Improvement of Tool point Rigidity of CNC Lathe through Shear Center Location

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Abstract— The power utilization of machine tools as per instance a CNC Lathe or machining centre depends upon the rigidity of cutting point, in other words the rigidity between cutting tool and work piece. In this machine, the cutting force at cutting point flows through various machine members like tool post, spindle system, bed etc. These forces in the machine member will bend or twist the structure. This is because the cutting force acting on the member will induce bending moment and torsional moment. In the present work a novel approach based on shear center is attempted which will reduce the deflection of the specimens. This improves the tool point rigidity between cutting tool and work piece. The concept of shear center is extended for analyzing the lathe bed. Three different configurations of the lathe bed are considered for analysis to reduce the deflections of the work piece and the best one is selected.

Keywords: CATIA V, ANSYS 14, Software

I. Introduction

The proper design of machine-tool structures requires a thorough knowledge of their forms, designs and properties of the material. It is generally accepted that the precision of machine tools is determined by their static characteristics. Especially, in reducing the deformation of machine tool structures, high static stiffness against bending and torsion are desired.

Recently, researches have been conducted in the field of improvement of structural design of machine tools by improving stiffness and reducing the weight which is especially urgent for the structural parts, such as bed, column, worktable, beam and so on. The arrangement of stiffening - ribs in machine tool structures is a key factor for structural stiffness and material consumption. So the design of stiffening-ribs is significant for machining performance and energy saving.

From user's point of view, machine tool deformation is an important factor because it adversely affects the quality of the machined surface. To improve both the static and dynamic performances, the machine tool structures should have high static stiffness. For improving the tool point rigidity, a novel approach is adopted which uses the concept of Shear center to analyse the lathe bed.

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This work presents some interesting aspects regarding the shear center issue, which may be applied in the concept and the design of the structures. Beside the theoretical aspects, a comparative study of three finite element models is presented.

Initially the concept of shear center is validated by performing theoretical and finite element analysis on simply supported beam with a central load of 100 N. The cross-section of the beam considered is C-section and Half-circular sections. Deflection of the beam for various values of the distance between the shear center and the centroid are analyzed and compared for validation.

In the next stage, the concept of shear center is extended for analyzing the lathe bed. Three different configurations of the lathe bed are considered for analysis to reduce the deflections of the work piece and the best one is selected. The dimensions of the original lathe were taken from M/s Lokesh Machine Tools Ltd.

The geometric modeling of all the models are done vin CATIA V5 package and finite element analysis is carried out using ANSYS 14 software.

II. Verification of Shear Center Concept for Simply Supported Beam

A. *Deflection due to Loads Applied at Centroid:*

Figure1 shows a simply supported beam with a central load and boundary conditions, the load being applied at the centroid of the cross section. The beam is subjected to a central load of 100 N at its centroid

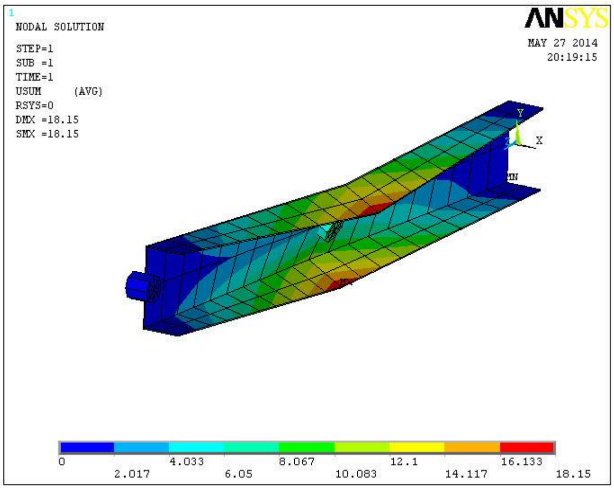

Fig. 1.1: Deflection due to load acting at centroid.

B. *Deflection due to Loads Applied at Shear Center*

Now the same load of 100 N is applied at the shear center of the cross section of the beam as shown in figure 1.2. The shear center is at a distance of 68.46 mm from the centroid.

