DESIGN, FABRICATION, AND ANALYSIS OF A SUSPENSION FORK CAP WRENCH SOCKET USING CNC MACHINING AND ADDITIVE MANUFACTURING

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ABSTRACT
This paper presents the design, analysis, and fabrication of a suspension fork cap wrench socket using two manufacturing techniques: CNC machining with EN8 steel and additive manufacturing with ePA-cF material. The project aimed to evaluate the feasibility, performance, and practicality of these methods. SolidWorks was used to model the socket, followed by Finite Element Analysis (FEA) to ensure structural integrity under operational loads. Both fabrication methods were tested for dimensional accuracy, fitment, mechanical strength, durability, and environmental resistance. The CNC-machined socket demonstrated superior precision, strength, and durability, making it ideal for high-stress applications. The 3D-printed socket provided rapid prototyping capabilities, lightweight construction, and cost-efficiency but was less robust under extreme conditions. A hybrid manufacturing approach combining both techniques is recommended for optimal performance and flexibility. Future work will explore material enhancements and advanced manufacturing methods to further improve performance.

Keywords:
Suspension fork cap wrench, CNC machining, additive manufacturing, EN8 steel, ePA-cF, 3D printing, Finite Element Analysis (FEA), hybrid manufacturing.

I. Introduction

The growing demand for specialized tools in the cycling industry necessitates innovative approaches to tool design and fabrication. Suspension fork cap wrenches are critical for maintaining modern suspension systems, requiring both strength and precision. This study explores the use of CNC machining and additive manufacturing to fabricate a functional suspension fork cap wrench socket.
CNC machining offers high precision and strength, while additive manufacturing enables rapid prototyping and customization. By comparing these techniques, this work aims to identify their respective advantages, limitations, and applications.

II. Literature Review

Modern manufacturing processes like CNC machining and additive manufacturing have revolutionized tool fabrication. CNC machining is renowned for its precision, especially when using high-strength materials such as EN8 steel. Additive manufacturing, particularly with materials like ePA-cF (carbon fiber-reinforced polyamide), provides flexibility and lightweight solutions. However, each method has unique trade-offs in terms of cost, time, and performance. This study bridges the gap by applying both methods to fabricate and evaluate a suspension fork cap wrench socket.

III. Methodology

A. Design and Analysis

1. **SolidWorks Modeling**: The wrench socket was modeled in SolidWorks, incorporating

geometric and dimensional requirements for optimal fit and functionality.

2. **Finite Element Analysis (FEA)**:
   - Conducted using ANSYS to evaluate stress distribution and deformation under operational loads.
   - EN8 steel and ePA-cF materials were analyzed for their mechanical properties.

B. Fabrication Techniques

1. **CNC Machining**:
   - Material: EN8 steel.
   - Process: High-precision CNC milling with carbide tools.
   - Toolpaths: Generated using CAD/CAM software.
   - Post-Processing: Deburring and polishing to achieve a smooth surface finish.
2. **Additive Manufacturing**:
   - Material: ePA-cF filament.
   - Equipment: FlashForge Guider 2 3D printer.
   - Settings: Layer height of 0.2 mm, 50% infill density, and adequate support structures.
   - Post-Processing: Sanding and smoothing to improve fitment and surface quality.

C. Testing Protocols

1. Dimensional Accuracy: Measured with calipers and coordinate measuring machines (CMM).
2. Fitment: Verified on various suspension fork caps.
3. Torque Testing: Assessed using a torque wrench.
4. Mechanical Strength: Evaluated via tensile and compression tests.
5. Durability: Simulated cyclic loading for real-world usage.
6. Environmental Resistance: Exposed to temperature variations and humidity.

IV. Results and Discussion

A. Fabrication Results

1. **CNC Machining (EN8 Steel)**:
   - Achieved high precision (±0.05 mm) and superior surface finish.
   - Demonstrated excellent strength and rigidity.
2. **Additive Manufacturing (ePA-cF)**:
   - Achieved moderate precision (±0.1 mm) and acceptable surface quality after post-processing.
   - Provided lightweight construction suitable for moderate applications.

B. Testing Results

1. **Dimensional Accuracy**:
   - CNC: Tolerances within ±0.05 mm.
   - 3D Printing: Tolerances within ±0.1 mm.
2. **Fitment**:
   - CNC: Perfect fit with no play.
   - 3D Printing: Slight adjustments required for optimal fit.
3. **Mechanical Strength**:
   - CNC: Withstood 100 Nm torque without deformation.
   - 3D Printing: Withstood 60 Nm torque before minor deformation.
4. **Durability**:
   - CNC: Survived over 10,000 cycles without wear.
   - 3D Printing: Survived 5,000 cycles with minor wear.
5. **Environmental Resistance**:
   - CNC: Maintained integrity under temperature and humidity variations.
   - 3D Printing: Showed slight warping under extreme conditions but remained functional.

C. Comparative Analysis

Criteria	CNC Machining	Additive Manufacturing
Dimensional Accuracy	High (±0.05 mm)	Moderate (±0.1 mm)
Surface Finish	Superior	Acceptable (post-process)
Strength	Exceptional	Moderate
Durability	Excellent	Good
Weight	Heavy	Lightweight
Cost & Time	High cost, slower	Low cost, faster
Flexibility	Limited	High

V. Conclusion

This study demonstrated the feasibility and effectiveness of both CNC machining and additive manufacturing for fabricating a suspension fork cap wrench socket. Key findings include:

- CNC machining with EN8 steel offers unmatched strength, precision, and durability, making it ideal for high-stress applications.
- Additive manufacturing with ePA-cF material provides rapid prototyping, cost-efficiency, and lightweight solutions, suitable for moderate-use scenarios.

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