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IMPROVEMENT OF TOOL POINT STIFFNESS OF A LATHE THROUGH IMPROVED BED DESIGN

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Abstract - *Tool point stiffness of a lathe is defined as the ratio of cutting force at tool to the deflection at the cutting point. Cutting force at the tool in a lathe gets transferred to the lathe bed through tool post and the carriage. The cutting force at the tool has two components, the radial and tangential and these get transferred to the lathe bed as a bending force and a moment. Under the influence of these two, the lathe bed undergoes bending and twisting deformations. The tool post that sits on the bed picks up these deformations and deflects in a lateral direction away from the work piece. This gives rise to flexibility at the cutting zone. The flexibility is undesirable in a lathe as it is known to cause chatter vibrations during machining. In the present research, another type of ribbing is provided in the lathe bed such that higher stiffness can be obtained for a lower bed weight itself. This is facilitated through optimum location of a section geometric property by name the shear center. The geometry of the lathe bed is suitably modified so as to locate the shear center such that the machine stiffness increases to the desired value, thereby, achieving a higher stiffness to weight ratio. In this thesis the final structural shape optimized bed model is obtained and analyzed with three other available models using the Finite element analysis in ANSYS software. The predicted results show us very drastic change in stiffness to weight ratio values compared to other models. Finally the Analytical results (deformations) are obtained for final model by simplifying the model by considering bed portion only, because so many constraints to calculate. This result matches with FEA result of same simplified model of final model.*

Key Words: Tool Point stiffness, Shear Centre, Bed Weight, and ANSYS.

1. INTRODUCTION

Lathe is defined as the machining tool, which means machine used for metal cutting operations. The principle of a machine tool is to produce required surface by giving required motion between the cutting tool and the work piece. These lathe machines are used for different machining operations such as turning, drilling, thread cutting, etc.

1.1 Parts of Lathe

The below fig-1 shows basic structure of a general purpose lathe used for metal cutting operation in every day. In this paper also similar type of lathe machine is considered for analysis.

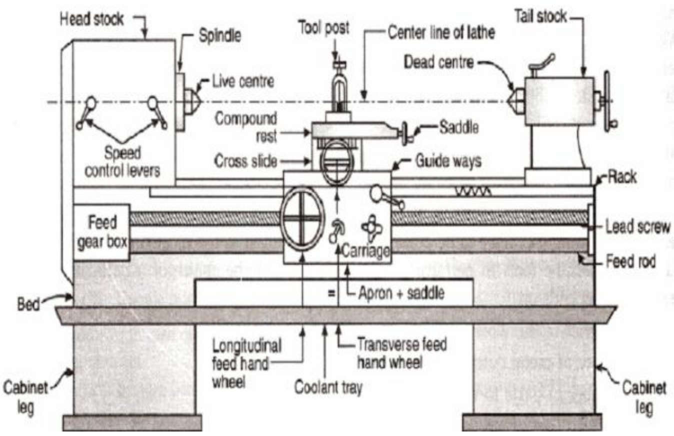

Fig -1: Lathe

The following are some of the important parts of Lathe machine:

1. Bed
2. Headstock
3. Carriage
4. Tail stock
5. Feed Mechanism
6. Leg

1.2 Lathe Bed

The lathe bed is the base of machine, on which different fixed and operations parts of lathe are fixed. This is usually made up of Grey cast iron material, because of its good material characteristics to bed conditions. One of the primary considerations is having a good damping property.

The lathe-bed is a critically important part of a lathe, on which the performance of a machine tool depends largely. The optimization of a lathe-bed is hence an important issue in machine tool design. As a supporting part of a lathe, the lathe-bed is generally used for placing such important components as lead rail and headstock. In order to meet the high requirements of speed, accuracy, productivity and reliability, lathes are to be superior in static and dynamic stiffness and vibration resistance. Due to the high complexity of lathe-beds with regard to structural shape, it will be very difficult to carry out calculations for its static/dynamic characteristics by means of conventional methods. With the maturity of finite element theory and the development of computer technique, it is a widely used method to perform a static/dynamic characteristic analysis by building three-dimensional modeling and performing finite element analysis with the software tool ANSYS.

In a bid to decrease the deflection at tool and thereby increase the machine stiffness, in some machines, a Warren ribbing is provided or increases the bed size in the lathe. These arrangements will increase the weight of the lathe bed, causes increase in cost of lathe and also not competitive in market. So in order to minimize these obstacles, we proved alternative design of lathe bed which improves the tool point stiffness along with maintains weight.

