

Original Article



Structural Design and Mechanical Simulation of PS-90-Y Hydraulic Disc Brake Device

Jingxi Lei^a, Qiang Wang^a, Haiwen Sun^d, Huan Li^b, Rui Su^b, Lijun Wang^b, Chao Liu^{c,d*}

^aChengdu Technological University, Sichuan, China

^bCNPC Baoji Oilfield Machinery CO., LTD, Baoji, China

^cCollege of Electromechanical Engineering, Qingdao University of Science & Technology, Qingdao, China

^dNational Engineering Research Center of Marine Geophysical Prospecting and Exploration and Development Equipment, China University of Petroleum (East China), Qingdao, China.

*Corresponding Author: Chao Liu

Abstract:

To improve the safety and reliability of mining operations for medium depth mine hoists, this paper designs a PS-90-Y hydraulic disc brake device and conducts in-depth research on its structure, and mechanical properties. Firstly, the basic structural composition and key parameters of the hydraulic disc brake system were elaborated, including core components such as working calipers, safety calipers, and hydraulic thrust cylinders. Based on the theory of braking dynamics, a mathematical model of the hydraulic disc brake system was established. The key parameters of the brake system, such as braking torque, positive pressure, and friction coefficient, were determined through theoretical calculations to ensure that the braking performance meets the high load requirements of the mine hoist. In terms of structural design, the overall optimization of the thrust hydraulic cylinder was emphasized to improve its load-bearing capacity and response speed. At the same time, mechanical simulations were conducted on key components such as working calipers, lever mechanisms, and brake discs to verify their structural strength, stiffness, and fatigue life under extreme working conditions, ensuring the reliability of system operation. The experimental and simulation results show that the designed PS-90-Y hydraulic disc brake device can achieve a maximum positive pressure of 90 KN on one side, fully meeting the high safety braking requirements of deep well drilling and mine hoisting. This study provides theoretical basis and engineering reference for the optimization design of the braking system of mine hoists, which is of great significance for improving the safety of mining operations.

Keywords: Hydraulic disc brake; Petroleum drilling machine; Brake system.

1 Introduction

The global surge in energy consumption has necessitated intensified exploration and exploitation of existing oil and gas reservoirs to meet escalating fuel demands. As drilling operations extend into deeper and more complex geological formations, the technical challenges associated with hydrocarbon extraction have grown exponentially. This paradigm shift

underscores the critical importance of advancing drilling technologies, particularly in enhancing the performance and reliability of core equipment such as braking systems. Modern drilling rigs, tasked with operating in extreme environments ranging from high-temperature deep wells to directional drilling applications, demand braking mechanisms capable of withstanding unprecedented mechanical stresses, thermal loads,

and dynamic operational conditions. Within this context, the evolution of braking systems from conventional band brakes to advanced disc brake configurations represents a pivotal technological leap in ensuring operational safety and efficiency.

Traditional band brakes, while historically prevalent in drilling operations, exhibit inherent limitations when deployed in contemporary high-load scenarios. Structural constraints manifest as insufficient braking torque, accelerated thermal degradation, and compromised reliability under cyclic loading – deficiencies that become particularly pronounced in deep-well and ultra-deep-well drilling exceeding 5,000 meters. These operational bottlenecks have catalyzed the adoption of disc brake systems, whose superior performance metrics derive from three fundamental advantages: 1) Redundant modular architecture enabling progressive torque distribution; 2) Enhanced thermal management through optimized heat dissipation pathways; 3) Precise controllability via integrated electro-hydraulic actuation. Empirical studies confirm that disc brakes demonstrate 30–40% greater heat dissipation efficiency and 25% higher mean time between failures compared to band brake counterparts in equivalent drilling conditions [5, 6]. Such performance differentials have established disc brakes as the *de facto* standard in modern drilling rigs, particularly for automated drilling systems requiring millimeter-level positioning accuracy during tool handling operations.

Since its introduction into the industrial field in the 1970s, disc brake technology has developed for decades and has become a high-performance braking solution centered around hydraulic drive and electronic control systems. In the process of brake design and optimization, the research focus includes: selecting materials for key components such as brake discs and brake pads based on material mechanics and thermodynamic properties [7,8]; By analyzing methods [9] and numerical simulations [10-12], and studying corrosion resistance and wear characteristics [13-14], the durability of the system can be improved. The parallel design of multiple brakes significantly improves system redundancy, while the hydraulic PLC collaborative control further optimizes dynamic response accuracy and adaptability to working conditions. Oilwell Corporation in the

United States was the first to combine disc brake energy management system with automatic drilling technology, promoting the innovation of winch braking technology; Norwegian MH company has achieved safe braking of a 2941 kW high-power electric winch through the application of water-cooled multi clamp disc brakes. These technological advancements provide important support for deep well drilling and automated drilling [15-17].