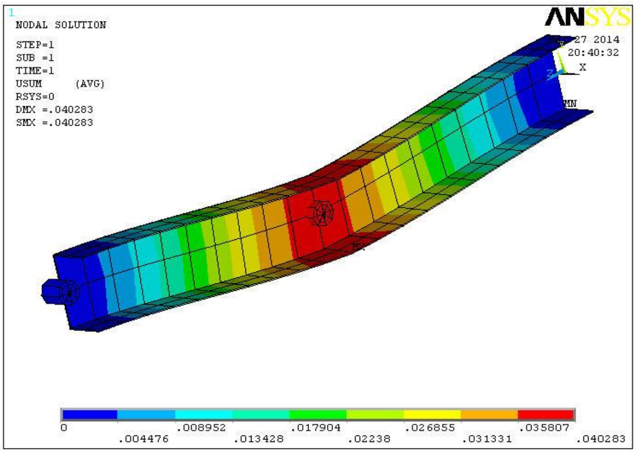

Fig. 1.2: Deflection due to load acting at Shear center.

The deflection of the beam for the two cases is shown in table1.

Loading position	Deflection
Centroid	18.15mm
Shear center	0.04 mm

Table 1: Comparison of deflections

The results are obtaining from table show a large reduction in deflection of the simply supported beam when the load is applied at the shear center compared to the load applied at the centroid. This is due to the fact that the torsional deformations will be zero when the loads are applied at the shear centers. This methodology is extended for analyzing a lathe bed to reduce the specimen deflections.

III. EFFECT OF MODIFICATION IN SHEAR CENTER LOCATION

The distance between the centroid and shear center is the most important parameter while reducing the total deflection (due to bending and torsion) of the beam. As the distance becomes zero, the torsional deformation will be zero and the problem is considered as a pure bending case. If the distance is maximum, the total deflection will be a result of both bending and torsion.

One can change the distance by adding or removing a material to the original structure i.e., by changing the cross section of the beam. Practically it is not possible to reduce the torsional deformations to zero but it should be kept minimal so that the tool point rigidity will be increased.

The distance between the Shear center and centroid for three different cases are analyzed by changing the combination of web and flange thicknesses as below. The cross sectional dimensions of a c-channel are shown in figure 2.1

Web thickness = 10mm and Flange thickness = 5mm

The location of centroid and shear center for a C-Chanel are determined from FEM analysis. The results are shown in figure 3. For the first case the distance between the two centers is 43.43 mm.

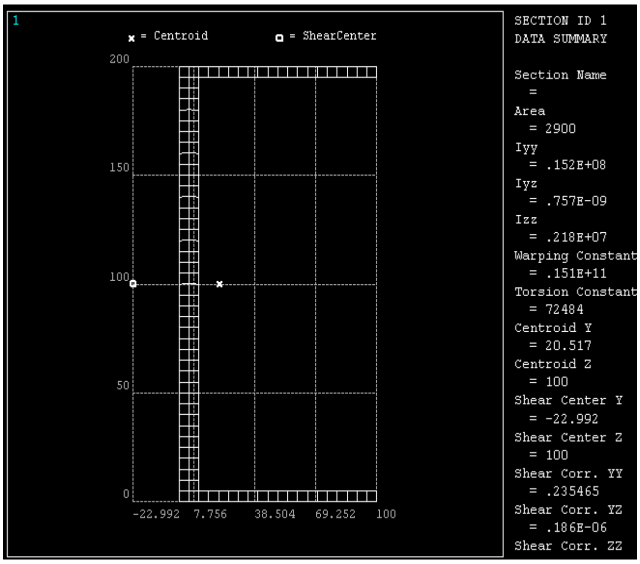

Fig. 2.1: Shear center of a C-section for 10 mm web and 5 mm flange thickness.

For Web thickness = 20mm and Flange thickness=5mm.

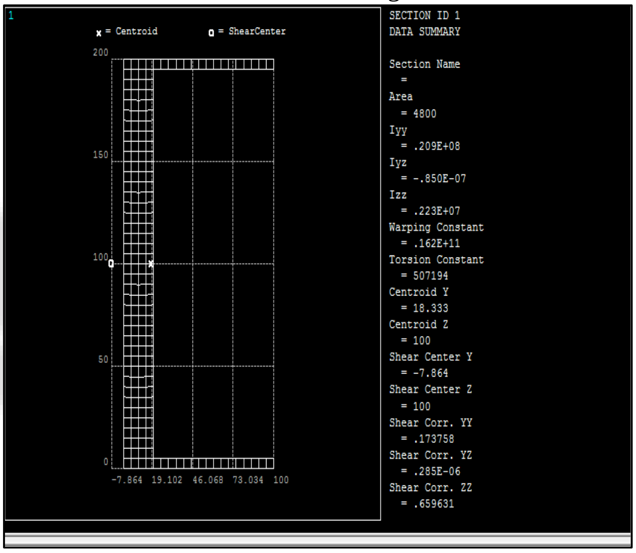

Fig. 2.2: Shear center of a C-section for 20 mm web thickness and 5 mm flange thickness.

