane by which the structure is fixed in assembly, for critical components. For analysis of Saddle, four mode shape of natural frequency are given in Fig. 4.12. Natural frequency for the four mode shapes are given as

Mode 1: 763Hz, Mode 2: 783 Hz, Mode 3: 886Hz and Mode 4: 889.

Table 4.15 FEA report and Result for Saddle of turning operation

Particulars	Details
Model description	Saddle
Software used	Creo 1.0
Assumptions	• Only static loading is considered • Self weight of structure is ignored • Units of measurement for result parameters is: mm N s i.e. millimeter, Newton, Second
Material used	FE 20
Type of element used	3D solid elements
Loads	• Turret, Tool disc, Guide way (1500N) • Ball screw (100N) • Motor X axis (120N) • Cutting force
Constraints	Fixed at four slides of L.M. block
Solution type	Standard Design Study, Static analysis

Results of Analysis

Parameters	Results
Displacement plot	Max. Displacement value: 1.259×10^{-3} mm
Von-Mises stress plot	Max. Von –Mises Stress value: 1.414 N/mm^2
Natural Frequency	Mode1: 763 Hz, Mode 2: 783 Hz Mode3: 886 Hz, Mode 4: 889 Hz

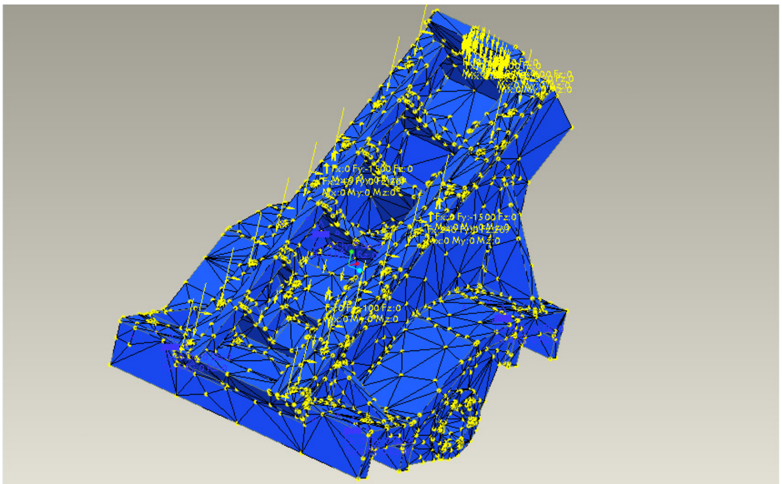

Fig.4.9 Saddle with meshing and load

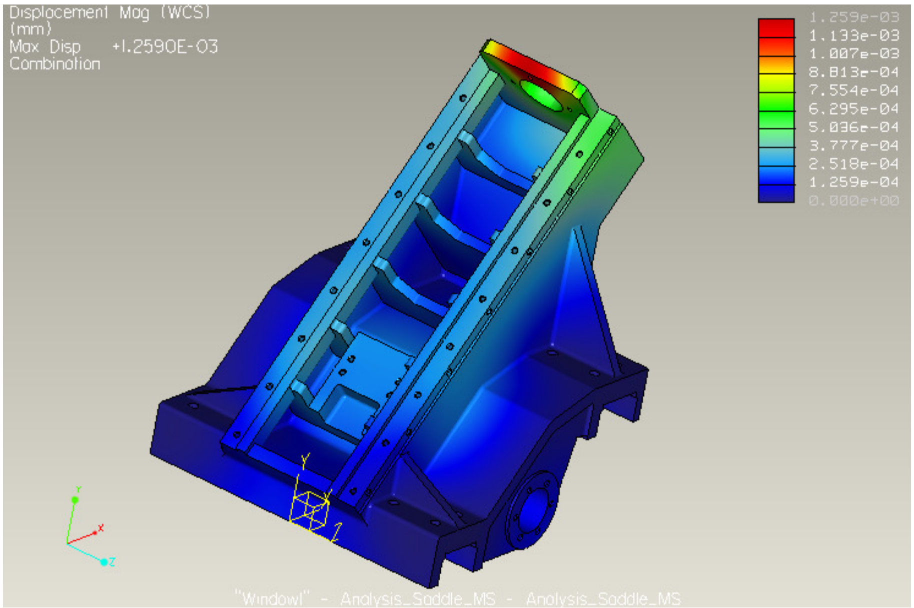

Fig 4.10 Saddle with Displacement result

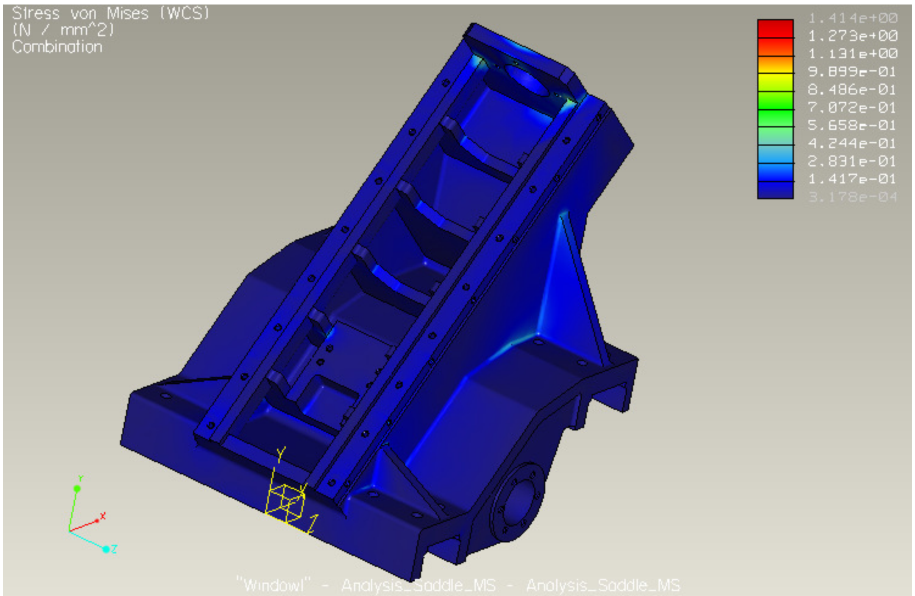

Fig 4.11 Saddle with Von Mises stress result

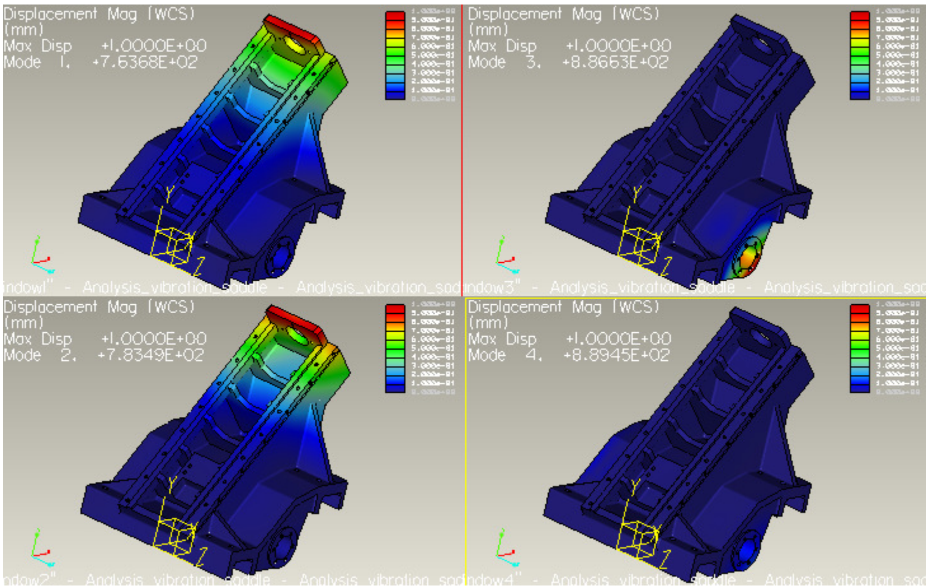

Fig. 4.12 Basic modes of vibration for Saddle

Table 4.16 Deformation and stress (Mild Steel and r = 0.8 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	1.298×10^{-3}	1.539
2	0.3	0.15	1.279×10^{-3}	1.507
3	0.3	0.20	1.267×10^{-3}	1.476
4	0.3*	0.30	1.259×10^{-3}	1.414
5	0.1	0.14	1.322×10^{-3}	1.573
6	0.3	0.14	1.283×10^{-3}	1.513
7	0.6	0.14	1.259×10^{-3}	1.425
8	0.9	0.14	1.278×10^{-3}	1.340
9	1.2	0.14	1.339×10^{-3}	1.281