Although disc brakes have achieved significant results in the field of oil drilling, there is still room for optimization in their system structure design and key component strength analysis [18-21]. In order to improve the safety and reliability of hydraulic disc brakes, optimize control accuracy, and reduce production costs, it is urgent to use finite element analysis technology to conduct multi physics coupling simulation and lightweight design of their structure. Firstly, the high-precision manufacturing requirements for brake discs and calipers increase the complexity of the process, and extreme loads and thermal shocks in the drilling environment may cause material fatigue failure. Secondly, with the popularization of electro-hydraulic control technology, the light weighting, integration, and intelligence of braking systems have become new research directions, and there is an urgent need to verify the balance performance and spatial constraints through structural innovation and simulation. In addition, existing research mostly focuses on functional implementation, and lacks systematic exploration of the dynamic mechanical characteristics and life prediction of braking systems under multiple operating conditions.

- a) Based on the modular design concept, the overall architecture of the brake system is proposed, and the spatial layout of the hydraulic power unit and brake caliper body is optimized;
- b) Conduct static and thermo mechanical coupling simulations on the brake disc and caliper body through finite element analysis to verify the strength and stability of key components under extreme loads;
- c) Combining electro-hydraulic control logic, explore the dynamic adjustment strategy of braking torque. The research results aim to provide theoretical basis for the design of high

reliability disc brake systems and technical reference for the intelligent upgrade of deep well drilling equipment.

2 Structural Design of PS-90-Y Hydraulic Brake

2.1 Structural Design of PS-90-Y Hydraulic Brake

The braking system constitutes a critical safety component in modern winch design, whose reliability fundamentally determines operational safety. Insufficient braking torque represents a primary causative factor for winch overload and slippage incidents.



Fig.1 Oil drilling rig hoisting winch and brake mechanism

This study systematically analyzes four essential functional requirements for winch braking systems:

- a) Stationary braking capability: The system must provide reliable braking when the drilling rig enters complete standby status.
- b) Dynamic braking performance: The system should effectively participate in motion control during both deceleration phases and weightless conditions, functioning as service brakes.
- c) Emergency response: The system must enable rapid and satisfactory braking operations during contingency scenarios or accident situations.
- d) Dual-drum coordination: The system should facilitate locking of the lifting drum while releasing the fixed drum during horizontal position adjustments or cable length modifications.

The proposed brake actuator adopts a

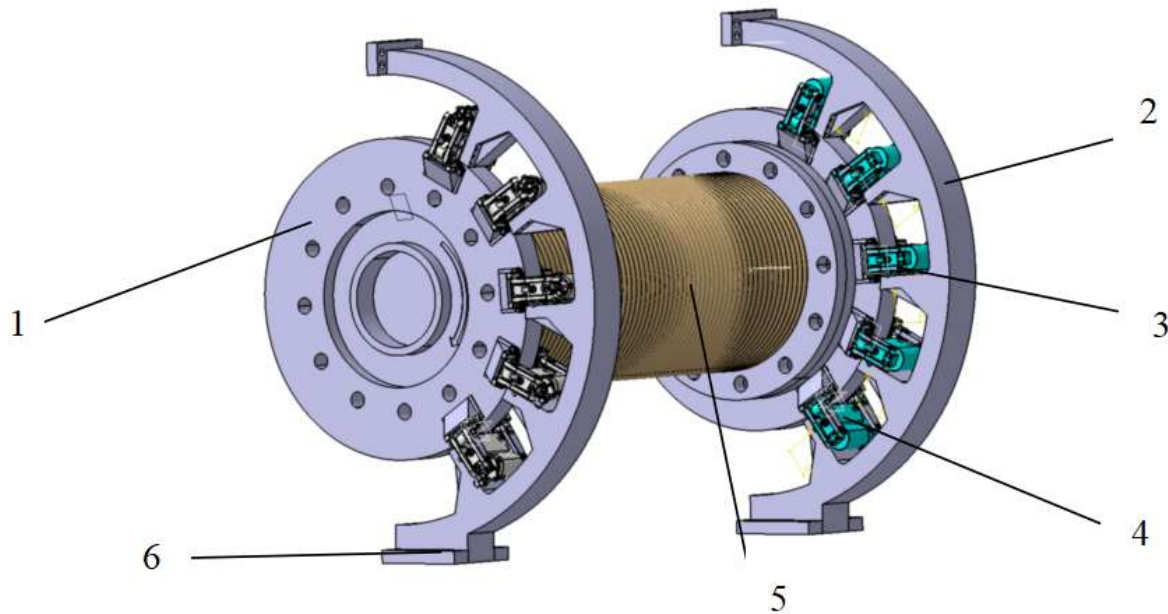
sophisticated yet efficient quad-component architecture comprising service calipers, safety calipers, brake discs, and caliper brackets. These components interact synergistically to achieve rapid activation and emergency braking under hydraulic system control. Key design innovation is a novel external caliper bracket configuration.

