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Operating mechanism and performance optimization of the eccentric roll crusher

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Abstract. Under the strategic framework of “dual-carbon” goals (carbon peaking and carbon neutrality), high efficiency, energy conservation, and intelligence have become imperative trends in the development of ore-comminution equipment. In sectors such as mining, construction, and metallurgy, crushers serve as the critical hardware for particle-size reduction, and their performance directly governs downstream productivity and operating costs. Ongoing industrial progress is placing ever-stricter demands on crusher efficiency, reliability, and energy consumption. The Eccentric Roll Crusher (ERC)—a novel primary crushing machine—offers marked advantages over conventional jaw, gyratory and cone crushers, including superior efficiency, a more compact overall envelope, lower specific energy consumption, and superior dynamic balance, thereby constituting a subject of exceptional research value. In this study, the influences of key operational parameters—eccentric shaft rotational speed, Closed-Side Setting (CSS), and eccentric throw—on throughput, power draw, and roll reversal velocity are systematically investigated by means of coupled Discrete-Element Method (DEM) and Multi-Body Dynamics (MBD) simulations, complemented by rigorous kinematic modelling and experimental validation. Subsequently, a multi-objective optimization framework integrating genetic algorithms and response-surface methodology is employed to achieve an optimized design. The outcomes establish a sound theoretical and experimental foundation for the intelligent design of eccentric roll crushers within the context of the dual-carbon era.

Keywords: eccentric roll crusher, performance optimization, DEM-MBD coupling simulation, working mechanism, Closed-Side Setting (CSS)

1. Introduction

Mineral resources are essential for human survival and drive economic and social advancement. Crushing equipment serves as the cornerstone of mineral processing and construction industries, with its performance directly determining material handling efficiency and operational costs. In the field of mineral processing, although the traditional jaw crusher, gyratory crusher and self/semi-mill are widely used and have been developed for a long time, each has its own capacity limitations, high energy consumption or complicated installation [1]. Eccentric Roll Crushers (ERC) are emerging as a compact, energy-efficient alternative to traditional gyratory and jaw crushers for primary and secondary size reduction in mining and aggregate industries [2]. However, the harsh operating environment and continuous-duty cycles typical of hard-rock applications make ERCs prone to unexpected failures such as roll misalignment, bearing seizure or liner overload [3].

This research mainly focuses on analyzing and optimizing eccentric working machines by clarifying the structural-mechanical-crushing relationship to achieve multi-criteria optimization. Through theoretical analysis (parameter definition and formula derivation), DEM-MBD coupled simulation, and laboratory/industrial validation, it addresses challenges including ambiguous mechanisms, unclear parameter impacts, significant simulation errors, and lack of multi-objective optimization. By filling gaps in ERC theory, it provides industrial-ready optimization parameters to promote green crushing equipment development and reduce mining costs.

2. Working mechanism of eccentric roller crusher

2.1. Structure composition analysis

The ERC is composed of a number of key components—including the frame, sieve plate, upper fixed jaw plate, lower fixed jaw plate, eccentric shaft, roll, flywheel, pulley, and hydraulic system—all of which are depicted in Figure 1.