Table 4.17 Deformation and stress (Mild Steel and r = 0.4 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	1.288×10^{-3}	1.534
2	0.3	0.15	1.265×10^{-3}	1.499
3	0.3	0.20	1.249×10^{-3}	1.465
4	0.3	0.30	1.233×10^{-3}	1.398
5	0.1	0.14	1.317×10^{-3}	1.571
6	0.3	0.14	1.269×10^{-3}	1.505
7	0.6	0.14	1.234×10^{-3}	1.410
8	0.9	0.14	1.245×10^{-3}	1.318
9	1.2	0.14	1.305×10^{-3}	1.305

Table 4.18 Deformation and stress (AISI 1040 steel and r = 0.8 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	1.301 x10^{-3}	1.544
2	0.3	0.15	1.283 x10^{-3}	1.515
3	0.3	0.20	1.270 x10^{-3}	1.484
4	0.3*	0.30	1.259 x10^{-3}	1.427
5	0.1	0.14	1.324 x10^{-3}	1.576
6	0.3	0.14	1.286 x10^{-3}	1.519
7	0.6	0.14	1.260 x10^{-3}	1.438
8	0.9	0.14	1.270 x10^{-3}	1.359
9	1.2	0.14	1.315 x 10^{-3}	1.284

Table 4.19 Deformation and stress (AISI 1040 Steel and r = 0.4 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	1.292 x 10^{-3}	1.539
2	0.3	0.15	1.270 x10^{-3}	1.507
3	0.3	0.20	1.253 x10^{-3}	1.474
4	0.3	0.30	1.243 x10^{-3}	1.412
5	0.1	0.14	1.320 x10^{-3}	1.573
6	0.3	0.14	1.274 x10^{-3}	1.512
7	0.6	0.14	1.237 x10^{-3}	1.424
8	0.9	0.14	1.239 x10^{-3}	1.339
9	1.2	0.14	1.273 x10^{-3}	1.265

Table 4.20 Deformation and stress (Aluminium and r = 0.8 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	1.319 x10^{-3}	1.570
2	0.3	0.15	1.307 x10^{-3}	1.554
3	0.3	0.20	1.302 x10^{-3}	1.545
4	0.3	0.30	1.290 x10^{-3}	1.527
5	0.3	0.14	1.310 x10^{-3}	1.558
6	0.6	0.14	1.282 x10^{-3}	1.513
7	0.9	0.14	1.265 x10^{-3}	1.469
8	1.2	0.14	1.259 x10^{-3}	1.425

Table 4.21 Deformation and stress (Aluminium and r = 0.4 mm)

Sr. No.	Depth of cut (d)	Feed (f)	Deformation (mm)	Stress (N/mm^2)
1	0.3	0.10	1.314 x10^{-3}	1.567
2	0.3	0.15	1.300 x10^{-3}	1.550
3	0.3	0.20	1.293 x10^{-3}	1.540
4	0.3	0.30	1.279 x10^{-3}	1.520
5	0.3	0.14	1.303 x10^{-3}	1.553
6	0.6	0.14	1.269 x10^{-3}	1.505
7	0.9	0.14	1.246 x10^{-3}	1.457
8	1.2	0.14	1.234 x10^{-3}	1.410

4.4.1 Result Analysis

Table 4.16 to 4.21 shows deformation and Von-Mises stress results for saddle with o.8 mm and 0.4 mm tool nose radius for different values of depth of cut and feed for turning of AISI 1040 steel , Mild steel and Aluminium. It has been seen that for constant depth of cut or feed, results are almost same for deformation as well as von-Mises stress. Because, by saddle load will be transferred to job via cutting tool. For the combinations of different cutting parameters and different materials only small spot (Deformation 1.259x 10^{-3}mm) appears at the location of fitting of X axis motor due to cantilever arrangement.

