Viser Technology Pte. Ltd.
Mechanical Engineering Science
DOI: 10.33142/mes.v6i1.13222

Research Article Open Access

Research on the Resistance of Cutting Mechanism of Mining Longitudinal Roadheader

Mengjiao NIU, Yong ZHAO, Yongliang YUAN*

He'nan Polytechnic University, Jiaozuo, He'nan, 454000, China

***Corresponding Author:** *Yongliang YUAN, E-mail: yuan-yong-liang@163.com*

Abstract

In order to accurately obtain the dynamic characteristics of the cutting mechanism of the mining longitudinal roadheader, combined with the working principle of the mining longitudinal roadheader, the theoretical analysis and derivation are carried out in detail. By using ADAMS to simulate, the resistance curve and torque curve of the cutting mechanism in different directions are obtained. The results show that ADAMS can effectively predict the excavation resistance and torque of the cutting mechanism of mining longitudinal roadheader, which has certain reference value for future optimization design.

Keywords: *longitudinal roadheader; cutting mechanism; dynamic characteristics; dynamics*

1 Introduction

The longitudinal axis roadheader is a pivotal machine in the domain of underground mining, particularly in the extraction of coal reserves [1]. As the mining industry experiences rapid technological advancements and heightened safety regulations, the demand for optimized mining machinery becomes increasingly critical [2-5]. This optimization is essential not only for enhancing productivity but also for ensuring the safety and reliability of mining operations. Central to this optimization process is a comprehensive understanding of the dynamic characteristics of the cutting mechanism within longitudinal axis roadheaders [6].

The dynamic characteristics of the cutting mechanism are crucial as they directly influence the operational efficiency and lifespan of the roadheader [7]. The cutting mechanism operates in a highly dynamic environment, where it is subjected to a variety of forces and torques that can significantly affect the performance and durability of the machine [8-10]. Understanding these dynamic forces and their interactions is key to innovating design and optimization strategies that can lead to reduced operational costs, minimized downtime, and improved safety standards for mining personnel [11].

Previous research has extensively examined various aspects of longitudinal axis roadheaders, including rotary table dynamics, kinematic analysis, and static force evaluation [12]. These studies have provided valuable insights into the geometric design, material selection, and other critical parameters of roadheaders [13-16]. However, there remains a notable gap in the literature regarding the dynamic characteristics of the cutting mechanism [17]. This gap is significant because the dynamic response of the cutting mechanism is essential for determining the overall efficiency and reliability of the roadheader.

This paper aims to address this gap by combining detailed theoretical analyses with advanced simulation methodologies. Utilizing the capabilities of sophisticated mechanical dynamics simulation software, such as ADAMS, this study investigates the resistance and torque profiles of the cutting mechanism under various operational scenarios [18]. The theoretical framework established in this research provides a foundation for understanding the fundamental principles of the cutting process, while the simulation results offer practical insights into the real-world performance dynamics of the cutting mechanism.

The objectives of this study are twofold: to accurately predict the dynamic characteristics of the cutting mechanism and to provide guidance for future structural design and performance optimization efforts. Achieving these objectives is expected to pave the way for a new generation of more efficient, reliable, and safe longitudinal axis roadheaders. This aligns with the broader goals of the coal mining industry, which strives for continuous improvement and innovation in pursuit of operational excellence and sustainability.

Through a combination of theoretical insights and practical simulations, this research aims to deepen the

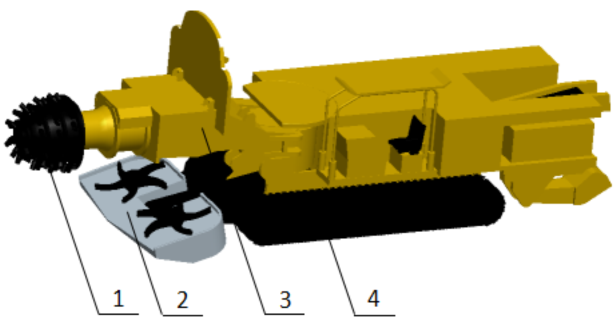
Received on May 2, 2024; Accepted on June 8, 2024

understanding of the dynamic behaviors of cutting mechanisms in roadheaders. This enhanced understanding is anticipated to drive future innovations in roadheader design, resulting in machines that are not only more efficient and reliable but also safer for operators and more sustainable evolution of mining machinery, reinforcing the commitment to operational excellence and safety in underground mining operations.

