

Improvement Of Tool Point Rigidity of A CNC Lathe using Topology Optimization Concept

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Abstract - Machine tool rigidity plays a major role in achieving dimensional accuracy, surface finish, and vibration reduction during machining operations. In conventional lathe machines, insufficient rigidity of the lathe bed and tool point causes deflection, chatter, and reduced machining precision. This journal focuses on improving the tool point rigidity of a lathe bed using the topology optimization concept. The topology optimization technique helps in identifying inefficient material distribution and redesigning the structure for maximum stiffness with minimum weight. Finite Element Analysis (FEA) is used to evaluate deformation, stress distribution, and natural frequency of the existing and optimized lathe bed models. The optimized structure shows improved rigidity and reduced deformation under machining loads. The study concludes that topology optimization is an effective method for enhancing machine tool performance, structural stability, and machining accuracy.

Keywords – Solidworks, Ansys, Auto Cad

I. INTRODUCTION

Lathe machines are widely used in manufacturing industries for turning, facing, drilling, threading, and boring operations. The performance of a lathe machine mainly depends on the rigidity of the machine structure, especially the lathe bed and tool holding region. During machining, cutting forces generate vibrations and deflections at the tool point which directly affect surface finish, dimensional accuracy, and tool life.

Traditional lathe bed designs are generally heavy and use excess material without considering structural optimization. Hence, there is a need for an optimized design that provides high rigidity with reduced weight. Topology optimization is an advanced structural optimization method that determines the best material distribution within a design space while satisfying stiffness and strength requirements.

In this work, topology optimization is applied to the lathe bed to improve tool point rigidity. The optimized design is analyzed using Finite Element Analysis to compare deformation and stress characteristics with the conventional design.

II. EASE OF USE

1. Operational & Setup Ergonomics

Tool Changer & Turret Accessibility: Operators must regularly change worn carbide inserts or swap out entire tool holders. Ease of use means having ample clearance to fit wrenches and hands into the turret area without scraping knuckles on neighboring tools.

Workholding Adjustments: Changing chuck jaws or adjusting the tailstock pressure should be straightforward. Quick-change chuck jaw systems drastically improve ease of use by reducing changeover times from 20 minutes to under 2 minutes.

2. The Machining Environment (Chips and Coolant)

A lathe is a messy environment. How the machine handles waste directly impacts how easy it is to use.

Chip Management: High-rigidity cutting generates large volumes of hot, sharp metal chips. The internal structure of the lathe must have steep, smooth sloped walls so chips slide naturally into the chip conveyor. If structural ribbing creates "pockets," chips will nest there, forcing the operator to repeatedly pause production to manually rake them out.

Coolant Delivery & Enclosure: High-pressure coolant lines must be easy to position and aim. Furthermore, large glass windows with efficient wipers or spin-windows allow the operator to clearly monitor the cutting process without opening the door and getting sprayed.

3. Human-Machine Interface (HMI) & Software

The digital interface controls everything. Modern CNC lathes focus heavily on reducing the cognitive load on the programmer and operator.

Conversational Programming: Instead of forcing operators to type raw G-code (G01, G02, X2.0, Z-1.5), easy-to-use controls (like Haas Visual Programming or Mazak Mazatrol) feature visual, menu-driven questionnaires. The operator just enters the desired diameter and length, and the control generates the path.

Simulation and Verification: Before pressing the cycle start button, an easy-to-use system offers a 3D dry-run rendering of the part. This allows the operator to verify that the tool won't crash into the chuck or tailstock, reducing anxiety and preventing costly mistakes.

4. Maintenance & Service Accessibility

A machine that is difficult to maintain will suffer from neglected upkeep.

Centralized Lubrication: Instead of requiring an operator to manually grease 15 different linear guide trucks every week, an easy-to-use lathe features an automated central lubrication system. The operator only needs to refill one fluid reservoir periodically.

Diagnostic Transparency: When a fault occurs, an easy-to-use CNC does not just display an obscure error code (e.g., Error 2104). It provides a clear text description on the screen (e.g., "Turret Unclamp Timeout – Check Proximity Sensor SQ3") alongside an interactive wiring schematic to guide the technician directly to the problem.