4.5 Sensitivity Study

In present study we will first look at the two other types of design studies: Sensitivity Studies and Optimization. The purpose of these design studies is to automate some of the repetitive work involved in design. This involves specifying one or more design parameters that control the geometry of the part. In a sensitivity study, we seek to find out how the variation in a design parameter affects the results of interest (like the maximum stress or displacement). Suppose, it is required to find out how a particular dimension or model property will affect the results of an analysis. In other words, we want to assess the sensitivity of the model to changes in this parameter. It is possible to do this by manually editing the model (geometry or properties) and performing the analysis many times. The purpose of a sensitivity study is to automate this task. Important thing here is to decide design parameter which should be taken for study and that again calls skill and experience of design engineer. Because specified variable should be given with range between which it will vary and it requires insurance of feasibility of model with the given range of selected parameters. Sometimes, some selected combinations of parameters will not generate mesh for analyses, which should be taken care. Between extreme values of range specified, increments of value are also crucial and it depends on particular application, how closely and exactly, the behavior of model is to be observed.

4.5.1 Sensitivity Study of Head

Here in present work, sensitivity study of Head is carried out. After analyzing different types of ribbing arrangement and benefits gained through box structures of machine tool, effective parameter, which should be taken into considerations for sensitivity study, is thickness of structure. For ease, only thickness of Head is taken for sensitivity analysis. After deciding the range of variation of design parameter, behavior of different parameters with variation in thickness can be obtained with ease. The procedure of repeating analysis for each increment of design parameter is done automatically. At the same time the designer should interpret the results obtained through sensitivity study.

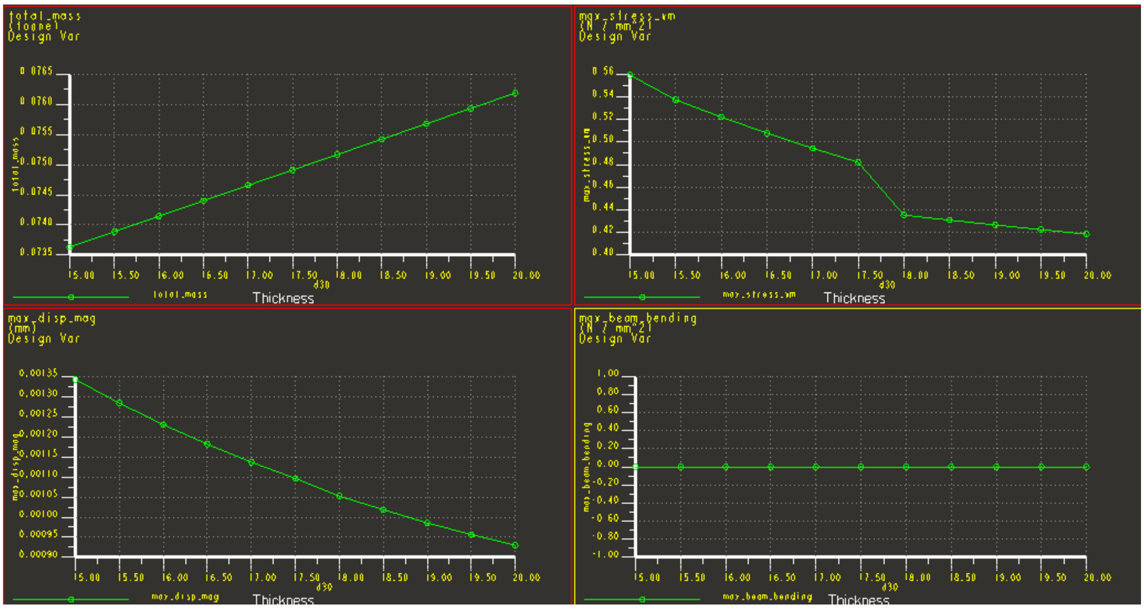

Fig. 4.13 Results of sensitivity analysis (Head)

(Top-Left) Variation in total mass with thickness
(Top-Right) Variation in stress von-Mises with thickness
(Bottom-Left) Variation in max. magnitude with thickness
(Bottom-Right) Variation in max. Beam bending with thickness

In present case, initially, head is having thickness of 17 mm. It is decided to vary the thickness between 15 to 20 mm. Figure 4.13 shows the different graphs for sensitivity analysis. From Fig. 4.13, 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.