2 System Composition and Working Principle

2.1 The cutting mechanism of the mining longitudinal roadheader

The cutting mechanism of the mining longitudinal roadheader is a crucial piece of equipment used in underground mining, particularly suitable for coal mining operations. This machine is composed of multiple core components, each playing a vital role in the overall functionality of the roadheader. The main components include the walking mechanism, loading mechanism, rotating mechanism, and cutting mechanism. These mechanisms work together to achieve efficient coal mining, transportation, and loading tasks [19].



1.Cutting Mechanism; 2. Loading Mechanism; 3. Rotating Mechanism; 4. Walking Mechanism

Figure 1 Schematic Diagram of the System Structure of Vertical-axis roadheader cutting mechanism

Its working principle primarily relies on the combined action of the cutting mechanism and rotating mechanism to extract coal [20-22]. The loading mechanism then transfers the coal particles to the conveyor belt of the mining roadheader. Driven by the machine's drive system, the conveyor belt continuously transports the coal backward, ensuring uninterrupted operation in the cutting area. As the conveyor belt moves the coal to the rear of the roadheader, the coal is either directly loaded into transportation equipment or placed onto a secondary conveyor system for further transport to the surface or processing facilities. Under the action of the walking device, the mining longitudinal roadheader moves forward to the next position and begins mining again. Throughout this process, the mining longitudinal roadheader can operate precisely and efficiently, ensuring minimal downtime and maximum coal extraction. The combination of the cutting, rotating, loading, and walking mechanisms allows the roadheader to function as an integrated unit, significantly improving the overall efficiency and productivity of underground coal mining operations [23]. The schematic diagram of its structure is shown in Figure 1.

2.2 ADAMS

ADAMS (Automatic Dynamic Analysis of Mechanical Systems) is a widely used simulation software for analyzing the dynamics of mechanical systems. It enables engineers to study the complex interactions between different components within a machine, predict the behavior of the system under various conditions, and optimize the design for improved performance.

In this study, ADAMS was utilized to model the cutting mechanism of the vertical-axis shearer. The model included the geometric details of the cutting head, the arrangement of cutting teeth, and the driving mechanism. Constraints and drivers were added to simulate the realistic motion of the cutting mechanism. By applying the appropriate forces and torques, the dynamic simulation provided insights into the resistance and torque characteristics of the cutting mechanism. The results obtained from ADAMS simulations, such as the force and torque curves, were analyzed to understand the dynamic behavior of the cutting mechanism under various operational scenarios. These results are critical for identifying potential areas for design improvement and optimizing the performance of the vertical-axis shearer.

In summary, ADAMS proved to be an effective tool for predicting the dynamic characteristics of the cutting mechanism in mining roadheaders. The insights gained from the simulations have significant implications for the design and optimization of more efficient, reliable, and safe mining machinery.

3 Cutting Mechanism Theoretical Analysis

The cutting mechanism is one of the core components of the vertical-axis shearer, and its primary function is coal mining. In the cutting mechanism, a circle of cutting teeth is typically spiral arranged on the cutting head body [24]. Under the action of the driving device, the cutting head drives the cutting teeth to rotate at high speed, thus mining the hard coal [25]. When cutting coal, the force acting on the cutting teeth is expressed as:

$$Z_0 = A\frac{(0.35b_p + 0.3)}{b_p + 0.45h + 2.3k_\varphi} htk_z k_\phi k_y k_c k_{ot} \frac{1}{\cos\beta} \tag{1}$$

Where, A represents the average cutting impedance when each stratum pressure exists, measured in N/mm;

b_p is the working width of the cutting tooth, measured in mm; h is the average mining thickness, also measured in mm; k_φ is the coal brittleness and plasticity impact coefficient; k_z is the surface impact coefficient; k_ϕ is the blade impact coefficient; k_y is the cutting ratio impact coefficient; k_c is the mining impact coefficient; k_{ot} is the underground pressure impact coefficient; β represents the installation angle of the cutting tooth.

