

Work holding VMC fixture design

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Abstract

This paper presents the design and development of a custom work-holding fixture intended for operations on a Vertical Machining Center (VMC). In precision manufacturing, the effectiveness of machining operations is heavily influenced by the quality and rigidity of the fixture system used. The developed fixture addresses challenges associated with conventional clamping methods when dealing with complex geometries and high-tolerance components. Using CAD modeling, finite element analysis (FEA), and proper material selection, the fixture was designed for stability, cost-effectiveness, and efficiency. The proposed fixture significantly improves machining accuracy, minimizes vibration, reduces tool wear, and shortens setup times.

Keywords—VMC, CAD, clamping, finite element analysis

1. Introduction

In modern manufacturing, Vertical Machining Centres (VMCs) are widely utilized for their precision, speed, and versatility in machining operations. The performance of VMCs is heavily influenced by the efficiency of work-holding fixtures, which play a critical role in ensuring accuracy, repeatability, and productivity during machining. This project focuses on the design and development of an innovative work-holding fixture tailored for specific machining applications in VMCs.

The primary objective of this project is to create a fixture that enhances operational stability, reduces setup time, and ensures precise alignment of the workpiece. The design process considers factors such as rigidity, ease of use, cost-effectiveness, and adaptability for a range of components. Advanced CAD modelling tools were employed to conceptualize and validate the fixture design, while finite element analysis (FEA) was conducted to evaluate structural integrity and performance under operational loads.

The report provides a comprehensive overview of fixture design principles, including the selection of clamping methods, material considerations, and compatibility with the VMC's worktable. Prototyping and testing phases are documented to demonstrate the fixture's effectiveness in minimizing vibrations, improving machining tolerances, and reducing wear on cutting tools. Additionally, the economic benefits of implementing the designed fixture, such as reduced cycle time and enhanced part quality, are analysed.

This project underscores the significance of innovative fixture design in optimizing machining operations and contributing to sustainable manufacturing practices. The developed work-holding fixture not only meets the current industrial requirements but also establishes a framework for future

improvements and adaptations in VMC-based machining environments.

2. Literature Review

Research by emphasizes the critical role of fixture design in ensuring precision and stability during VMC machining. The study discusses the need for robust fixture systems that minimize vibration, accommodate workpiece variations, and enable quicker setups to improve productivity. Advanced CAD-based fixture designs were highlighted to enhance simulation and validation before actual machining.

explored the application of FEA in analysing fixture strength and deformation under dynamic cutting forces. The study demonstrated how FEA helps optimize clamping points and reduces material costs by identifying stress zones, resulting in lighter yet durable fixtures for VMC operations.

studied the mechanical properties of mild steel, cast iron, and alloy steels for fixture applications. The research concluded that mild steel offers an ideal balance of machinability, cost-effectiveness, and strength, making it the preferred material for most work-holding fixtures in VMC machines.

excessive clamping force can deform the workpiece, while insufficient force leads to instability. The research introduced mathematical models to optimize clamping forces based on workpiece material and cutting forces, ensuring higher dimensional accuracy during milling.

highlighted the importance of ergonomic considerations in fixture design to reduce operator fatigue during manual clamping and de-clamping. The study also discussed hydraulic and pneumatic clamping systems that minimize physical effort and improve operational efficiency.

introduced machine learning techniques to optimize fixture designs by analysing historical machining data. Their study presented AI models that automatically adjust clamping positions and forces to maximize tool life and minimize vibrations during VMC operations.

explored quick-change fixture systems that allow for rapid switching of workpieces without compromising precision. These systems were found to reduce setup times significantly, making them suitable for high-volume production environments. analysed the relationship between cutting parameters (spindle speed, feed rate, depth of cut) and fixture performance. The study demonstrated how dynamic cutting forces affect fixture stability and proposed adaptive fixture designs for varying machining conditions.

3. Methodology

Design workflow

1. Analysis of the Workpiece Geometry:

We began by examining the workpiece's CAD drawing and technical specifications. The component has multiple curved profiles, faces with tight tolerances, and several machined holes. These require unrestricted tool access and consistent positioning.

