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Stress-Strain and Lightweight Analysis of Cold Header Supports and Connecting Rods

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Abstract

This study employs the finite element analysis method to thoroughly investigate the stress-strain performance of cold header supports under different reinforcement rib lengths. Through a comparative analysis of simulation results with varying reinforcement rib lengths, it is found that as the rib length increases, the stiffness of the support is significantly enhanced, resulting in a substantial reduction in the maximum deformation and stress levels at the top. Specifically, when the reinforcement rib length is set to 140mm, the stress-strain performance of the support reaches its optimal state, effectively ensuring the stable operation of the cold header under high-speed and high-precision working conditions. Furthermore, for cases where the strength of the support is limited or cannot be changed, this study explores lightweight design strategies for the connecting rod of the cold header. While ensuring the structural strength of the connecting rod, a significant reduction in its mass is achieved through optimized design and material selection. Finite element analysis results show that the lightweight design effectively reduces the maximum stress concentration area of the connecting rod, significantly decreasing the potential risk of fatigue failure, thus extending its service life and improving its reliability. This study not only provides important references for the optimized design of cold header supports, but also offers new ideas and methods for the lightweight design of cold header connecting rods. These research outcomes are of great significance for enhancing the overall performance and stability of cold headers.

Keywords

Cold Header Support; Finite Element Analysis; Reinforcement Rib Length; Stress-Strain; Lightweight Design.

1. Introduction

The nut cold forging machine is a specialized mechanical device that manufactures nuts using the cold forging process. Its working principle is based on the plastic deformation characteristics of metal materials, where metal wire is gradually extruded, cut, and formed through precise mold design and mechanical actions at room temperature to produce standard-compliant nut products[1].

The structure of the nut cold forging machine typically includes feeding, cutting, forming, ejection mechanisms, and a control system, all working together to ensure a smooth production process. Among these, the internal support bracket is a key component, supporting and fixing other parts, bearing forces and vibrations from various directions, and ensuring stability and precision during high-speed operation. Therefore, the design and optimization of the internal support bracket are crucial for enhancing the overall performance of the nut cold forging machine[2].

The strength of the cold forging machine bracket refers to its ability to withstand external loads without breaking or undergoing excessive deformation. During operation, the bracket must bear forces and vibrations from various directions, including the impact force of the metal billet, the extrusion force of the mold, and vibrations generated during machine operation. Hence, the strength of the bracket is vital for ensuring stable operation and extending the service life of the cold forging machine. Specifically, bracket strength is influenced by several factors, including material strength, geometric shape, and manufacturing processes[3]. High-strength materials, such as alloy-added ductile iron, with high tensile strength and wear resistance, can be used to enhance bracket strength. Additionally, optimizing the geometric shape and structural design of the bracket, such as using rib reinforcement, can effectively increase its load-bearing capacity. When the load capacity is high, lightweight design of the cold forging machine can achieve optimal results[4].

With the continuous development of industrial technology, lightweight design has become an important trend in modern mechanical design. Lightweight design aims to reduce the weight of mechanical equipment while maintaining or enhancing its performance through optimizing material selection, structural design, and manufacturing processes. In the design of nut cold forging machines, lightweight design is significant. Firstly, it improves the dynamic performance of the machine by reducing its weight, lowering inertial forces, and enhancing dynamic response speed and processing precision[5]. Under high-speed operating conditions, lightweight design ensures more stable and reliable operation of the cold forging machine. Secondly, it helps reduce production costs by optimizing material usage and structural layout, reducing unnecessary material consumption and processing time. Furthermore, lightweight design reduces energy consumption and transportation costs, improving economic efficiency. Finally, it facilitates green production by reducing material consumption and energy usage, aligning with sustainable development principles.

The connecting rod, as an important transmission component in nut cold forging machines, bears forces and vibrations from multiple directions. Its performance directly affects the stability and processing precision of the machine. Therefore, lightweight design of the connecting rod is crucial. This can be achieved through optimizing material selection, cross-sectional shape design, and structural layout. High-strength, lightweight materials can reduce the weight of the connecting rod while maintaining its strength and rigidity. Rational cross-sectional design can reduce weight without compromising strength and rigidity. Structural layout optimization can minimize vibrations and impacts during operation, enhancing its service life and stability[6].

In the process of lightweight design of the connecting rod, advanced techniques like finite element analysis play a vital role. Finite element analysis allows for precise stress analysis and structural optimization of the connecting rod. Based on analysis results, targeted optimization of material, cross-sectional shape, and structural layout can be performed, achieving lightweight design. This method not only enhances performance and stability but also reduces production costs and energy consumption, promoting green production. In summary, the structural principles, significance of lightweight design, and the critical role of connecting rod lightweight design constitute key aspects of modern nut cold forging machine design[7]. Continuous design optimization and technological innovation can further improve the performance and production efficiency of nut cold forging machines, contributing significantly to the development of modern industry.