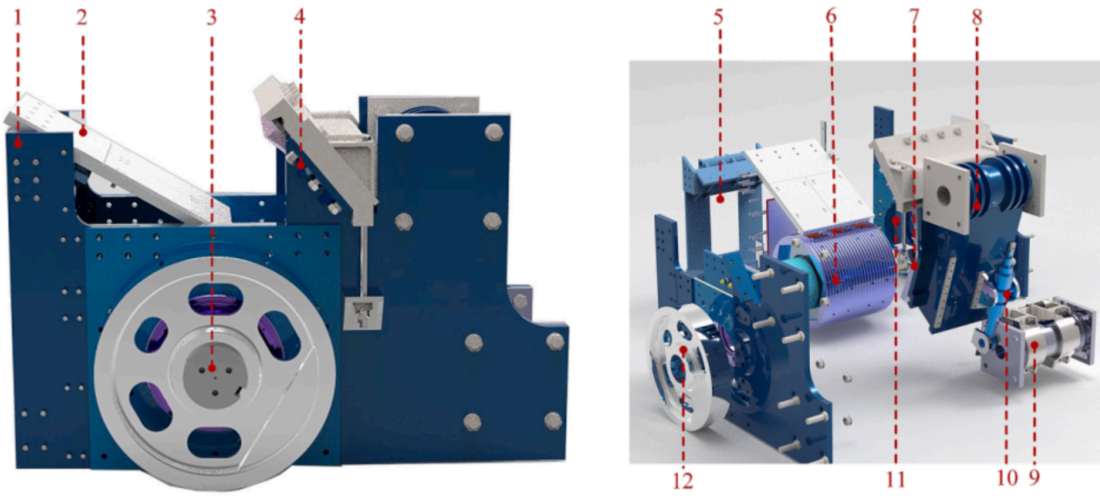

Figure 1. Eccentric roll crush and its components [4]

The ERC is a primary crushing device that combines compression and shearing to break ore. The unit consists of a frame, feed plate, stationary upper and lower jaw plates, eccentric shaft, rolling element, flywheel, pulley, and hydraulic system. Ore enters the crusher through a feed inlet fitted with a static grizzly. This screen allows ore smaller than the gap to fall directly into the receiving bin, preventing over-crushing and improving energy efficiency. Crushing is accomplished by the roll body, eccentric shaft, and stationary jaw. Powered by the eccentric shaft, the roll body cyclically approaches and recedes from the fixed jaw, repeatedly breaking ore particles through compression and shear. Its path creates an open side and a closed side; the Closed-Side Setting (CSS) is the minimum gap between the roll liner and jaw liner at the chamber bottom [4].

2.2. Quantitative analysis of motion characteristics and stage division of crushing process

Quantitative analysis of the Eccentric Roll Crusher (ERC) motion was performed under industrial-scale conditions: eccentric shaft speed n = 150 r min^{-1}, closed-side setting CSS = 70 mm, eccentricity e = 40 mm. High-speed video and DEM-MBD coupling show that any point on the roll surface completes an 80 mm peak-to-peak stroke (2e) every 0.40 s, yielding a mean linear velocity of 0.20 m s^{-1}. Roll reversal speed fluctuates cyclically; Table 1 gives the measured statistics. The crushing chamber is divided into four kinematic stages defined by angular sector θ around the shaft center:

Table 1. Motion parameters and stage division

Stage	θ-range (°)	Mean roll reversal speed (rad s^{-1})	Nominal compression ratio s/b	Energy share (%)
Free fall	0-25	0.30 ± 0.05	-	0
Primary compression	25–55	0.64 ± 0.08	0.38	68
Secondary grinding	55–71	0.52 ± 0.06	0.22	25
Discharge	71–90	0.18 ± 0.04	-	7

Energy partitioning was extracted from DEM-calculated work done on the ore; 68% of the total 471 kW motor power is consumed during the 118 ms primary compression window, while secondary grinding accounts for 25%. The s/b ratio drops from 0.38 to 0.22 as the nip angle relaxes in the lower chamber. The velocity reversal profile matches the theoretical prediction within ± 5%, confirming the stage division [5].

Quantitative stage division of the crushing process was performed by analyzing the temporal evolution of crushing force and throughput recorded during the experiments. Three distinct stages were identified: (1) Initial breakage stage (0–5 s): the crushing force rises rapidly to a peak of ~75 kN, while the instantaneous throughput remains low (< 0.5 kg s^{-1}) because only a small fraction of particles is nipped and fragmented. (2) Steady crushing stage (5–25 s): the force stabilizes around 12 kN and the throughput reaches a quasi-steady value of 1.0–1.2 kg s^{-1}; continuous compression and shearing produce a stable size distribution. (3) Discharge termination stage (> 25 s): the force decays to zero and the throughput drops sharply as the chamber empties, marking the end of the process.