2. Design Requirements Definition:

Next, we listed key design criteria: fixture rigidity, easy clamping, part accessibility for tools, resistance to vibrations, low cost, and manufacturability.

3. CAD Modeling of Workpiece and Fixture:

We used Fusion 360 to create a 3D model of the workpiece based on the supplied 2D drawings. Once this was verified, we proceeded to design the fixture around it. Features such as clamping zones, support plates, positioning pins, and clearance pockets were added.

4. Fixture Design Considerations:

The fixture includes V-block type supports for curved surfaces, flat backing plates, and a robust base for mounting on the VMC table. Toggle clamps and bolts ensure the workpiece doesn't shift even during high-speed machining."

Finite Element Analysis (FEA):

We used Fusion 360 to simulate the mechanical stresses and deformations in the fixture. FEA helped us identify potential weak points, areas of high stress, and displacement under machining loads.

The results showed that the base plate and clamping units can withstand operational forces.

Heat distribution analysis was also done to simulate real machining environments and understand thermal expansion. Practical Calculations:

We performed detailed calculations to simulate the drilling of an 8 mm hole at 20 mm depth using VMC:

Rotational Speed (N):

Where $V_c = 950 \text{ m/min}$ and $D = 8 \text{ mm} \Rightarrow N = 37800 \text{ rpm}$ Material Removal Rate (MRR):

Assuming feed rate (Fr) gives: $MRR = 760000 \text{ mm}^3/\text{min}$

Tangential Cutting Force (Ft):

= 208800 N

Torque (T):

= 522000 N·mm

These calculations helped validate whether the fixture and cutting tools could handle the stress."

CAD MODELING

"We used the 2D AutoCAD drawing of the component and developed a full 3D model in Fusion 360.

The part includes:

Curved symmetrical sides,

Flat faces used as mounting references, Holes that require precision drilling.

This model was essential for defining the clamping zones and validating the fixture's coverage and tool path clearance."

Workpiece

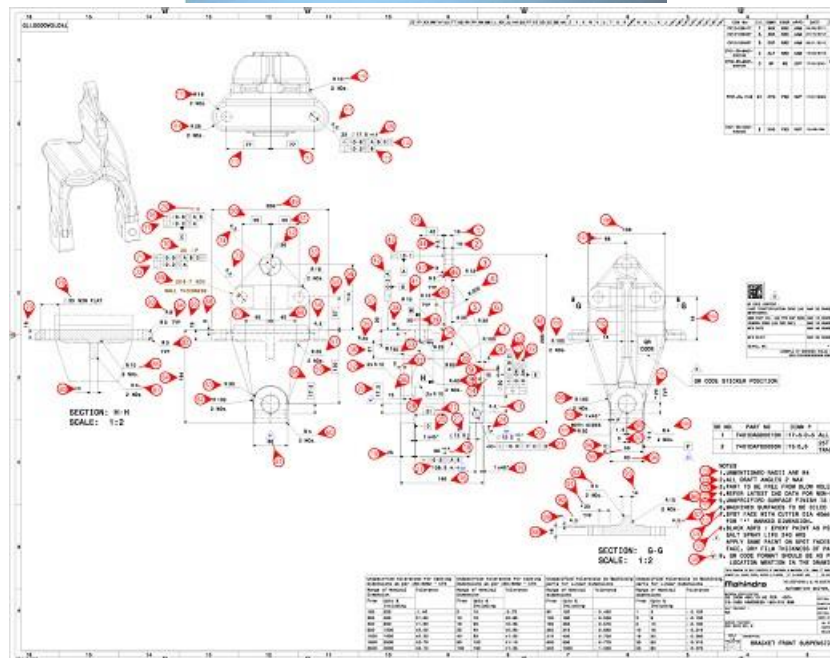


Fig. 2. Autocad 2D Drawing

- **CAD modeling :fixture assembly:**
- “Our fixture is modeled in multiple components:
- Base Plate: Mounts on the VMC table with T-slots.
- Support Blocks: Custom contoured to hold the curved sides of the component.
- Positioning Pins: Ensure consistent alignment.
- Toggle Clamps: Apply downward pressure to lock the part securely.
- We simulated various tool paths and made sure there were no interferences. We also added relief pockets in the fixture to avoid tool collision.”