The braking actuator mechanism incorporates several critical design features to ensure optimal functionality. The drum and brake disc are integrally welded to maintain concentric rotation during operation. Both service and safety calipers are bolted to the caliper bracket, which serves as a structural foundation to precisely position these components relative to the brake disc. This configuration enables controlled engagement between the calipers and rotating disc when braking is required.

The drum assembly functions as the interface for wire rope connection, where rope movement directly drives drum rotation, consequently

transferring motion to the brake disc. During braking operations, simultaneous contact is established between the disc and both caliper units (service and safety). Additionally, the transition

plate provides essential structural anchoring by securing the entire actuator assembly to the mounting surface.



1- brake disc; 2- caliper holder; 3- safety caliper; 4- working caliper; 5- drum; 6- transition plate.

Fig.2 Hoisting winch and disc brake device

2.2 Design of Work Pliers

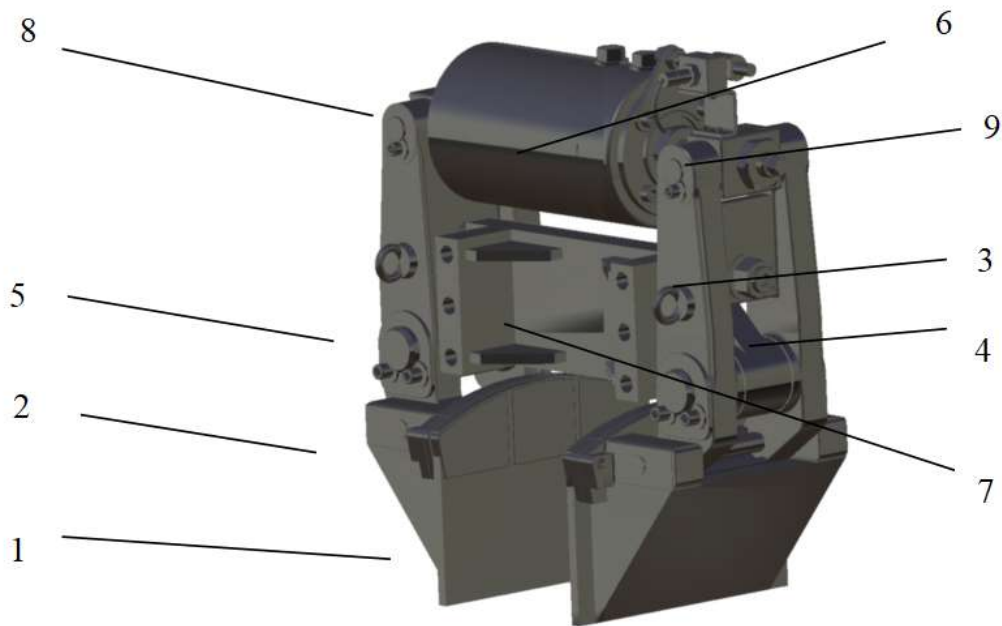
The brake pad serves as the primary friction element, while the caliper block functions as its structural support. The hydraulic cylinder assembly, consisting of the cylinder body and piston, forms the core actuation system.

As a vital component of hydraulic disc brakes, the service caliper plays a pivotal role in the braking system. Despite the predominant use of pusher-type brakes in most applications, the service caliper in disc brake systems undertakes significant braking responsibilities while enduring substantial mechanical stresses during operation. The service caliper assembly integrates multiple functional elements: a non-current open-type single-acting hydraulic cylinder, lever mechanism, spring-loaded return spring, brake pad, and brake disc.

The operational principle can be described as follows: During drill pipe braking, the service caliper of the traction mechanism is activated through the hydraulic system. The hydraulic

power unit supplies pressurized oil to the caliper's cylinder via hydraulic circuits. When the hydraulic pressure reaches a predetermined threshold, it generates theoretical thrust. This force acts upon the piston within the single-acting cylinder, which subsequently transfers the force to the lever mechanism. Simultaneously, the hydraulic pressure exerts a reaction force on the cylinder's rear end, causing the entire cylinder assembly to displace rearward.

As the brake pad approaches the disc, the hydraulic pressure is mechanically amplified through the lever system, creating normal force between the pad and disc. This normal force induces frictional resistance between the contacting surfaces, resulting in the service caliper's braking action. The braking force exhibits direct proportionality to the hydraulic pressure supplied by the power unit. When the system pressure attains the designated value, the brake disc enters a static braking condition. Notably, the braking force varies dynamically with changes in the hydraulic pressure input.



1- Brake pad; 2- Clamp body; 3- Pin shaft I; 4- Leverage; 5- Pin shaft II; 6- Cylinder end cover; 7- Support rod; 8- Hydraulic cylinder body; 9- Piston.

