Optimizing Shear Center Location to Enhance Tool Point Rigidity in CNC Lathes

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Abstract— This project explores a novel approach based on the shear centre concept to minimize deflection and enhance tool point rigidity between the cutting tool and the work piece in CNC lathe operations. Initially, the shear centre concept is validated through both theoretical and finite element analyses. Building on this, the shear centre concept is applied to the analysis of the lathe bed's structural performance. Three different lathe bed configurations are evaluated to determine their effect on deflection reduction, with the most effective configuration being selected. The lathe dimensions for the analysis are sourced from M/s L. Machine Tools Ltd. The results of this study show that optimizing the shear centre location within the lathe bed significantly improves the rigidity at the tool-point interface, enhancing machining accuracy, reducing vibrations, and extending tool life.

Keywords— CATIA V5, ANSYS-14

I. INTRODUCTION

The design of machine tool structures requires an in-depth understanding of their forms, material properties, and design principles. Precision in machine tools is primarily determined by their static characteristics, with a focus on minimizing deformation. In particular, high static stiffness against bending and torsion is crucial for reducing structural deformation. Recent research has focused on enhancing the structural design of machine tools by improving stiffness while reducing weight, which is especially critical for key components such as the bed, column, worktable, and beams. The arrangement of stiffening ribs plays a significant role in both structural stiffness and material usage, making the design of these ribs vital for optimizing machining performance and energy efficiency.

From the user's perspective, machine tool deformation negatively impacts the quality of the machined surface, making it a critical factor to address. To enhance both static and dynamic performance, machine tool structures must exhibit high static stiffness. To improve tool point rigidity, this work introduces a novel approach based on the concept of the shear centre, applied to analyse the lathe bed.

The efficiency of machine tools, such as CNC lathes and machining centres, is heavily dependent on the rigidity of the cutting point, which refers to the rigidity between the cutting tool and the work piece. The cutting forces at the tool point are transmitted through various machine components, such as the tool post, spindle system, and bed, all of which can undergo bending or twisting due to these forces. The induced bending and torsional moments lead to structural deformation, which affects machining accuracy and quality.

This research explores the shear centre concept, which can be applied to the design and analysis of machine tool structures. In addition to theoretical discussions, a comparative study of three finite element models is presented. Initially, the shear centre concept is validated through theoretical and finite element analyses of a simply supported beam with a central load of 100 N. The beam cross-sections considered are C-section and half-circular sections. The deflection of the beam is analysed and compared for varying distances between the shear centre and centroid, serving as a foundation for further application to machine tool structures.

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II. DETERMINATION OF SHEAR CENTRE FOR C-SECTION AND HALF CIRCULAR SECTION:

The shear center of the C-Section and Half circular section is determined from theoretical method and compared with finite element analysis results for validation.

The dimensions of the C- section shown in figure 4.10 are *b* = 100 mm, h = 150 mm, and t = 3 mm.

Fig 1: C-channel beam section

The dimensions of the C- section shown in figure 1 are *b* = 100 mm, h = 150 mm, and t = 3 mm.
The shear center for C-section is given by

$$e = \frac{3b^2}{h+6b}$$

$$e = \frac{3 \times (100)^2}{150 + 6(100)}$$

$$\mathbf{e = 40mm}$$

Shear center of C-Section by FEM analysis:

The C-section is modeled in ANSYS and is meshed with BEAM element (Beam 188). The geometric properties of the C-section are displayed in figure 4.11 from which the shear center location is selected.

Figure 2: FEM analysis for C-Section

The FEM results are compared with the theoretical results and tabulated in table 4.6.1. It gives an error of 0.015 percent.