1.3 Centroid and Shear Center

Centroid and shear center of a beam are two important sectional properties that are used to determine the structural response. The centroid is defined as the location where an axial load does not cause a change in curvature and a bending moment does not produce axial strain. Likewise, shear forces acting at the shear center do not cause twist. In other words, the load acting at the centroid decouples the structural response between axial extensions and bending, whereas, shear center decouples bending and twisting, mechanisms of a beam [1].

Shear center is defined as the point about which the external load has to be applied so that it produces no twisting moment.

2. DESIGN OF LATHE BED

2.1 Load Calculations

Initial data considered for forces acting on the lathe bed and its effects are assumed as below (For considered lathe specifications):

1. Spindle power (P): 5kW
2. Cutting Speed (v): 200mt/min
3. Work piece diameter (R): 120mm

We know that cutting speed equation in terms of speed,

$$v = 2\pi RN$$

$$N = \frac{v}{2\pi R} = \frac{200 \times 10^3}{2 \times \pi \times 60} = 530.52 \text{ rpm}$$

3. Torque: The Torque (kgf-mm) eq. in terms of P & N [2]

$$T = \frac{975000 \times P}{N} = \frac{975000 \times 5}{530.52} = 9189.09\ kgf - mm$$

4. Forces: Three force components are generated at cutting zone and calculated from the torque. [2]

$$F_Y(\text{Tangential}) = \frac{T}{R} = \frac{9189.09}{60} = 153.15\ kgf = 1502.4\ N$$

$$F_X(\text{Radial}) = \frac{F_Y}{3} = \frac{1502.4}{3} = 51.05\ kgf = 500.8\ N$$

$$F_Z(\text{Axial}) = F_Y \times 0.45 = 153.15 \times 0.45 = 68.92\ kgf = 676.10\ N$$

2.2 Finite Element Analysis

These force components are applied at the tool point on all 3 versions of lathe bed design, which are already in practice and its tool displacements results are compared with the final optimized model of lathe bed. All these versions are Modeled, Meshed and analyzed in ANSYS Software.

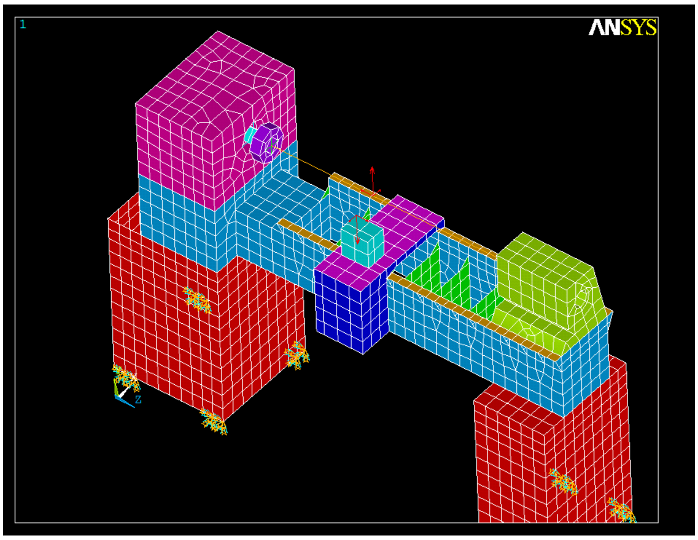

Fig -2: FEM model of version-1 lathe bed design

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From the version-1 the displacements at the tool point are calculated as follows:

1. U_x = -0.3525 mm
2. U_Y = -0.11517 mm
3. U_Z = -0.0033 mm

Similarly below Fig-3 shows the version-2 (single cross rib) of lathe bed design. On this same load conditions are applied and analyzed for tool point displacements.

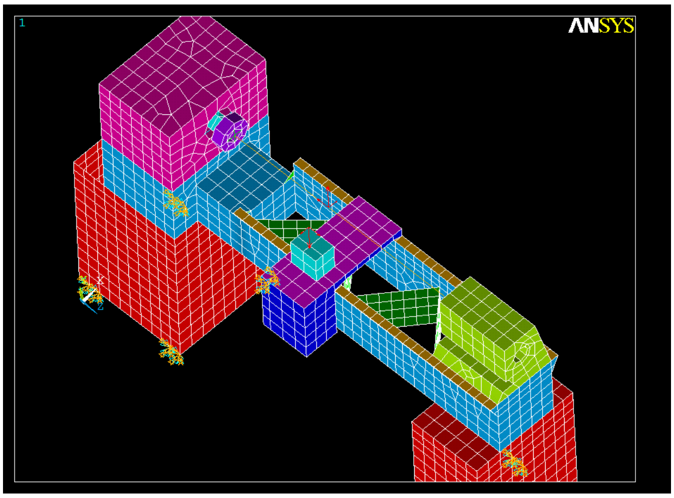

Fig -3: FEM model of version-2 lathe bed design

The tool point displacements at version-2 are calculated as below:

1. U_x = -0.1887 mm
2. U_Y = -0.0916 mm
3. U_Z = 0.0034 mm

Below Fig-4 shows the double cross rib type (version-3) construction of lathe bed. In this also the tool point displacements are calculated.