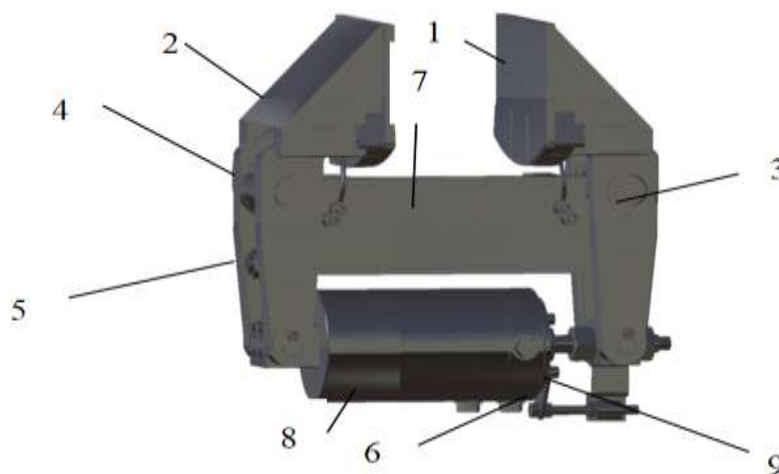
Fig.3 Overall structure of working pliers

2.3 Safety Clamp Design

The safety caliper, equally critical as the service caliper, constitutes an essential component of disc brake systems. While structurally similar to the service caliper in machining aspects, it differs primarily in its hydraulic cylinder configuration within the safety transmission mechanism. Operationally, the safety caliper activates under distinct conditions - primarily during parking or emergency braking scenarios, in accordance with the braking system's design specifications.

The safety caliper assembly incorporates several

key components: a normally closed single-acting cylinder with integrated disc springs, a lever mechanism, support rods, and brake linings. Its operational principle exhibits an inverse relationship to the service caliper: Under non-pressurized conditions, the disc spring's elastic force is transmitted via the lever to engage the brake lining with the disc, achieving braking action. When hydraulic pressure is applied, the increased oil pressure counteracts the disc spring's restoring force, causing spring compression through the lever mechanism and consequently releasing the brake.



1- Brake pad; 2- Clamp body ;3- Pin shaft I; 4- Leverage; 5- Pin shaft II; 6- Cylinder end cover; 7- Support rod; 8- Hydraulic cylinder body; 9- Piston.

Fig.4 Overall structure of safety clamp

2.4 Brake Disc Design

The brake pads establish essential frictional contact surfaces within the disc brake assembly, with winches typically employing dual disc brake units mounted at separate locations. Three distinct brake disc cooling variants exist in practice. Air-cooled discs incorporate specialized ventilation channels designed to promote heat dissipation through natural convective airflow, where thermal energy transfers primarily through surface evaporation from the disc faces. Water-cooled versions feature an integrated closed-loop cooling system with internally machined fluid channels, having inlet and outlet ports strategically positioned at the disc's inner diameter while including drainage ports to prevent fluid accumulation and potential freezing in low-

temperature conditions. These discs maintain sealed outer diameter pressure ports during standard operation but activate emergency coolant circulation when detecting disc seizure, structural fractures, or excessive frictional heat generation. Solid disc variants find principal application in industrial machinery and compact oil drilling rigs where thermal management demands are less critical, offering simplified construction at the expense of cooling capacity. The selection between these cooling methodologies involves careful consideration of thermal dissipation requirements, structural durability under thermal loading, failsafe mechanism reliability, and operational environment constraints, with each configuration presenting distinct advantages tailored to specific application scenarios.

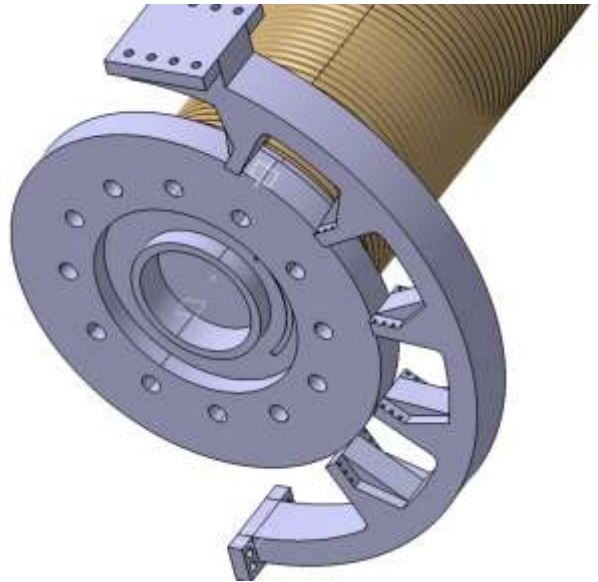


Fig.5 Three dimensional design of brake disc

2.5 Clamp Frame Design

The caliper bracket serves as the fundamental structural foundation for disc brake mechanisms, providing critical positional stability and load-bearing capacity for the entire actuation system. As a core component of the braking assembly, each brake system typically incorporates a pair of symmetrically arranged caliper brackets that are rigidly mounted on the winch base frame. These dual brackets are strategically positioned at the

frontal region of the drum assembly, ensuring balanced force distribution during braking operations.