Table 1: Location of Shear center for C-Section:

	Theoretical	FEM	Percentage error
Shear center location	40	39.4	0.015

III. 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.

For the analysis, a **Heavy duty CNC lathe FL-520 MC SERIES 45 degree slant bed** is considered as shown in figure

The specifications of the machine are

Swing over bed diameter =1030mm

Swing over cross slide diameter =800mm

Maximum turning length =2000mm

Maximum turning diameter 260=320mm

The outer most dimensions of the lathe bed cross sections are considered for analysis Baseline model is created using the dimensions of figure 3 for a length of 1000 mm as shown in figure 5.2. The geometric model of the bed is created in CATIA V5 modelling package and is imported into the ANSYS 11 environment for finite element analysis

Figure 3: Shear center for modified design of lathe bed

Tool point rigidity of a cutting tool :

The rigidity of a cutting tool point is very important factor while machining a work piece to the required tolerance limits. The cutting tool has to be rigid enough to get precise finished components. The tool point rigidity of a cutting tool can be increased by minimizing the total deflection of the lathe bed. The total deflection of the lathe bed is due to two factors,

1. Torsion.
2. Bending.

The deflection due to torsional loading can be reduced by minimizing the distance between the shear centre and the centroid.

Figure 4 shows the free body diagram of a cutting tool, work piece and shear center location in a lathe machine. The deformation is always maximum when the tool point is in contact with the work piece.

Fig 4: Free body diagram of lathe bed

S.C= Shear center location
F_C = Main force or Cutting force component
F_R = Radial force component
ϴ = angle of twist
d = Length of the torque arm

The lathe beds are made of high strength steels, the properties of which are given in table 2.

Table 2: Properties of the lathe bed material

Property	Value
Young's modulus	210
Poison's ratio	0.3
Density	7830
Rigidity modulus	80.7

Angle of twist for Initial, Modified and Optimized design:

Figure 5 shows the free body diagram of a cutting tool, work piece and shear center location for the initial, modified and optimized designs. SC_1, SC_2 and SC_3 represent the shear center locations for the initial, modified and final designs.

Fig 5: Torque arm relation for shear center of the lathe bed.

From the torsion equation, we have

Angle of twist for initial design :

Length of the torque arm, d = 303.6 mm

Cutting force, F_C (assumed) = 2000N

$I_P = 0.395 \text{ X } 10^{10}$ mm^4 (from FEM analysis)

T= Fxd

ϴ $=0.00145^0$

Angle of twist for modified design:

Length of the torque arm, d = 259.6 mm

Cutting force, F_C (assumed) = 2500 N

$I_P = 0.367 \text{ x } 10^{10}$ mm^4 (from FEM analysis)

T= Fxd

ϴ =0.000002189 rad
ϴ $=0.00124^0$

Angle of twist for Optimized design:

Length of the torque arm, d = 201.6 mm Cutting force, F_C (assumed) =2500N

I_P = mm^4 (from FEM analysis)

T= Fxd = $0.54 \text{ x } 10^6$ N-mm

ϴ.00000160 rad

ϴ =0.000093

The angle of twist for different values of e obtained from the calculations are shown in table

The meshed model of the lathe bed for final design is shown in figure 6. After the analysis the deflection of the specimen is 08 microns.

Table 3: Angle of twist for different values of 'e'

	between shear center and centroid distance 'e', (mm)	Angle of twist
Initial Design	165.15	0.00145^0
Modified design	106.81	0.000124^0
Optimized design	71.40	0.000093^0

The results of table 3 shows that the angle of twist decreases as the distance between the shear center and centroid is minimized. As the angle of twist decreases, the rigidity of the cutting tool increases.

Analysis of final or optimized Design of Lathe Bed

The meshed model of the lathe bed for final design is shown in figure 6. After the analysis the deflection of the specimen is 08 microns.

Table 4 : Deflections for SC

Figure 6. : Deflection of work piece in Modified Design

	Distance	Angle of twist (degrees)	Force, N	Deflection, (micron)
Initial Design	165.15	0.00145^0	2500	20.35
Modified design	106.82	0.000124^0	2500	16.95
Optimized design	71.40	0.000093^0	2500	8.00

Conclusion: shows, how the distance between the shear center and centroid varies as the material is added or removed from the existing design. 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
The results of table 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 figure 6 . The minimization of angle of twist indicates that the tool point rigidity is increased.

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