4.6 OPTIMIZATION

Optimization, as in general sense, a task that is goal oriented while simultaneously not violating some constraints, which is specified by problem directly or indirectly. Same is the concept for structural optimization, at the same time not compromising with their functional capabilities. The techniques for the optimization of functional properties of machine tool structures aim at the minimization of product cost satisfying the functional requirements, which include the following:

- The minimum weight design exhibiting maximum static stiffness at tool point and dynamic stability. The machine structural elements should exhibit maximum stiffness at tool point rather than as isolated members. Machine elements which have maximum stiffness to weight ratio need not necessarily exhibit minimum tool point deformation unless due consideration is given to its shear center position, thus stressing the importance of functional optimization.
- Thermal stability and accuracies. The functional optimization of precision machine tools calls for thermal stability and accuracy in addition to vibration free machining. Unbalanced heat distribution in the machine tool causes undesirable thermal deformations.

While optimizing machine tool structural elements, importance should be given to their optimization for the functional requirements of maximum tool point stiffness, stability and accuracy and stress level in joints. Thus by reducing production costs and not compromising with functional properties is the goal of achieving optimum result. Almost all FEA software gives facility for optimization of design in some or other way. Here, optimization is approached with Head. As it is already stated, to reduce production cost, straight way is to reduce material mass, same time not compromising with its functional properties. Again at this stage, the skill and expertise of design engineer comes into picture, as it is required to decide where to make change? Because what FEA software can do is nothing but the mechanical calculation work, which is rather tedious and long procedure.

We are familiar with simple numerical optimization algorithms such as the method of steepest descent. The algorithm in Pro/Mechanica is considerably more complex than this, although the basic idea is the same. The algorithm is considerably more efficient than simple steepest descent, and also must contend with the limits (known as constraints in optimization theory) in the search space. Pro/M evaluates the current design and tries to decide in what direction to move in the search space in order to either remove a constraint violation (like exceeding the allowed stress) or improve on the goal (in our case to reduce the mass). According to the documentation, you can select from two optimization algorithms the sequential quadratic programming (SQP) algorithm and the gradient projection (GDP) algorithm. The default is the SQP, which is generally faster for problems with multiple design variables.

If the initial design point is feasible (that is, no constraints are violated), the algorithm moves the design point in a direction to better satisfy the goal until/unless a constraint boundary is met in the search space. Then it moves in a direction tangent to the constraint surface, all the while seeking out the minimum value of the objective function. If the initial design point is infeasible (i.e. constraints are violated), then one or more correction steps are taken to reach the (nearest?) constraint boundary. Thus, if the first design is infeasible, the design at the end of these first iteration steps is not guaranteed to be feasible. The GDP has the advantage that, if started with a feasible design, it tends to produce a series of intermediate designs that are always feasible, even if it is unable to locate the global optimum design (either due to the objective function or limits set by you). In contrast, the SQP algorithm does not guarantee that intermediate designs are feasible but only that the optimum (if found) is feasible. The advantage of SQP is its generally increased speed over GDP.

4.6.1 Optimization applied to Head

We have studied the behavior of head with varying thickness. It is interesting rather obvious that as thickness is reducing, displacement is increasing and total mass of the structure is almost directly proportional to the thickness. After studying the results of sensitivity study, our search space for finding optimum result will confined to thickness value of 12 to 20 mm. At the same time, constraint for optimized result search is required; which should be obeyed while finding optimum results. In the case of machine tool structure, it will be some limiting value of maximum displacement that is allowable. In case of Head, allowed value for displacement is taken as 3 µm. Again it is required to give some convergence value for desired parameter, which will work together with no. of passes specified during optimization for finding the optimized result. Every time, after executing one pass, convergence value is checked for its validity, if it gets satisfied then process of optimized result search will stop.