As illustrated in Fig.5, the three-dimensional representation demonstrates the bracket's optimized geometry, which has been developed to satisfy these operational demands while minimizing weight and maximizing structural integrity.

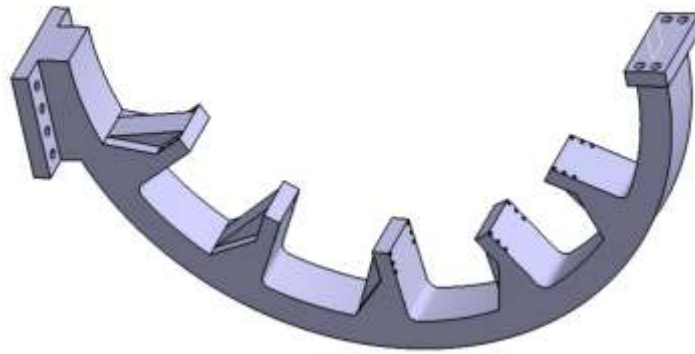


Fig.6 Clamp Frame Design

2.6 Shaft Design

The pin shaft constitutes the most critical load-bearing component in disc brake systems, serving as the fundamental force-transfer element for both service and safety caliper assemblies. Given its paramount importance in ensuring braking reliability, comprehensive strength verification through analytical calculations and numerical simulations is imperative prior to manufacturing.

Mechanical Load Analysis: The pivot shaft primarily sustains radial forces during operation, resulting in significant internal bending moments. These bending moments induce corresponding bending stresses along the shaft's cross-section. Through rigorous mechanical analysis, the maximum bending normal stress must satisfy the strength criterion: $\sigma_{\max} \leq 300 \text{ MPa}$, which represents the design safety threshold for this application.

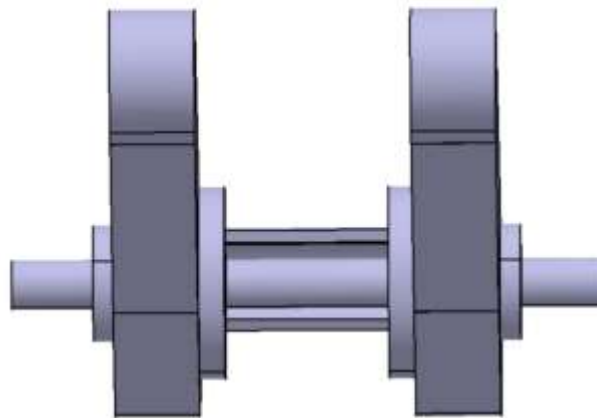


Fig.7 Shaft design

3 Finite Element Simulation Analysis of PS-90-Y Hydraulic Brake

3.1 Axis Pin Simulation Experiment

The stress-strain characteristics of the pivot shaft were numerically investigated through finite element analysis employing ANSYS software, wherein the computational model was established by implementing a refined meshing strategy with localized mesh density enhancement in regions anticipated to experience elevated stress

concentrations or structural vulnerabilities. Following the application of appropriate boundary conditions including fixed constraints and operational loading scenarios, the resultant stress and strain distributions were obtained and visualized in Fig.8 and Fig.9 respectively, revealing significant mechanical behavior trends across the component.

The analysis demonstrated a distinct stress gradient distribution, with minimum stress levels occurring at the brake pad contact interface and

progressively increasing towards the ribbed reinforcement section. Corresponding deformation analysis revealed maximum displacements in the

unsupported distal regions, with intermediate deformation near the ribbed sections and minimal displacement at the centrally constrained area.