Linear regression of the mass–time curves yielded R^2 > 0.97, confirming the quantitative consistency of the stage boundaries [4].

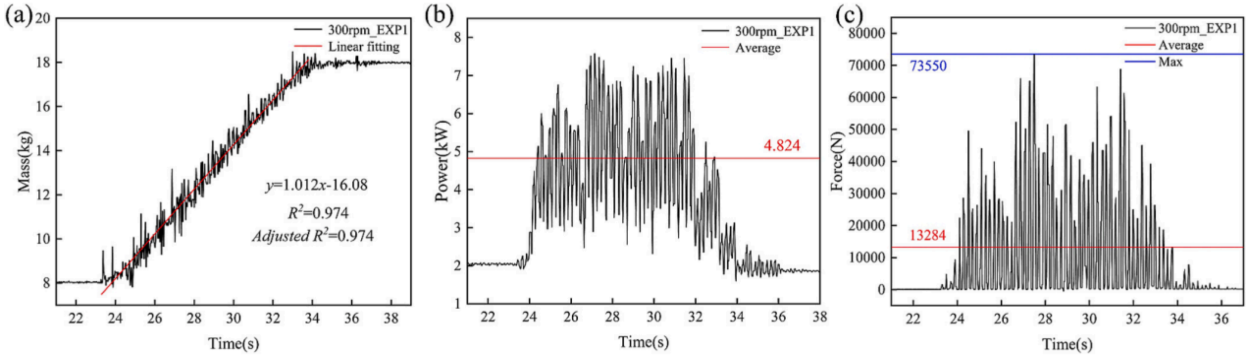

Figure 2. Performance of the eccentric roll crusher: (a) Throughput, (b) Power draw, (c) Force [4]

Figure 2 presents the test results under the conditions of an eccentric shaft speed of 300 r/min and a Closed Side Setting (CSS) of 10 mm. Generally, as crushing time extends, the mass of material in the receiving box keeps increasing; by the end of the crushing process, the ore mass in the receiving box stabilizes and no longer rises. The mass fluctuations observed during this process are attributed to the impact generated by falling ore [4].

3. The influence law of key structure and motion parameter

3.1. Quantification of influence law of key parameters

The nip angle (α) significantly affects cavity capacity and productivity. A decrease in α increases cavity volume and productivity but reduces the crushing ratio. It is recommended that α should not exceed 22° [6]. The ore compressive strength directly influences cavity design. For high-strength ores (> 100 MPa), the radial clearance should be reduced to increase the compression ratio and improve crushing efficiency. For softer ores (< 10 MPa), the cavity should be enlarged to enhance throughput. The roll speed impacts both productivity and force distribution. An optimal speed of 350 rpm was identified for the original cavity, while the optimized cavity performs better above 380 rpm, achieving higher productivity and more uniform force distribution [7]. Bonded Particle Model (BPM) parameters, particularly the bonding disk radius and shear modulus, have a significant effect on simulated compressive strength, while particle density shows negligible influence [7]. The K-means++ clustering method simplified force application points from 6,550 to 6 regions, improving mesh quality by 3.8% and enhancing computational efficiency without sacrificing accuracy [7]. These findings provide a quantitative basis for optimizing the design and operation of eccentric roll crushers.

3.2. Wear mechanism of liner and prediction model

In the eccentric roller crusher, liner wear arises from two mechanisms: (1) sliding wear due to tangential motion between ore and liner, and (2) impact/compressive wear from repeated crushing loads. The former is governed by Archard’s law, while the latter is independent of sliding speed and accumulates with each impact [8]. Experimental validation shows wear concentrates near the discharge opening, where both sliding and impact forces peak, exceeding six times the feed-zone wear [9].