2. Physical Model and Numerical Simulation Method

2.1 Determination of the Physical Model

As a core structural component, the performance of the cold forging machine bracket directly relates to the overall stability and operational efficiency of the machine. From a strength perspective, the bracket must withstand various loads from the cold forging process, including the impact force of metal materials and the extrusion force of the mold, without structural failure or significant deformation. Therefore, material selection and design of the bracket must consider its tensile and impact strength, ensuring stability in high-strength working environments. In terms of rigidity, the bracket's resistance to deformation is critical for machining precision and product quality. Insufficient rigidity can affect positioning accuracy and machining stability, reducing product quality. Hence, the

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design should focus on its geometric shape and elastic modulus, enhancing rigidity through optimized structural layout and high-elastic modulus materials, ensuring stable operation under high-speed, high-precision conditions. Careful material selection and design optimization are necessary to ensure sufficient strength and rigidity for efficient, stable operation of the cold forging machine, as shown in Figure 1.

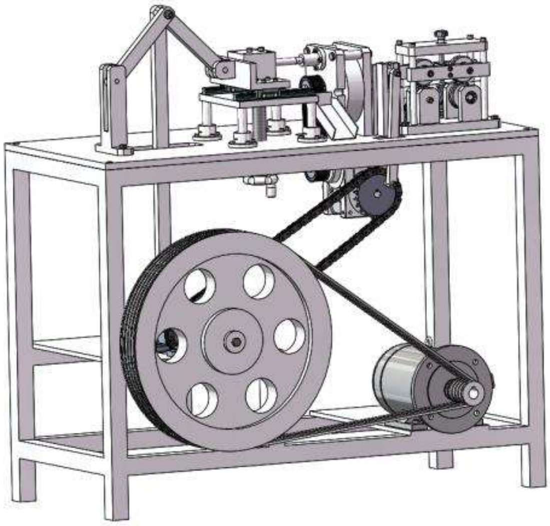

Figure 1. Cold heading machine and its support structure

2.2 Model Establishment for Cold Forging Machine Bracket

(1) Solid Model and Mesh Generation

Firstly, mesh generation for the static finite element model of the bearing seat is conducted, with settings for the mesh. High-quality mesh Jacobian points are set at 16 points, with cell size at 2mm, tolerance at 0.1mm, total node count at 96438, total cell count at 64221, and maximum aspect ratio at 13.656. The aspect ratio < 3 is 99.6%, and the aspect ratio > 10 is 0.00623, as shown in Figure 2.

Figure 2. Mesh Generation of Finite Element Model

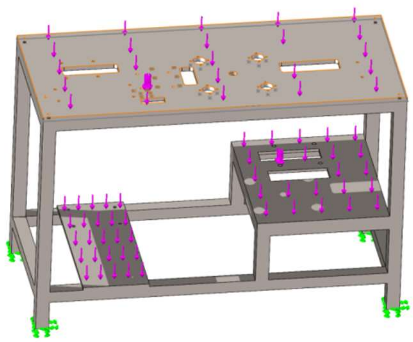

Figure 3. Applied Constraints and Loads

(2) Loads and Constraints

For static analysis of the bracket environment, fixed constraints are applied to its four bottom supports. Vertical loads of 1500N, 300N, and 200N are uniformly applied at the top, middle, and bottom, respectively, as shown in Figure 3. The material of the bracket is defined as AISI1045 steel, with properties shown in Table 1.

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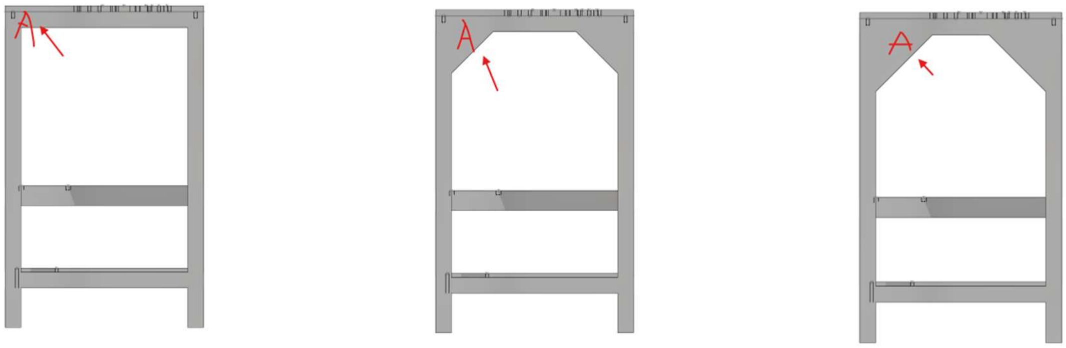
Table 1. Material Properties