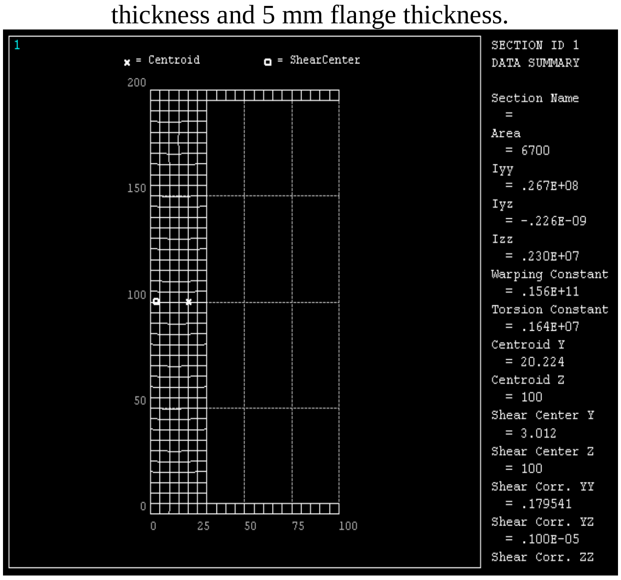

Fig. 2.3: Shear center of a C-section for 30 mm web thickness and 5 mm flange thickness.

Now for the second case, the thickness of the web is increased to 20 mm and flange thickness is taken as 5 mm and this material is added towards the centroid location. For this case the distance is 26.19 mm is as shown in figure 2.2.

For Web thickness 30mm and Flange thickness 10mm.

In the 3rd case, the web thickness is taken as 30 mm and the flange thickness is taken as 10 mm. For this case the distance is 17.1 mm. is shown in figure 2.3

The distance between the shear center and the centroid for all the five cases are tabulated in table 2

Sl no	Web thickness, mm	Flange thickness, mm	Distance between S.C and centroid, mm
1	10	5	43.43
2	20	5	26.19
3	30	5	17.22

Table 4.8: Centroid to Shear center distance.

Table 4 shows, how the distance between the shear center and centroid varies as the material is added or removed. If the material is added to the web portion the distance decreases, as the cross section will tend to become symmetric for which the distance is zero. If the material is added to the flange, the distance increases upto certain thickness and thereafter the distance starts decreasing and finally becomes zero. This trial and error method is extended for analysing and finding the suitable cross section for the lathe bed so that the specimen deflections will be minimum.

IV. FINITE ELEMENT ANALYSIS OF LATHE BED

Most of the existing lathe beds are designed by indirect methods i.e., by varying the weight and changing the shape of the sections iteratively to get the best possible design which meets the customer requirement. The various finite element analysis software's are available for this purpose. But this way of designing a lathe bed is not very much accurate and requires a lot of time.

In the present work, a novel approach using shear center is adopted for analyzing the lathe beds to reduce the specimen deformation. This reduction in specimen deformation will finally result in good finished product.

A. Shear Centre for Baseline Design of Lathe Bed:

The geometric model of the lathe bed cross section is created in ANSYS11 as per the dimensions of figure 3.1. The model is meshed with BEAM 188 element for analysis as shown in figure 3.2.

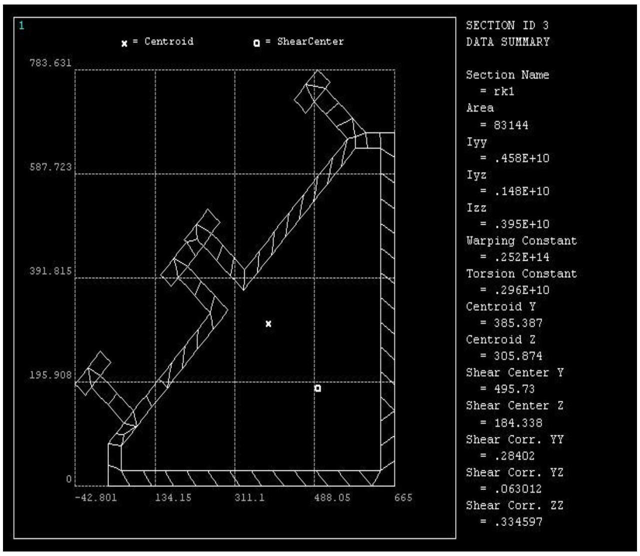

Fig. 3.1: Shear center for existing (Base line or initial) design of lathe bed

Figure 3.1 shows the distance between the centroid and the shear center is 164.15 mm. This value indicates that the lathe bed is subjected to both bending and torsion. This value is to be minimised so that the overall deflection of the lathe bed is reduced. To reduce the distance, the cross section needs to be modified by adding or removing material in the existing design.