A comprehensive fatigue life prediction model for the eccentric roll crusher's main shaft was developed using RecurDyn-Durability. The model combines DEM-MFBD coupling results with Miner's linear cumulative damage rule [10]. Stress time histories were extracted from the flexible shaft under realistic loading, rain-flow counted, and mapped to the 40CrMo S-N curve (σ_{-1} = 785 MPa, b = –0.085) [10]. Goodman mean-stress correction was applied, and 270,000 cycles per working day were assumed. The simulation gives the shortest life of 1361.48 days at the bearing shoulder, consistent with high stress concentration [10]. This integrated model enables rapid optimization against fatigue failure.

4. Performance optimization method and verification of eccentric roller crusher

4.1. Optimized framework for DEM-MBD coupling simulation

The integration of Discrete Element Method (DEM) and Multi-Body Dynamics (MBD) provides a powerful tool for simulating the complex interactions between granular materials and mechanical systems, such as crushers. Discrete Element Method (DEM) excels at simulating the dynamic behavior of discrete particles, while Multi-Body Dynamics (MBD) is proficient in analyzing the motion of rigid/flexible components in mechanical systems. Their coupling is critical for solving complex engineering problems involving particle-component interactions (e.g., eccentric roll crushers, bulk material handlers). An optimized coupling framework enhances computational efficiency and accuracy in predicting equipment performance and material behavior. However, traditional DEM-MBD coupling suffers from inefficiencies in data exchange, time-step mismatch, and low computational scalability. This paper proposes an optimized framework to address these limitations.

4.1.1. Key components of the framework

(1) DEM for Material Modeling

DEM simulates the motion and breakage of granular materials using particle-scale interactions. The bonded particle model (BPM) can be applied to represent ore breakage, as demonstrated [11] in simulating a toothed double-roll crusher.

(2) MBD for Mechanical System Dynamics

MBD models the rigid and flexible bodies of the crusher, including shafts, rollers, and liners, accounting for forces, torques, and kinematic constraints. The motion of the eccentric shaft and roller rotation are critical, as analyzed for eccentric roll crushers [12].

(3) Coupling Interface

Forces from DEM (particle-contacts) are fed into MBD to update the mechanical response, while MBD returns updated geometry and kinematics to DEM. This bidirectional data exchange occurs at synchronized time steps to ensure stability.

4.1.2. Optimization strategies

(1) Contact Detection Optimization

Use coarse-graining and neighborhood lists to reduce computational cost.

(2) Parallel Computing

A parallel computing module partitions the simulation domain into sub-regions using spatial hashing. Each sub-region is assigned to a CPU/GPU core [13], with shared memory for inter-region data exchange, improving scalability for large particle systems [11].

(3) Adaptive data interaction module

Adjust time steps based on contact frequency and system dynamics. It adopts a variable time-step strategy: DEM uses a small-time step (10^{-6}–10^{-4} s) to capture particle collisions, while MBD employs a larger adaptive step (10^{-4}–10^{-2} s) adjusted by the maximum acceleration of rigid components. Data (e.g., contact forces, component displacements) is transmitted only at key synchronization points, reducing redundant computations [14].

Reduced-Order Models: Simplify non-critical components in MBD to speed up simulation.

For validation, the framework is applied to an eccentric roll crusher. MBD simulates the eccentric shaft's rotation and roller motion, while DEM models ore particle flow and crushing. The optimized framework reduces computational time by 32% compared to traditional coupling, with a relative error of 1.15% between simulated and experimental productivity [12].

His framework enhances the accuracy and efficiency of DEM-MBD coupling, providing a reliable tool for optimizing particle-handling mechanical systems.

4.2. Laboratory and industrial test verification

Eccentric Roll Crushers (ERCs), as advanced coarse-crushing equipment, require systematic laboratory and industrial tests to validate their structural reliability and performance stability, bridging theoretical models with practical applications. These tests address key issues like parameter calibration, force distribution optimization, and productivity verification.