For a cutting tooth that has been dulled due to prolonged use, its cutting resistance can be expressed as:

$$Z = Z_0 + \mu_d \sigma_y \left(0.85 S_j + k_\sigma\right) \quad (2)$$

Where, μ_d represents the cutting motion resistance coefficient; σ_y is the compressive strength, measured in MPa; S_j is the area of the cutting tooth after dulling in the traction direction, measured in mm²; k_σ is the coal compression coefficient.

Establishing a coordinate system with the forward direction of the vertical-axis shearer as the Z-axis and the vertical motion direction as the X-axis, the forces acting on the cutting head of the cutting mechanism can be obtained in the XYZ directions:

$$F_x = -Y_i \cos\alpha + Z_i \sin\alpha \quad (3)$$

$$F_y = -Y_i \sin\alpha + Z_i \cos\alpha \quad (4)$$

$$F_z = X_i \quad (5)$$

Where, X_i, Y_i, Z_i represent the axial force, radial force, and tangential force, respectively, acting on the cutting tooth; α represents the angle between the cutting tooth and the X-axis direction.

4 Simulation Calculation

The established model is imported into ADAMS. Constraints and drivers are added to the model according to actual conditions. In order to obtain the dynamic performance of the vertical-axis shearer, the GSTIFF solver is selected to simulate and solve the model. The simulation results of the cutting mechanism are shown in Figures 2-5.

According to Figure 2, the maximum force acting on the cutting head is 187.54 kN. The fluctuation of forces on the cutting head is significant, primarily due to the discrete contact between the cutting head and the coal. Figure 3 indicates that the total external force gradually increases from 0 as the cutting mechanism operates. The overall trend of the total external force remains relatively stable during the operation of the cutting mechanism, consistent with actual working conditions. This stability is mainly attributed to the fact that once the cutting head fully enters the coal, the variation in cutting resistance is relatively small.