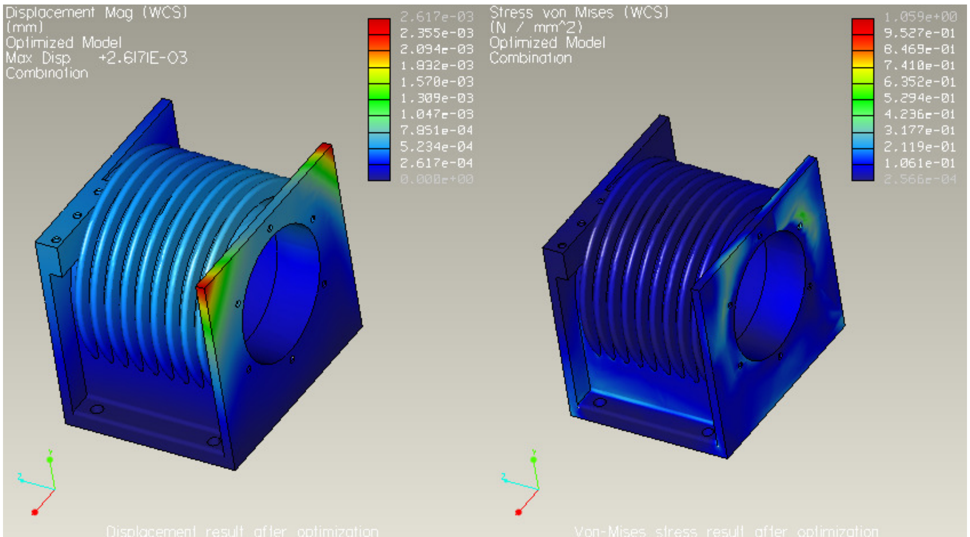

Fig. 4.14 Displacement and stress result after optimization for Head

The whole story of process carried out during optimized result search can be seen in the summary of the analysis, which is very useful tool for review. Studying the results, it is clearly seen that for initial value of design parameter total mass is minimum and maximum displacement magnitude is also minimum and fall within the specified value. After optimization total mass is also get reduced by 73.6 kg to 72.1 kg (1.5 kg) for thickness 17 mm to 12 mm. And also deflection is increased to 1.84 x10^{-3} mm to 2.617 x

10^{-3} mm, and still not violating constrain of displacement allowable. Results of optimization study are shown in Fig.4.14 and summery of design study is given below.

Summary for Design Study "Study_optimiztion"

Mechanica Structure Model Summary

Principal System of Units: millimeter Newton Second (mm Ns)

Length: mm

Force: N

Time: sec

Temperature: C

Model Type: Three Dimensional

Points: 2809

Edges: 14684

Faces: 21475

Springs: 0

Masses: 0

Beams: 0

Shells: 0

Solids: 9606

Elements: 9606

Optimization Design Study

Using Gradient Projection Optimization Algorithm

Fri Jul 26, 2013 14:36:35

Goal

Minimize: total mass

Limit: 1

Analysis: Analysis_HEAD17MS

Load Set: Load_cuttingload_1mmcut

max_disp_mag < 3.0000e-003

Parameter	Min. Value	Initial Value	Max. Value
d30	12	12	20

Optimization Convergence Tolerance: 1 %

Maximum Number of Optimization Iterations: 20

Begin Analysis of Goal and Limits of (14:36:35)

Initial Design

Initial Design Status

Parameters:

d30 12

Status of Optimization Limits:

1. Max_disp_mag 2.617e-03 < 3.0000e-03 (satisfied)

Goal (before optimization): 7.2107e-02

Resource Check (14:42:34)

Elapsed Time (sec): 367.10

CPU Time (sec): 314.98

Memory Usage (kb): 535207

Wrk Dir Dsk Usage (kb): 0

Begin Optimization Iteration 1 (14:42:34)

Optimization converged on limit boundary.

Best Design Found:

Parameters:

d30 12

Goal: 7.2107e-02

Run Completed

--

4.6.2 Optimization applied to Bed

Main structural part of the any Turning centre is Bed. For the optimization study objective function and constraints are as follows for Bed.