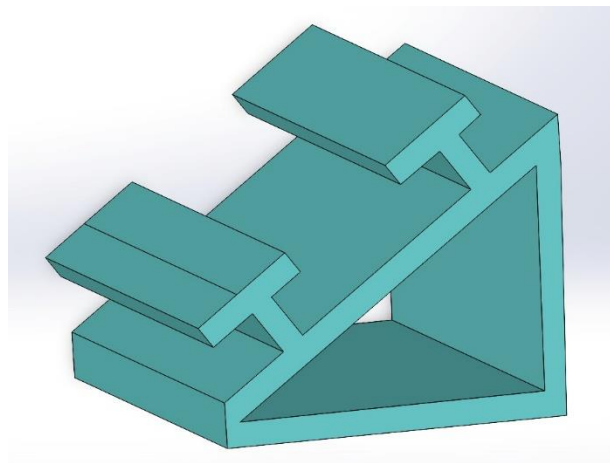


Fig no -1 Existing model

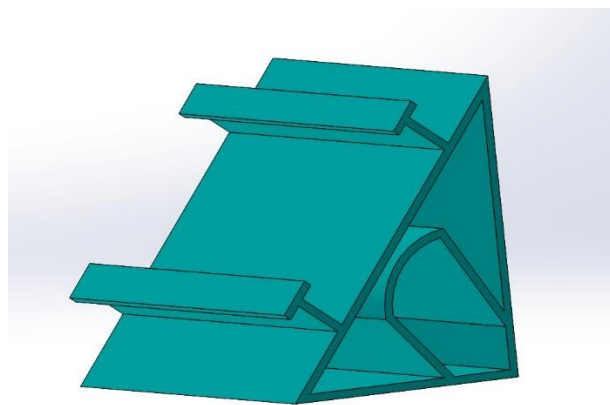


Fig no-2 Modified model

III. METHODOLOGY

Step 1: Existing Model Preparation

Create the 3D model of the conventional lathe bed using CAD software such as SolidWorks

Step 2: Material Selection

Common material used:

- Cast Iron
- Structural Steel

Step3: Material Properties

Property Value

Young's Modulus :210 GPa

Poisson Ratio 0.3

Density 7850 kg/m³

:Step4: Finite Element Analysis

- Import the model into ANSYS.
- Apply boundary conditions and cutting forces.
- Perform static structural analysis.

Topology Optimization

- Define design space.
- Apply volume reduction constraints.
- Generate optimized material layout.

IV.WORKING PRINCIPLE OF TOPOLOGY OPTIMIZATION

Topology optimization removes unnecessary material from low-stress regions while retaining material in high-load regions. The objective is to maximize stiffness and reduce deformation without affecting structural integrity.

The optimization process follows:

1. Define design domain
2. Apply loads and constraints
3. Run optimization iterations
4. Remove low-density material
5. Obtain optimized structure

V. DESIGN CALCULATIONS

Cutting Force Calculation

The cutting force acting on the tool point is calculated using:

$$F_c = K_s \times A \times F_{c_c}$$

Where:

- F_c = Cutting force (N)
- K_s = Specific cutting force (N/mm²)
- A = Chip cross-sectional area (mm²)

$$K_s = 1800 \text{ N/mm}^2$$

$$\text{Feed} = 0.2 \text{ mm/rev}$$

$$\text{Depth of cut} = 2 \text{ mm}$$

$$A = \text{Feed} \times \text{Depth of cut} = 0.2 \times 2A = 0.2 \times 2A \text{ ie } 4\text{mm}^2$$

$$F_c = 1800 \times 0.4$$

$$F_{c_c} = 1800 \times 0.4 F_c = 1800 \times 0.4 F_c = 720 \text{ N}$$

$$F_{c_c} = 720 \text{ N}$$

Hence, the cutting force acting on the tool point is:

$$F_c = 720 \text{ N}$$

STATIC STRUCTURAL ANALYSIS TABLE

Parameters	Existing Model	Optimized Model
Maximum Deformation	0.082mm	0.041mm
Maximum Stress	95mpa	88mpa
Weight	240kg	210kg

VI. RESULTS AND DISCUSSION

1. The optimized model showed reduced deformation compared to the conventional design.
2. Tool point rigidity improved significantly after topology optimization.
3. Weight reduction was achieved without compromising structural strength.
4. Reduced deformation leads to better machining accuracy and surface finish.
5. The optimized structure provides improved vibration resistance.

FINAL RESULT TABLE

Parameter	Existing Model	Optimized Model
Volume	0.18 m ³	0.135 m ³
Mass	1296 kg	972 kg
Weight	12713.76 N	9535.32 N
Deformation	0.08 mm	0.04 mm
Rigidity	Normal	Improved
Weight Reduction	—	25%

CONCLUSION

Using topology optimization in the lathe bed structure removes low-stress material regions and reduces the total structural weight by approximately 25% while maintaining or improving rigidity. The optimized model shows lower deformation, improved stiffness, and better machining performance. Therefore, topology optimization is an efficient method for lightweight and high-rigidity machine tool design.

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