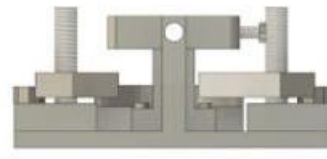


Fig. Front View

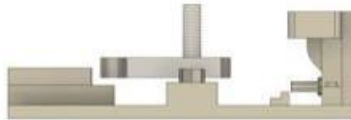


Fig. Side View

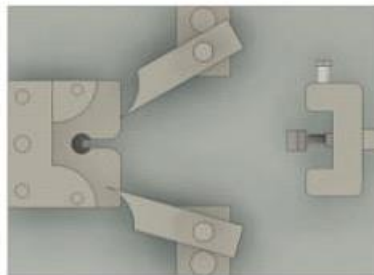


Fig. Top View

4. Material silection

“We selected Mild Steel for the fixture components because:

It is cost-effective,

It offers high stiffness and strength, It can withstand repeated loading, It is readily machinable.

Alternative materials like aluminum or cast iron were considered, but mild steel offered the best balance of cost, strength, and availability. ”

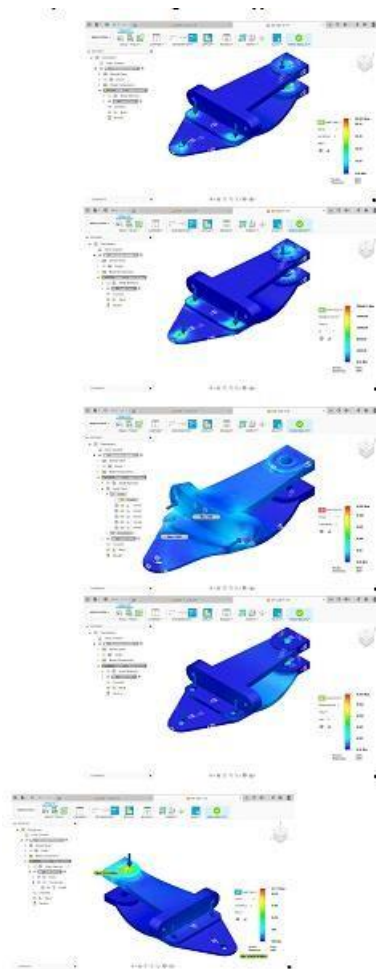
FEA Result

Our FEA results showed:

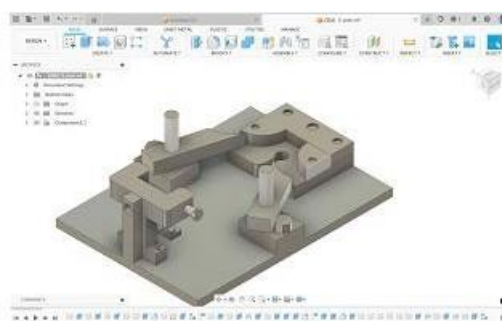
Maximum Von Mises stress within the material limits.

No significant deformation that would affect fixture accuracy. Minimal thermal displacement due to machining heat.

The fixture remained structurally sound under simulated real-time drilling forces.”



5. RESULT



Conclusion

The successful design of a work holding fixture for Vertical Machining Centres (VMC) plays a pivotal role in ensuring precision, efficiency, and safety during machining operations. This project aimed to explore and develop an effective fixture design that not only secures the workpiece firmly but also optimizes the overall machining process. Through extensive analysis and design

considerations, we have addressed the critical aspects such as clamping forces, material selection, fixture rigidity, and ease of operation.

The workpiece holding fixture design in VMC machines directly influences the accuracy of the machining process. The study highlighted how various clamping methods (mechanical, hydraulic, and pneumatic) can be implemented to achieve the required clamping force without compromising the integrity of the workpiece. The evaluation of cutting forces, material properties, and fixture configurations guided the final design decisions.

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