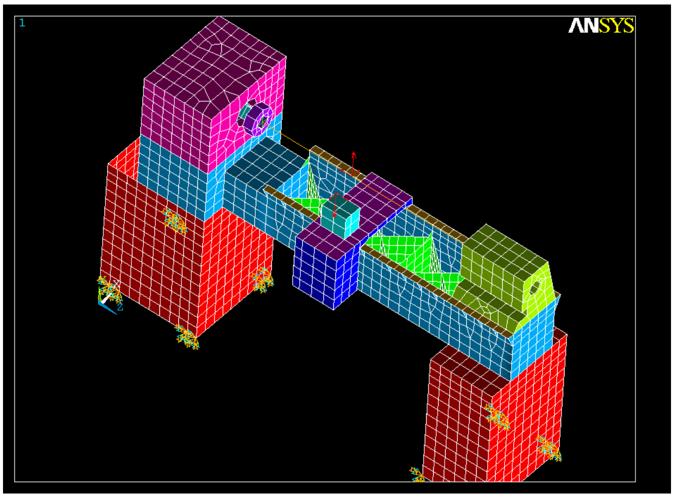

Fig -4: FEM model of version-3 lathe bed design

The tool point displacements are:

1. U_x = -0.1275 mm
2. U_Y = -0.080 mm
3. U_Z = -0.0027 mm

The final optimized model (version-4) is obtained through optimum location of shear center and triangular section of cross rib (good facilitation of chips). This section proved at last having better results than others. The thicknesses of whole bed section is differed in dimensions and also reduced for less weight keeping the stiffness of tool point.

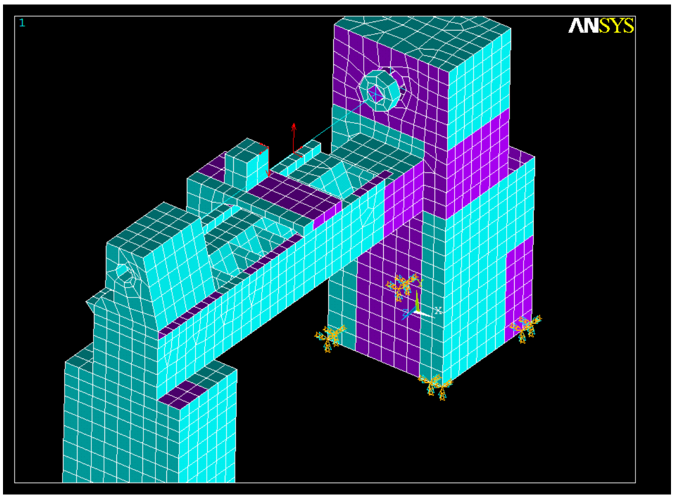

Fig -5: FEM model of version-4 lathe bed design

The tool point displacements of version-4 are calculated as below:

1. U_x = -0.1224 mm
2. U_Y = -0.0750 mm
3. U_Z = -0.002 mm

At the same time the total weight and bed weight of each version is calculated using density of material in the ANSYS. It is also kept in mind for final concluding the model.

The below Fig-6 shows the sectional view of version-4 lathe bed model. For continuity, the box is made closed and analyzed for shear center, center of gravity and moment of inertia of given cross section using ANSYS.

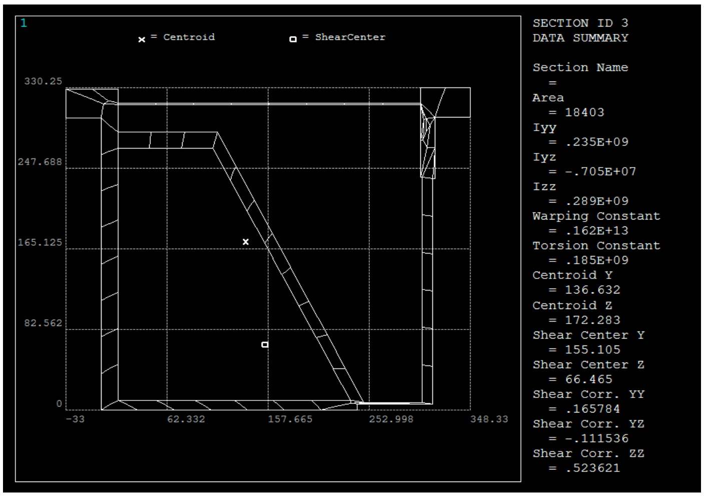

Fig -6: Optimized lathe bed sectional view (version-4)