B. Shear center in Modified Lathe Bed Cross Section:

In the first stage (initial design as in figure 3.1) analysis, the thicknesses of the flange, web and slant portion are taken as 30 mm, 30 mm and 20 mm respectively. In the next stage analysis, these dimensions are altered for changing the distance between the centroid and the shear center.

In the second stage analysis, the thickness of the slant portion is increased to 30 mm and the thickness of the flange and web are reduced to 20mm, without changing the peripheral dimensions of initial design. The dimensions are as shown in figure 3.2. From the analysis, the distance between Shear center and centroid is obtained as 105.81 mm.

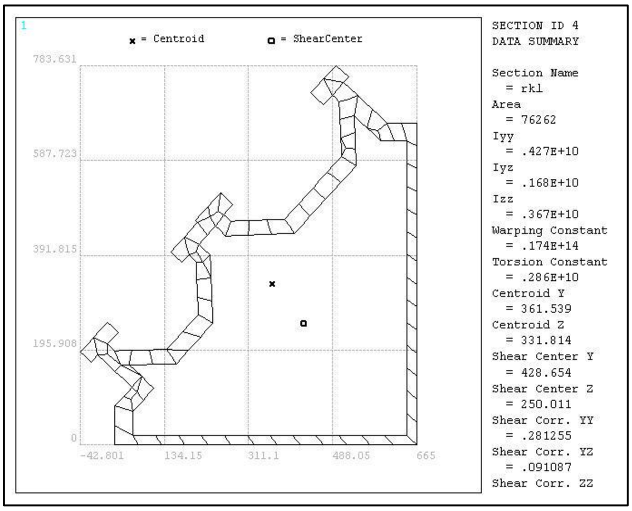

Fig. 3.2: Shear center for modified design of lathe bed

C. Shear center in Final Stage Design of Lathe Bed:

In the final stage analysis, the ribs are added to the lathe bed which reduces the twisting moment and increases the stiffness of the lathe bed as shown in figure 8. The analysis is done for different positions (orientations) of the rib and a best configuration is selected which gives minimum distance between the shear center and the centroid as shown in figure 3.3. The distance for the final design is obtained as 70.46 mm.

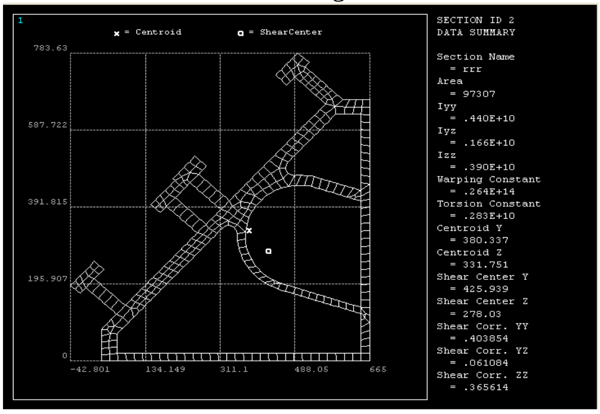

Fig. 3.3: Shear center for optimized design of lathe bed

V. THREE DIMENSIONAL ANALYSIS

The geometric modelling of the lathe bed is done in CATIA V5 modelling package and then it is imported into the ANSYS 14 environment for finite element analysis. The model is meshed with tetrahedron elements as shown in figure 6.2. The base of the lathe bed is constrained in all directions. Cutting forces are applied at the middle portion of the work piece along cutting tool direction; the cutting tool is held parallel to the slant portion (45^0) of the lathe bed. The analysis is done by assuming a maximum cutting force of 2500 N acting on the work piece at its centre.

A. Analysis of Initial Design of Lathe Bed

The meshed model of the lathe bed for initial design is shown in figure 6.2. After the analysis the deflection of the specimen is 20 microns.