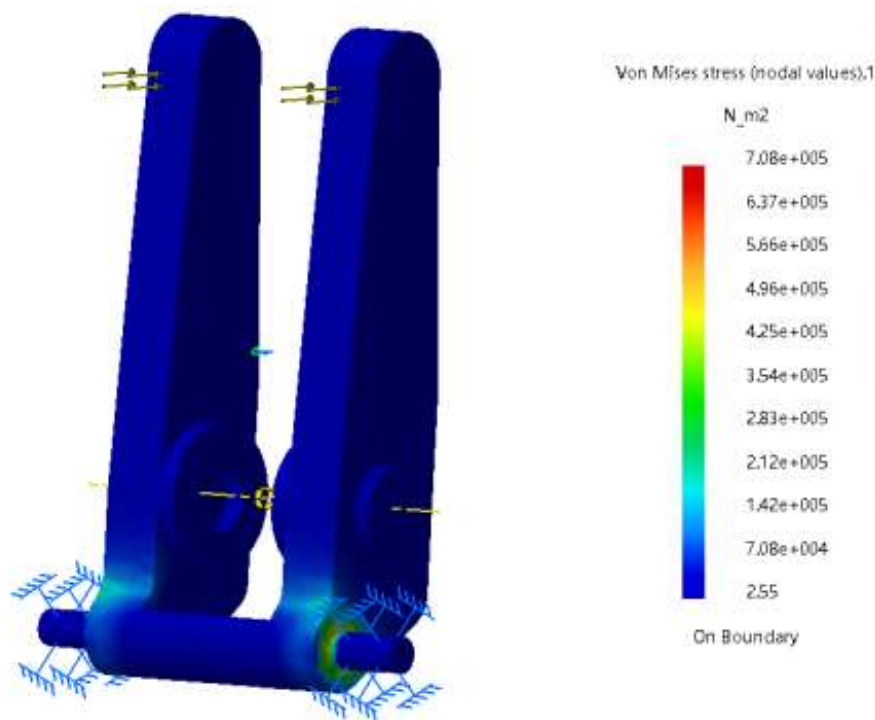


Fig.8 Stress cloud map

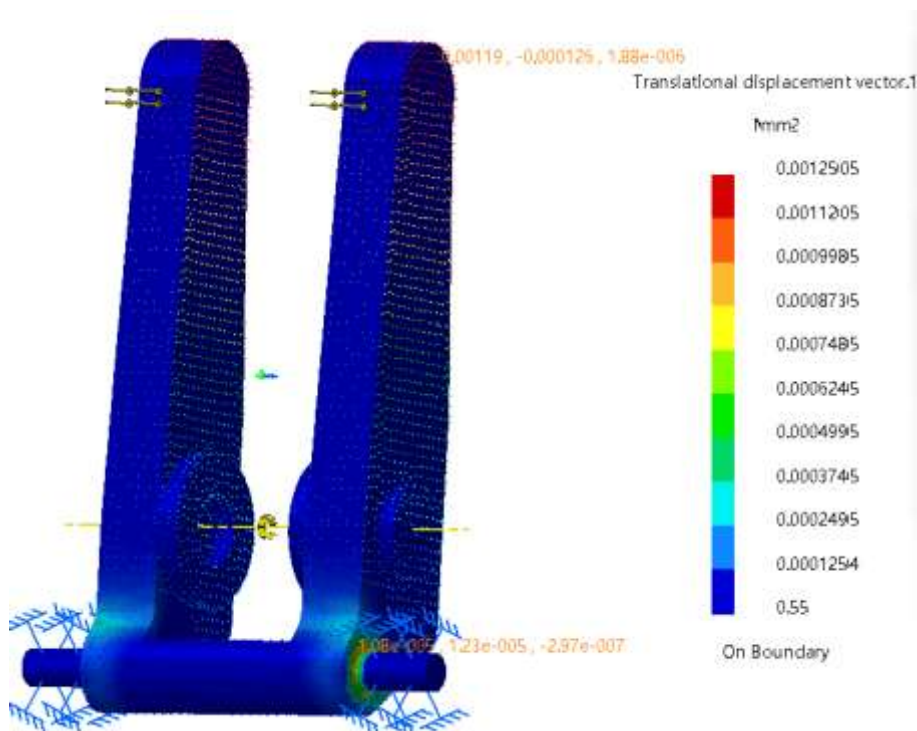


Fig.9 Stress deformation diagram

3.2 Brake disc simulation experiment

A comprehensive finite element analysis was conducted using ANSYS to evaluate the

mechanical behavior of the brake disc under operational loading conditions. The computational model was established through a refined meshing strategy, with localized mesh density

enhancement applied to regions anticipated to experience elevated stress concentrations or structural vulnerabilities, as illustrated in the discretized mesh configuration presented. Following the application of appropriate boundary conditions, including fixed constraints and simulated braking forces, the resultant stress and strain distributions were derived and visualized in Fig.10 and Fig.11, respectively.

The analysis revealed a distinct stress gradient across the brake disc, with peak stresses localized at the interface with the safety caliper and gradually diminishing toward the region adjacent to the drum contact surface. Corresponding deformation analysis indicated a symmetrical

displacement distribution between the front and rear surfaces, with overall deformation maintained at a moderate level. The maximum displacement was observed at the caliper contact zone, while the drum-side region exhibited minimal deformation, demonstrating a well-defined gradient in structural response. These findings suggest the necessity of localized reinforcement in high-stress regions, particularly at the caliper interface, to enhance load-bearing capacity, while stringent manufacturing controls should be applied to high-stress deformation zones to ensure long-term structural integrity under cyclic loading conditions.