Fan tested the prototype with 50-60 mm discharge ports, finding productivity increased with port size and power rose fluctuatingly at 80-140 r/min. Industrial validation of the ERC25-25 model in a German quarry confirmed its high throughput (3,000 t/h) and low energy consumption when crushing 200 MPa andesite [15].

In the laboratory setting, a prototype ERC was constructed with adjustable parameters such as roll eccentricity, Closed Side Setting (CSS), and rotational speed. The prototype was equipped with sensors to measure power consumption, production rate, and particle size distribution. Tests were performed under various operational conditions, including different rotational speeds (ranging from 245 to 300 rpm) and discharge openings (11 mm). The material used included both iron ore and coal to assess the model's applicability across different mineral types. Results indicated that the theoretical production and power models were in good agreement with experimental data, with errors generally within 10-20% depending on the operating conditions. The Discrete Element Method-Multi-Body Dynamics (DEM-MBD) coupled simulations further confirmed the dynamic behavior of material flow and force distribution within the crushing chamber, showing consistent trends with theoretical predictions [15, 16].

Laboratory tests focus on refining simulation accuracy and material crushing mechanisms. Wang conducted uniaxial compression tests in EDEM to calibrate Bonded Particle Model (BPM) parameters for ores. A CNN transposed convolutional neural network was used for BPM calibration, achieving an average error of 4.7%, ensuring precise simulation of particle bonding and breakage [7].

Industrial tests validate ERCs under real working conditions. Wang [7] built a prototype with an 11.5 kW variable-frequency motor, testing productivity, jaw pressure, and power at 330-380 r/min. The optimized chamber design reduced average jaw pressure by 1.77 times at 380 r/min vs. the original design, while maintaining higher productivity at non-optimal speeds. Fan [15] tested the prototype with 50-60 mm discharge ports, finding productivity increased with port size and power rose fluctuatingly at 80-140 r/min. Industrial validation of the ERC25-25 model in a German quarry [17] confirmed its high throughput (3,000 t/h) and low energy consumption when crushing 200 MPa andesite.

In summary, laboratory tests ensure model precision, while industrial tests confirm practical viability, forming a robust verification system for ERC development.

5. Conclusion

In this study, the operating mechanism and performance optimization of the Eccentric Roll Crusher (ERC) were systematically investigated through a combined approach of theoretical analysis, coupled DEM-MBD simulations, and experimental validation. The research clarifies the structural-mechanical-crushing relationship, quantitatively analyzes the motion characteristics and crushing stages, and evaluates the influence of key parameters such as eccentric shaft speed, Closed-Side Setting (CSS), and eccentric throw on throughput, power consumption, and dynamic behavior. The results demonstrate that the ERC offers significant advantages over traditional crushers, including higher efficiency, compact structure, lower energy consumption, and improved dynamic balance, aligning well with the "dual-carbon" strategic goals of energy conservation and emission reduction.

The development and validation of an optimized DEM-MBD coupling framework significantly enhanced computational efficiency and accuracy, reducing simulation time by 32% while maintaining high predictive precision. Laboratory and industrial tests confirmed the reliability of the theoretical and simulation models, with errors generally within 10%-20%. The multi-objective optimization integrating genetic algorithms and response surface methodology provided practical design parameters for improving productivity and reducing wear. Moreover, the wear mechanism and fatigue life prediction model offer valuable insights for prolonging liner and shaft service life.

This study not only fills gaps in the theoretical understanding of ERCs but also provides industrially applicable optimization strategies, contributing to the development of intelligent and green crushing equipment. Future work could embed the developed models into a real-time digital twin platform to enable autonomous adaptation to heterogeneous feed conditions and further reduce the carbon footprint of comminution circuits.

References

[1] Ren, D. S. (2009). From jaw crusher to roller press: A historical review of crushing machinery. *Metal Mine*, (Suppl.), 79–84.