Objective function	:	Minimize total mass
Constraints	:	Max. Displacement Magnitude < 2.5 µm

Studying the results, it is clearly seen that for initial value of design parameter total mass is minimum and maximum displacement magnitude is also minimum and fall within the specified value. After optimization total mass is also get reduced by 1415 kg to 1405 kg (10 kg) for thickness 17 mm to 15 mm. And also deflection is increased to 1.474 $\times 10^{-3}$ mm to 1.486 x 10^{-3} mm, and still not violating constrain of displacement allowable. Optimization study is shown in Fig.4.15 and summery of design study is given below.

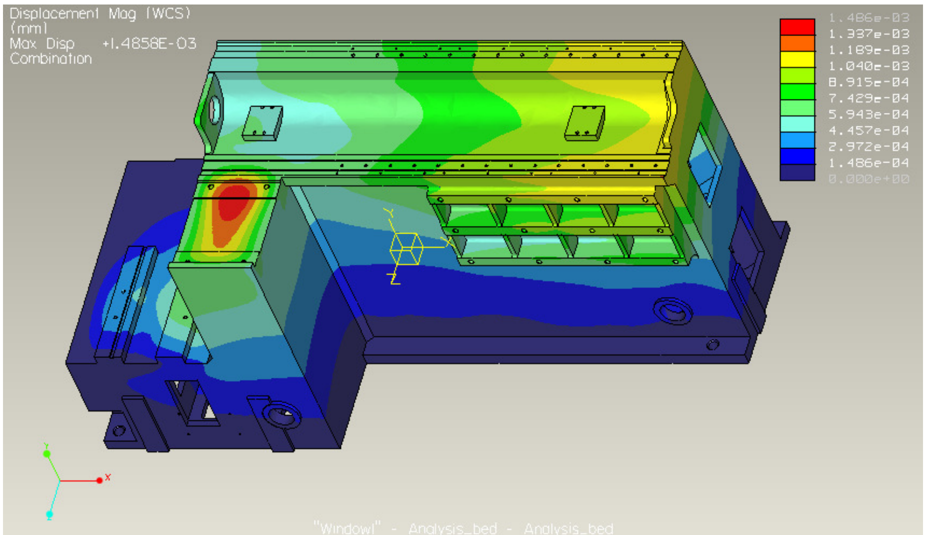

Fig. 4.15 Displacement result after optimization for Bed

Summary for Design Study "study_optimiztion"

Mechanica Structure Model Summary

Principal System of Units: millimeter Newton Second (mmNs)

Length: mm

Force: N

Time: sec

Temperature: C

Model Type: Three Dimensional

Points: 9222

Edges: 47587

Faces: 68181

Springs: 0

Masses: 0

Beams: 0

Shells: 0

Solids: 29865

Elements: 29865

Optimization Design Study

Description:

Optimization in the thickness of bed.

Using Gradient Projection Optimization Algorithm

Fri Apr 17, 2015 11:40:55

Goal

Minimize: total_mass

Limit: 1

Analysis: Analysis_bed_ss0

Load Set: LoadSet2_cuttingforce

max_disp_mag < 2.5000e-003

Parameter	Min. Value	Initial Value	Max. Value
d390	15	15	30

Optimization Convergence Tolerance: 1 %

Maximum Number of Optimization Iterations: 10

Begin Analysis of Goal and Limits of (11:40:55)

Initial Design

Initial Design Status

Parameters:

d390 15

Status of Optimization Limits:

1. max_disp_mag 1.486 e-03 < 2.5000e-03 (satisfied)

Goal (before optimization): 1.4054e+00

Resource Check (12:19:09)

Elapsed Time (sec): 2330.23

CPU Time (sec): 2059.76

Memory Usage (kb): 1398945

Wrk Dir Dsk Usage (kb): 0

Begin Optimization Iteration 1 (12:19:09)

Optimization converged on limit boundary.

Best Design Found:

Parameters:

d390 15

Goal: 1.4054e+00

Run Completed

4.6.3 Optimization applied to Saddle

For the optimization study objective function and constraints are as follows for Saddle a part of turning centre.