Part	Name	Properties
bracket	Material:	AISI 1035 Steel (SS)
	Model Type:	Linear Elastic Isotropy
	Default Failure Criterion:	Maximum von Mises Stress
	Yield Strength:	282.685 N/mm^2
	Tensile Strength:	585 N/mm^2
	Elastic Modulus:	205,000 N/mm^2
	Poisson's Ratio:	0.29
	Density:	7.85 g/cm^3
	Shear Modulus:	80,000 N/mm^2
	Thermal Expansion Coefficient:	1.1e-05 /Kelvin

The 3D model of the bracket is imported, constraints are applied to the four bottom supports, and external forces are loaded as 1500N at the top, 300N at the middle, and 200N at the bottom. The design of ribs is shown in Figure 4.



(a) Rib Length 0mm; (b) Rib Length 105mm; (c) Rib Length 140mm

Figure 4. Rib Models with Different Sizes:

This simulation selects three representative rib sizes for analysis, with simulation conditions shown in Table 2.

Table 2. Simulation Conditions

Variable Name	Unit	Values
Rib Length A	mm	0, 105, 140
Applied Load	N	1500, 300, 200

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3. Experimental Results and Analysis

Finite element analysis of the cold forging machine bracket with rib length A = 0mm reveals a maximum top deformation of 0.048mm, indicating significant rigidity, with deformation controlled at a high level. The maximum stress is 6.284MPa, a relatively high level. Overall, the bracket shows poor stress-strain performance with zero rib length, requiring additional measures to enhance rigidity for structural safety.

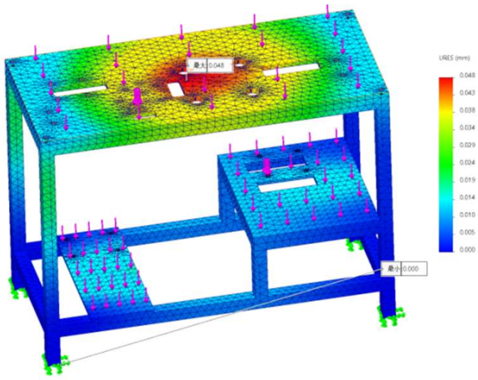

Figure 5. Displacement Analysis for 0mm Rib

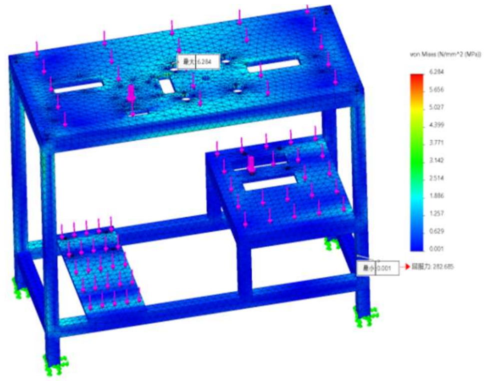

Figure 6. Stress Analysis for 0mm Rib

Finite element analysis of the bracket with rib length A = 105mm shows a maximum top deformation of 0.045mm, slightly reduced from the no-rib case (0.048mm), indicating improved rigidity. The maximum stress is 5.895MPa, lower than the no-rib case, further confirming the optimization effect of the ribs. Despite slightly higher top deformation, the overall stress-strain performance is improved.

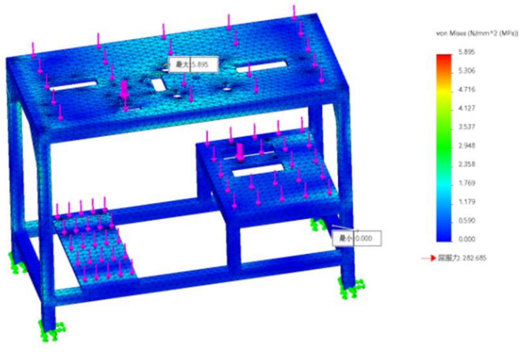

Figure 7. Displacement Analysis for 105mm Rib

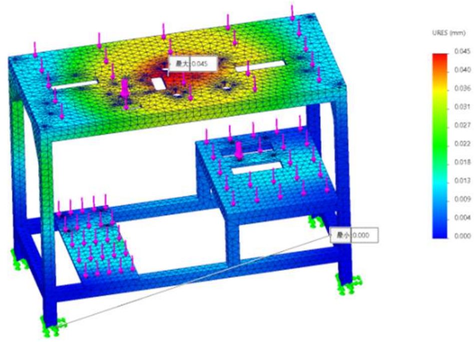

Figure 8. Stress Analysis for 105mm Rib

Finite element analysis of the bracket with rib length A = 140mm shows significant optimization. The maximum top deformation is reduced to 0.043mm, indicating significantly improved rigidity. The maximum stress is 5.710MPa, further reduced, indicating a higher safety margin under load. The stress-strain performance is optimal with a 140mm rib length, ensuring sufficient rigidity and structural stability for stable operation of the cold forging machine.