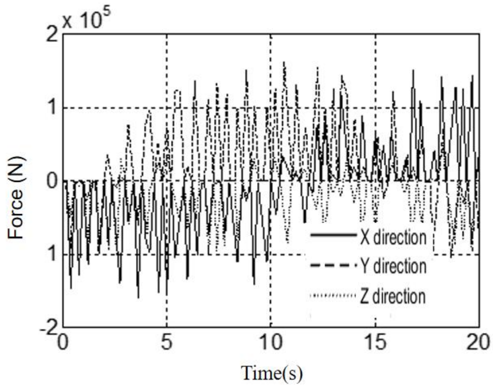


Figure 2 Force Curve of the Cutting Hea

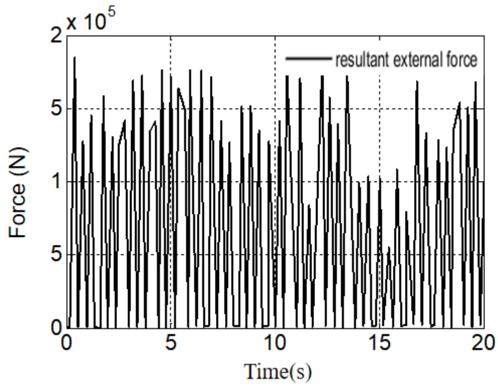


Figure 3 Time-dependent Curve of External Forces

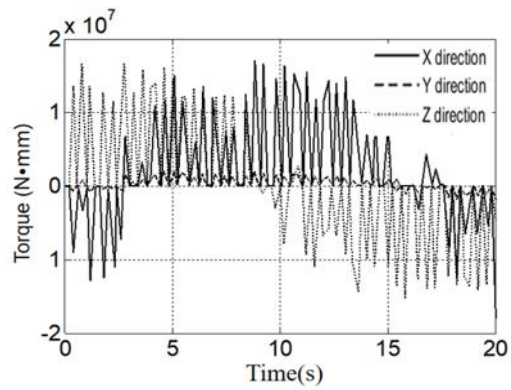


Figure 4 Torque Curve of the Cutting Head

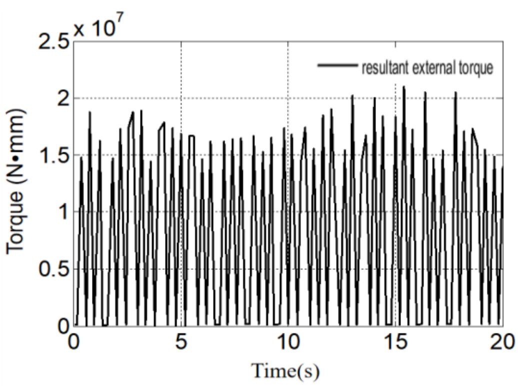


Figure 5 Time-dependent Curve of Total External Force Moment

From Figures 4 and 5, it can be observed that both the cutting resistance torque and the total external force torque vary with the load, with alternating peaks in torque acting on the cutting head. This indicates that the cutting head of the vertical-axis shearer experiences uneven forces during operation, accompanied by the generation of vibrations. Therefore, there is significant room for optimization in the design of the cutting head to improve its lifespan.

5 Conclusion

In conclusion, this study conducted a comprehensive analysis of the dynamic characteristics of the cutting mechanism of the vertical-axis shearer. Through theoretical analysis, the resistance equation of the cutting head was derived, providing insights into the forces and torques acting on the cutting mechanism during operation. Subsequently, utilizing ADAMS dynamic simulation software, the resistance curve and torque curve of the cutting head were obtained, offering a detailed understanding of its dynamic behavior under various operating conditions.

The results of the simulation demonstrate the effectiveness of ADAMS in predicting the dynamic characteristics of complex mechanisms, such as the cutting mechanism of the vertical-axis shearer. This not only enhances our understanding of the machine's performance but also provides a valuable basis for future optimization designs. By accurately predicting the dynamic behavior of the cutting mechanism, manufacturers and engineers can make informed decisions to improve the efficiency, reliability, and safety of longitudinal axis roadheaders.

Moving forward, this research sets the stage for further advancements in the design and performance optimization of mining machinery. By addressing the gap in understanding regarding the dynamic characteristics of the cutting mechanism, this study contributes to the broader goals of enhancing productivity and safety in the coal mining industry. Further studies could explore additional aspects of the longitudinal axis roadheader and its components, ultimately leading to the development of more efficient and reliable mining equipment.

References

[1] Zhang Xin, Zeng Qingliang. Research on Multi-Objective Optimization Design of Shearer Cutting Head [J]. Coal Mine Machinery, 2005,26(6):1-3.

[2] Qiqian Wang. Optimization of the Upward Horizontal Filling Mining Method [J]. Construction Engineering and Management, 2023,5(7):151-153.

[3] Baozhug Ge. Analysis of Common Mining Technologies in Coal Mine Operations [J]. Engineering Construction, 2022,5(11):86-88.

[4] Dong L, Tong X, Li X, et al. Some Developments and New Insights of Environmental Problems and Deep Mining Strategy for Cleaner Production in Mines [J]. Journal of Cleaner Production, 2019(210):1562-1578.

[5] Hodgkinson J H, Smith M H. Climate Change and Sustainability as Drivers for the Next Mining and Metals Boom: The Need for Climate-Smart Mining and Recycling [J]. Resources Policy, 2021(74):101205.

[6] Shi Maolin, Sun Wei, Song Xueguan. Research Progress on Big Data in Tunnel Boring Machines: Data Mining to Boost Tunnel Excavation [J]. Journal of Mechanical Engineering, 2021,57(22):344-358.