Objective function : Minimize total mass

Constraints : Max. Displacement Magnitude < 1.5 µm

Studying the results, it is clearly seen that for initial value of design parameter total mass is minimum and maximum displacement magnitude is also minimum and fall within the specified value. After optimization total mass is also get reduced by 114 kg to 113 kg (1 kg) for thickness 20 mm to 15 mm. And also deflection is increased to 1.259 x10^{-3} mm to 1.322 x 10^{-3} mm, and still not violating constrain of displacement allowable. Optimization study is shown in Fig.4.16 and summery of design study is given below

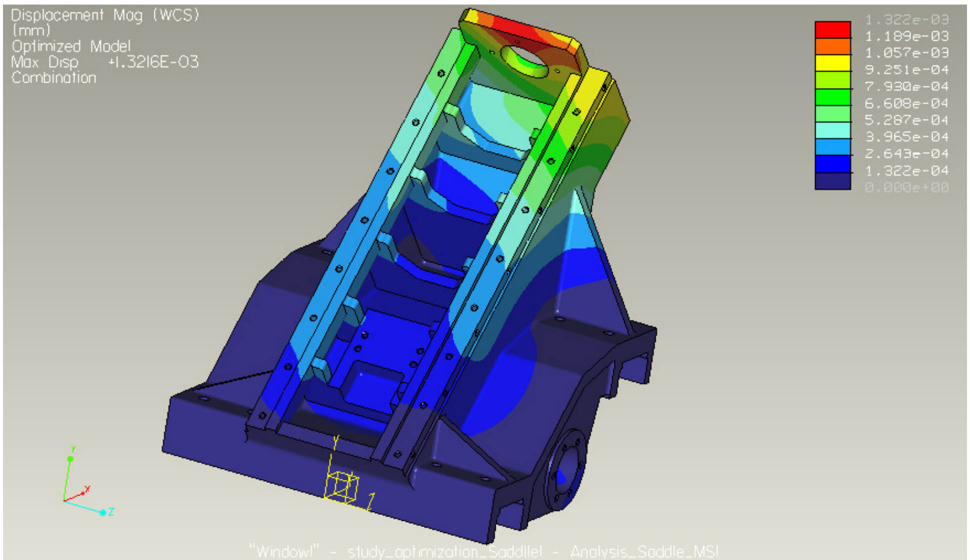

Fig. 4.16 Displacement result after optimization for Bed

Summary for Design Study "study_optimization_Saddlle"

Mechanica Structure Model Summary

Principal System of Units: millimeter Newton Second (mm Ns)

Length: mm

Force: N

Time: sec

Temperature: C

Model Type: Three Dimensional

Points: 5140

Edges: 26621

Faces: 38277

Springs: 0

Masses: 0

Beams: 0

Shells: 0

Solids: 16817

Elements: 16817

Optimization Design Study

Description:

Optimization in the thickness of saddle for M.S. material

Using Gradient Projection Optimization Algorithm

Tue Jul 14, 2015 14:44:43

Goal

Minimize: total_mass

Limit: 1
Analysis: Analysis_Saddle_MS1
Load Set: Load_cutting_1mmcut

max_disp_mag < 1.5000e-003

Parameter	Min. Value	Initial Value	Max. Value
d67	15	15	30

Optimization Convergence Tolerance: 1 %

Maximum Number of Optimization Iterations: 5

Begin Analysis of Goal and Limits of (14:44:43)

Initial Design

Initial Design Status

Parameters:

d67 15

Status of Optimization Limits:

1. Max_disp_mag 1.332 e-03 < 1.5000e-03 (Satisfied)

Goal (before optimization): 1.1320e-01

Resource Check (14:58:30)

Elapsed Time (sec): 843.43

CPU Time (sec): 686.20

Memory Usage (kb): 783749

Wrk Dir Dsk Usage (kb): 0

Begin Optimization Iteration 1 (14:58:30)

Optimization converged on limit boundary.

Best Design Found:

Parameters:

d67 15

Goal: 1.1320e-01

Run Completed

In next chapter Regression analysis is done by considering two set of materials like AISI 1040 steel, Aluminium and AISI 410steel, Aluminium.