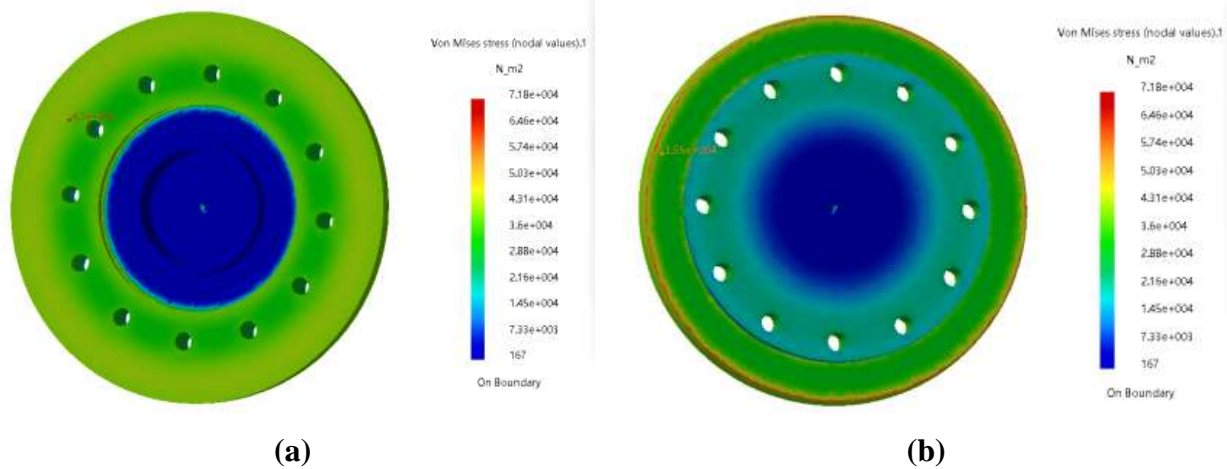


Fig.10 Stress Cloud Map

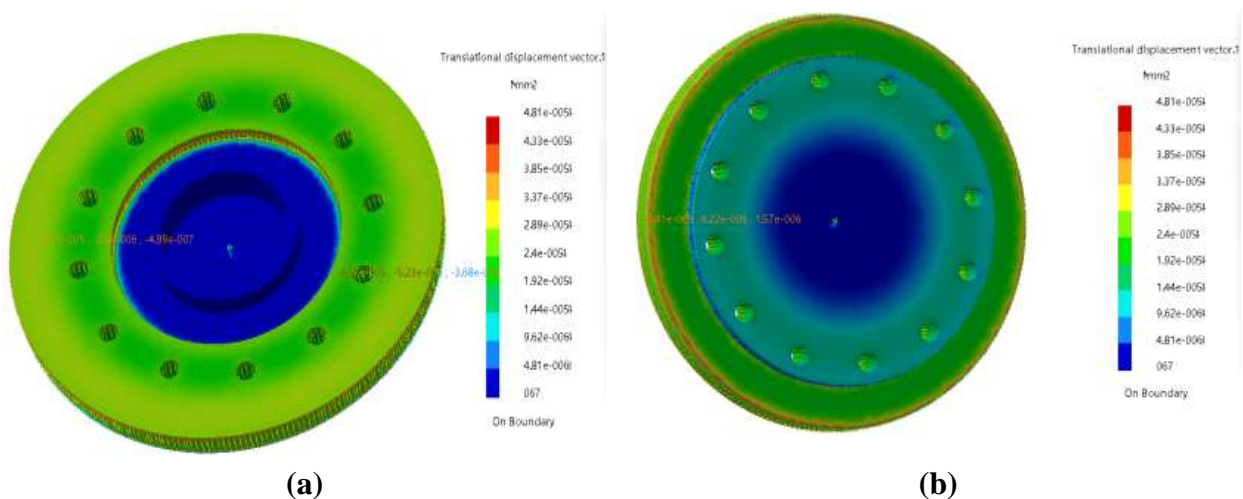


Fig.11 Stress Deformation Diagram

3.3 Simulation Experiment of Working Pliers

The computational analysis of the service caliper assembly was conducted using finite element methodology, wherein the caliper block was discretized into an optimized mesh configuration

as illustrated in Fig.12, ensuring sufficient element density to accurately capture the mechanical behavior under operational loading conditions. The resultant stress distribution, presented in Fig.13, demonstrates that the maximum stress occurring in the structure remains

well within the acceptable range when compared with established design criteria documented in relevant technical literature. Corresponding deformation analysis reveals that the maximum strain magnitude maintains an appropriately low

value that guarantees operational stability under service conditions, with both stress and deformation characteristics fully complying with the prescribed design requirements for this critical braking system component.