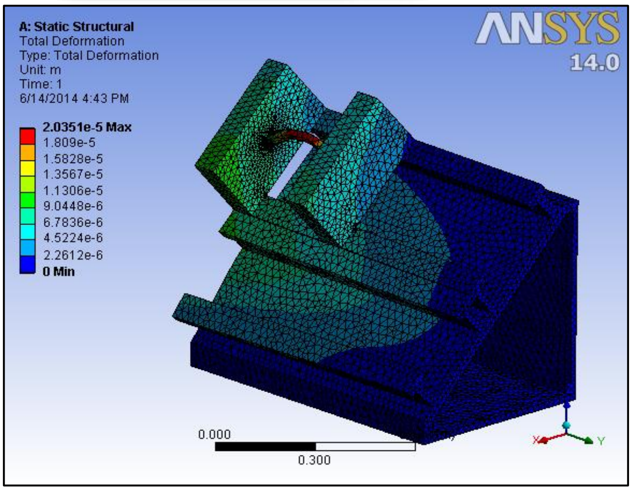

Fig. 6.2: Deflection of work piece in basic design.

B. Analysis of modified Design of Lathe Bed

The meshed model of the lathe bed for the modified design is shown in figure 6.3. After the analysis the deflection of the specimen is16 microns.

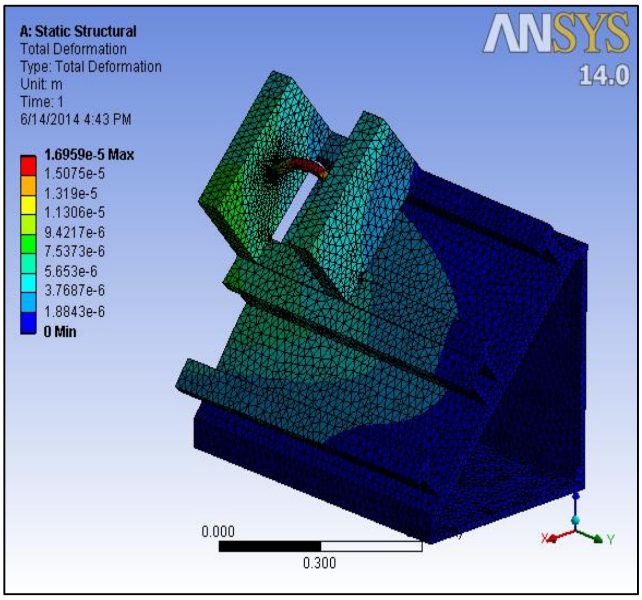

Fig. 6.3: Deflection of work piece in Modified Design

C. Analysis of final or optimized Design of Lathe Bed:

The meshed model of the lathe bed for final design is shown in figure 6.4. After the analysis the deflection of the specimen is 08 microns.

	Distance between shear center and centroid 'e', (mm)	Angle of twist (degrees)	Force, N	Deflection, (micron)
Initial Design	164.15	0.000136^0	2500	20.35
Modified design	105.81	0.000125^0	2500	16.95
Optimized design	70.46	0.000091^0	2500	8.00

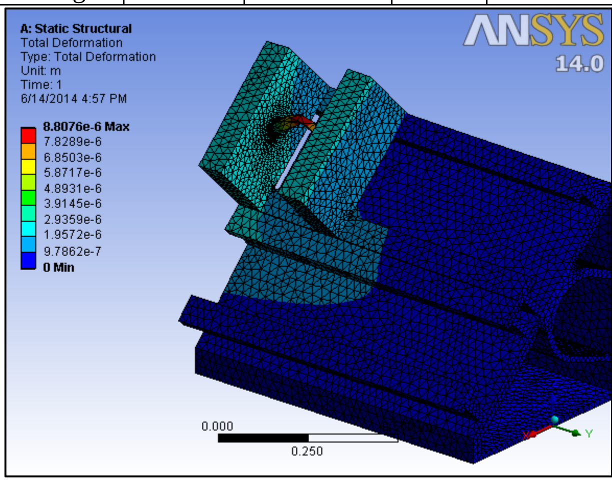

Fig. 4.4: Deflection of workpiece in Optimized design.

The results of the analysis are tabulated in table 6.1, which indicates a reduction in deflection of the specimen for final optimized design of the lathe bed.

VI. CONCLUSION

The Three dimensional model of the lathe bed is modeled in CATIA V5 and meshed in ANSYS 14 environment. The analysis is done with proper loads and boundary conditions, as discussed in

The results of table 7.4 shows that the deflection of the specimen can be reduced by keeping the distance between the centroid and the shear center as minimum as possible. This is done by making suitable modifications in the lathe bed cross-sections as shown in figures 6.2 to 6.4. The minimization of angle of twist indicates that the tool point rigidity is increased.

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