3. RESULTS AND DISCUSSIONS

Table -1: Comparisons of FEM results

Versions	Resultant Displacements (R_U) mm	Bed Weight kg	Stiffness(R_N) $=R_F/R_U$ N/mm	R_N/Bed wt.
Ver-1	0.371	243.95	4641.37	19.03
Ver-2	0.21	246.54	8199.76	33.26
Ver-3	0.1505	366.53	11441.53	31.22
Ver-4	0.1436	280.41	11994.26	41.02

The above table shows the final Fem results for all four versions of lathe bed design. Where R_F= 1721.95N means Resultant force, calculated by force components applied. The other thing to notify is the last column that is, ratio of Tool point stiffness to bed weight. This ratio should be highest, because it shows Newton force required for unit tool point deflection and for unit bed weight.

3.1 Analytical Calculations

The analytical calculations are carried out to verify the optimized bed design, this is done using the simplified model of version-4, i.e. fig-7.

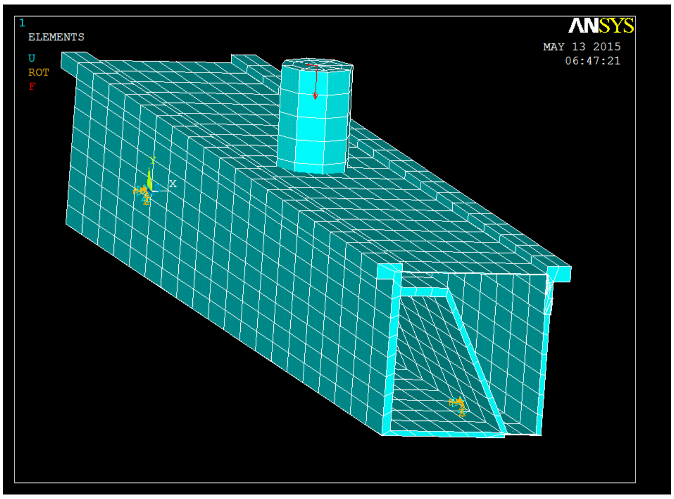

Fig -7: Simplified FEM model of version-4 lathe bed design and analyzed for theoretical calculation

Because of complex calculations of so many components displacements, which are influencing on the on bed. This method is used in Analytical calculations. In Fig-7 shows forces are being applied on a dummy beam considered at a same distance as tool point.
Below are sub grid solutions (disp.) at the top end of dummy beam by ANSYS.

1. U_X = -0.0113mm
2. U_Y = -0.0063 mm

The displacements are calculated analytically by adding two methods. That is displacements caused due to bending and due to twisting force (torsion of beam).

1. Displacements due to bending of both end fixed beam type:

$$U_X = \frac{WL^3}{192EI_{zz}} = \frac{500.8 \times 2077.7^3}{192 \times 130000 \times 0.289 \times 10^9} = 0.623 \times 10^{-3}\ \mathrm{mm}$$

2. Displacements due to twisting force:

$$T = F_X \times r = 500.8 \times 442.9 = 221.8 \times 10^3\ \mathrm{N\text{-}mm}$$

$$\theta = \frac{TL}{JG} = \frac{221.8 \times 10^3 \times 1038.85}{0.185 \times 10^9 \times 51.18 \times 10^3} = 2.43 \times 10^{-05}\ rad$$

$$S = r \times \theta = 448.5 \times 2.43 \times 10^{-05} = 10.898 \times 10^{-03}\ mm$$

Therefore, total displacement along U_x direction is,

$$U_X = S + 0.623 \times 10^{-3} = 11.513 \times 10^{-3}\ \mathrm{mm}$$

From this both results FEM and Analytical are matching and the error percentage is 1.88%. Hence finally these methods will also being applied to validate the full model of optimized bed design.

4. CONCLUSIONS

The tool point stiffness is much important in deciding the accuracy of job, as well as helps to improve the chatter vibration. From the Table-1 of FEM results, shows that ratio of stiffness to bed weight is increased by 115.5% compared to version-1. By all these analysis proves that this type of ribbing to the lathe bed (Triangular form) will improve the stiffness and also reduction in weight.

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