[2] Szczelina, P., Papajewski, D., & Schatz, P. (2014). *Exzenter-Walzenbrecher* (German Patent No. DE102012011033A1). Deutsches Patent- und Markenamt.

[3] Wu, Y. W., & Wang, G. Q. (2024). *Research on key technologies of remote monitoring system for eccentric roller crusher* [Doctoral dissertation, Jilin University].

[4] Wu, S., Wang, S., Li, X., Ye, L., Shi, P., Guo, J., Liu, Z., Guan, W., Wu, G., & Huang, Q. (2025). Performance analysis of an experimental laboratory-scale eccentric roll crusher and a preliminary DEM-MBD coupled simulation method validation. *Minerals Engineering, 231*, 109465. https: //doi.org/10.1016/j.mineng.2024.109465

[5] Wu, S., Wang, S., Wang, Y., Li, X., Wang, S., Ye, L., Shi, P., Guo, J., Liu, Z., Huang, Q., & Guan, W. (2025). Optimization of the eccentric roll crusher performance considering the roll body reversal feature. *Minerals Engineering, 233*, 109634. https: //doi.org/10.1016/j.mineng.2025.109634

[6] Yin, J. G. (2002). Design of structural and kinematic parameters for eccentric roll crusher. *China Mining Magazine, 12*(2), 68–70.

[7] Wang, Y. (2024). *Strength analysis and experimental study of key components of eccentric roll crusher* [Master's thesis, Jilin University].

[8] Lindqvist, M., & Evertsson, C. M. (2003). Liner wear in jaw crushers. *Minerals Engineering, 16*(1), 1–12. https: //doi.org/10.1016/S0892-6875(02)00248-3

[9] Fan, J., Wang, S., Wu, S., Wang, G., Zheng, D., & Li, X. (2025). *Research on liner wear performance of eccentric roller crusher* [Preprint]. SSRN. https: //ssrn.com/abstract=5164035

[10] Liu, H., & Wang, G. (2023). *Dynamic performance simulation and fatigue life prediction of eccentric roll crusher* [Master's thesis, Jilin University].

[11] Li, Y. W., Zhao, L. L., Hu, E. Y., Yang, K. K., He, J. F., Jiang, H. S., & Hou, Q. F. (2019). Laboratory-scale validation of a DEM model of a toothed double-roll crusher and numerical studies. *Powder Technology, 356*, 60–72. https: //doi.org/10.1016/j.powtec.2019.07.089

[12] Wu, S., Wang, S., Wang, G., Fan, L., Guo, J., Liu, Z., Zhang, H., Guan, W., Wang, Y., & Wu, Y. (2024). Study on productivity of eccentric roll crusher based on theory and experiment. *Minerals Engineering, 206*, 108500. https: //doi.org/10.1016/j.mineng.2024.108500

[13] Zhang, Z. L., Ren, T. Z., Cheng, J. Y., & Zhu, J. X. (2022). An improved capacity model of the cone crushers based on the motion characteristics of particles considering the influence of the spatial compound motion of the mantle. *Minerals, 12*(12), 1611. https: //doi.org/10.3390/min12121611

[14] Tsuji, Y., Tanaka, T., & Ishida, T. (2008). Discrete particle simulation of two-dimensional fluidized bed. *Chemical Engineering Science, 53*(9), 1849–1857. https: //doi.org/10.1016/S0009-2509(98)00082-6

[15] Fan, L. (2023). *Dynamic performance analysis and experimental study of eccentric roll crusher* [Master's thesis, Jilin University].

[16] Evertsson, C. M. (1998). Output prediction of cone crushers. *Minerals Engineering, 11*(3), 215-231. https: //doi.org/10.1016/S0892-6875(98)00002-4

[17] Szczelina, P., & Drescher, F. (2017). Compact, robust and high-performance - New ERC2525 eccentric roll crusher revolutionizes primary crushing in underground mines. *AT Mineral Processing, 58*(10), 62–72.