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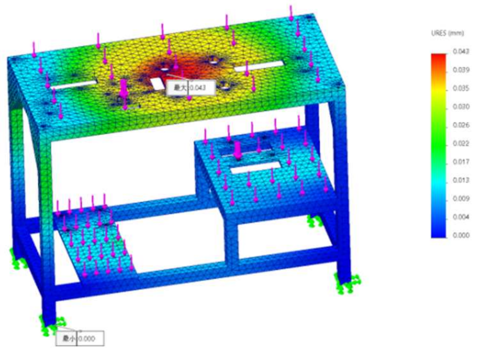

Figure 9. Displacement Analysis for 140mm Rib

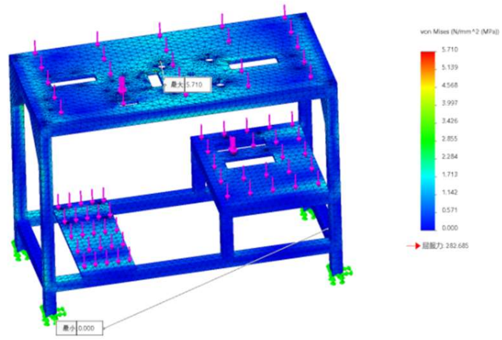

Figure 10. Stress Analysis for 140mm Rib

4. Lightweight Analysis

Using finite element analysis software, the effects of different design variables on bracket deformation were investigated. Results show that increasing rib length A reduces stress concentration by 0.574MPa and lowers end deformation by 0.005mm. In cases where bracket strength is limited or cannot be modified, lightweight design strategies for the cold forging machine and its components were proposed. Specifically, lightweight design of the cold forging machine connecting rod was studied. Ensuring structural strength, the mass of the connecting rod was significantly reduced. Finite element analysis revealed that lightweight design effectively reduces the maximum stress concentration area, reducing stress concentration and fatigue failure risk, thereby extending service life and enhancing reliability. In this study, lightweight design reduced the connecting rod mass from 1.086kg to 0.334kg, a weight reduction of nearly 70%, as shown in Figures 11 and 12.

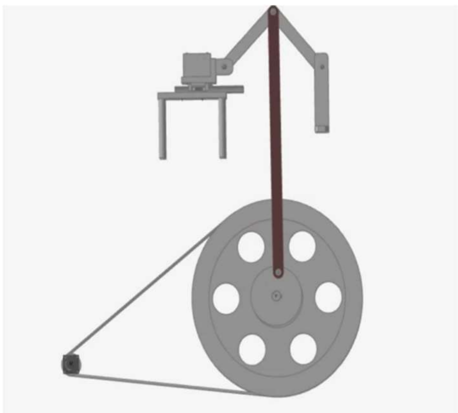

Figure 11. Pre-Optimization Connecting Rod Model

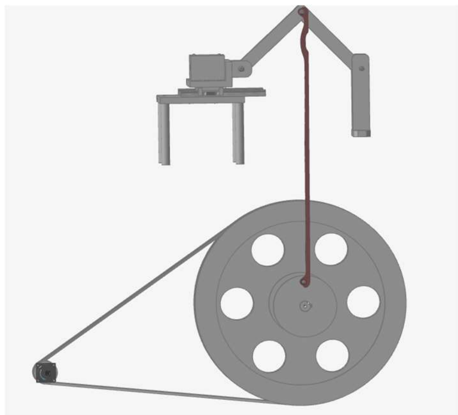

Figure 12. Post-Optimization ConnectingRod Model

5. Conclusion

This study deeply analyzes and optimizes the strength and rigidity of the cold forging machine bracket. As a core structural component, its performance significantly affects the overall stability and operational efficiency of the machine. Finite element analysis reveals poor stress-strain performance with zero rib length, characterized by large deformation and high stress levels. Increasing rib length optimizes bracket design, enhancing rigidity. Experimental results show significant improvements in rigidity and stress levels with increasing rib length, with optimal performance at 140mm. This optimization ensures stable high-speed, high-precision operation of the cold forging machine. Additionally, considering bracket strength limitations, lightweight design strategies, particularly for the connecting rod, were explored. Optimizing design and material selection achieved significant

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weight reduction while maintaining structural strength, extending service life, and improving reliability. These findings offer new insights and methods for improving the overall performance of cold forging machines.

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