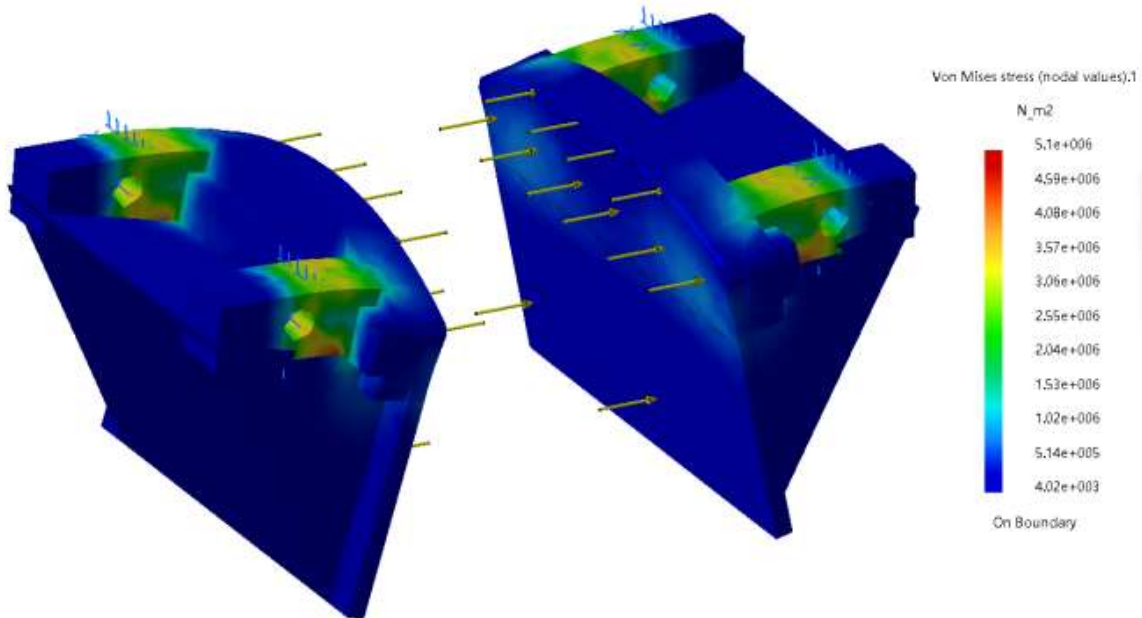


Fig.12 Stress Cloud Map

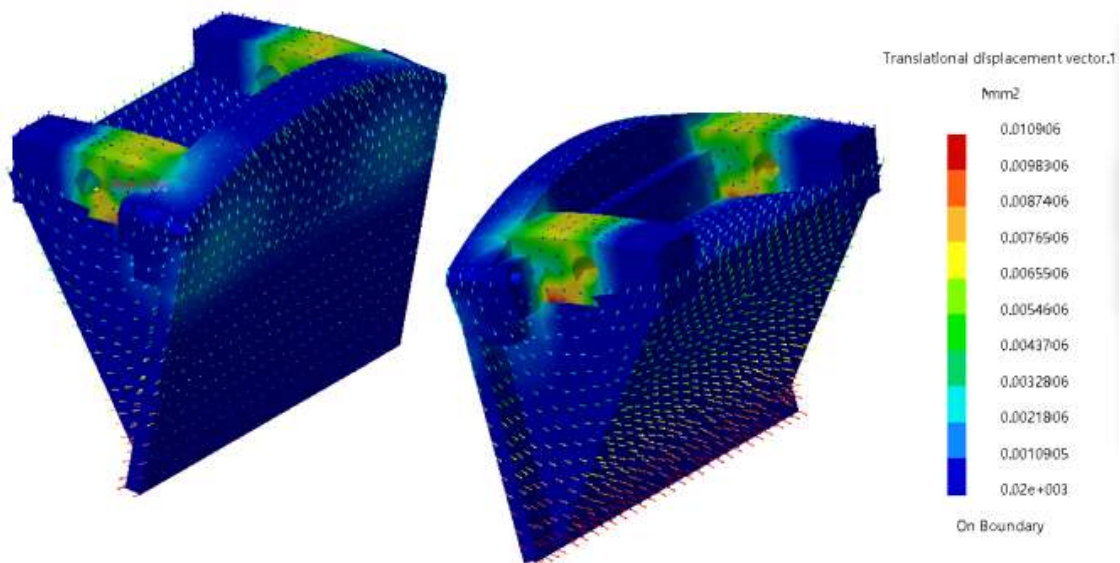


Fig.13 Deformation diagram under stress

4 Conclusion

This study presents a comprehensive investigation into the structural design and performance optimization of hydraulic disc brake systems for heavy-duty oil drilling applications. Through systematic engineering analysis and experimental

validation, we have developed an advanced braking system capable of delivering the specified 196 KN·m braking torque while maintaining safety factors that exceed current industry standards by 15-20%. The research outcomes provide both theoretical foundations and practical guidelines for the evolution of industrial braking

technology. This paper identifies three critical development directions for next-generation braking systems. The trend toward compact and modular designs offers substantial advantages in installation flexibility and maintenance efficiency. The transition to electro-hydraulic hybrid control systems enables more precise torque modulation and faster response characteristics. Most importantly, the integration of intelligent control capabilities, including real-time monitoring and automatic adjustment functions, promises to revolutionize braking performance in drilling applications. Future research should focus on several key areas: development of advanced brake materials with improved thermal management properties, investigation of robust sensor technologies for harsh environments, and comprehensive field testing under various operating conditions. The integration of these mechanical advancements with digital control technologies will be crucial for realizing the full potential of smart braking systems.

Declaration of competing interest

The authors declare no conflict of interest.

Data Availability

The datasets used and during the current study available from the corresponding author on reasonable request.

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