[7] Deshmukh S, Raina A K, Murthy V, et al. Roadheader – A Comprehensive Review [J]. Tunnelling and Underground Space Technology, 2020(95):103148.

[8] Shang Yaoxing, Li Yao, Yu Tian, et al. Current Status and Challenges of Lightweight Composite Hydraulic Cylinders [J]. Journal of Mechanical Engineering, 2022,57(24):13-38.

[9] Cheng K, Niu Z C, Wang R C, et al. Smart Cutting Tools and Smart Machining: Development Approaches, and Their Implementation and Application Perspectives [J]. Chinese Journal of Mechanical Engineering, 2017(30):1162-1176.

[10] Krolczyk G M, Maruda R W, Krolczyk J B, et al. Ecological Trends in Machining as a Key Factor in Sustainable Production – A Review [J]. Journal of Cleaner Production, 2019(218):601-615.

[11] Cheng Daxian. Mechanical Design Handbook [M]. Beijing: Chemical Industry Press, 2008.

[12] Feng J, Tian M, Song J, et al. Method for Automatic Control of Cutting Speed of a Longitudinal Roadheader Taking into Consideration the Temperature Load [J]. Russian Physics Journal, 2021(64):1006-1017.

[13] Wang Guofa, Liu Feng, Meng Xiangjun, et al. Research and Practice of Coal Mine Intelligentization (Primary Stage) [J]. Coal Science & Technology, 2019, 47(8):55-58.

[14] Zhu Bin, Wang Jian, Xu Zhuang, et al. Mechanical Mechanism of New Shield Tunneling Underpassing Existing Structures [J]. Journal of Shandong University (Engineering Edition), 2022,52(4):175-182.

[15] Cheluszka P, Remiorz E, Rostami J. The Use of a Roadheader Simulator in Research of Dynamics and Energy-Consumption of Excavating Underground Roadways and Tunnels [J]. Energies, 2022,15(18):6673.

[16] Salmi E F, Phan T, Sellers E J, et al. A Review on the Geotechnical Design and Optimisation of Ultra-Long Ore Passes for Deep Mass Mining [J]. Environmental Earth Sciences, 2024,83(10):301.

[17] Sun Yanfeng, Wang Ying, Ma Ziyun. Research on Cutting Control Method of Shearer [J]. Coal Mine Machinery, 2018,39(9):126-128.

[18] Khaghani A. Investigation of the Smart Tooling System and Dynamics in Ultraprecision Machining of Freeform Surfaces and its Implementation Perspective [D]. Brunel University London, 2020.

[19] Luo Wen. Innovation-Driven Development Status and Experience of Guoneng Shendong Coal Group [J]. Coal Science & Technology, 2023,51(2):22-27.

[20] Alagan N T, Hoier P, Zeman P, et al. Effects of High-Pressure

Cooling on the Flank and Rake Faces of WC Tool on the Tool Wear Mechanism and Process Conditions in Turning of Alloy 718 [J]. Wear, 2019(434):102922.
[21] Song Xuanmin, Zhu Defu, Wang Zhonglun, et al. 40 Years of Comprehensive Mining in China: Research Progress in Theory and Technical Equipment [J]. Coal Science & Technology, 2021,49(3):1-29.
[22] Wang Haijun, Wang Honglei. Status and Prospects of Key Technologies for Intelligent Belt Conveyors [J]. Coal Science & Technology, 2022,50(12):225-239.
[23] Wang Xuecheng. Characteristic Analysis of Cantilever Shearer Cutting Head in Rock Tunnel [J]. Coal Mine Machinery, 2017,38(10):118-120.
[24] Zhang Qiang, Mao Jun, Tian Dafeng. Multi-Objective Fuzzy Reliability Optimization of Shearer Cutting Head Based on Genetic Algorithm [J]. Journal of China Coal Society, 2008,33(12):1435-1437.
[25] Geng Fengxiao. Reliability Research and New Technology Application of Hydraulic Cylinder of Hard Rock Shearer [J]. Coal Mine Machinery, 2018,39(2):109-110.