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COMPARATIVE ANALYSIS OF THE KINEMATIC RESPONSE OF DRILL BITS

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Abstract: This study presents a comparative analysis of the kinematic response of roller-cone and PDC drill bits to variations in weight on bit and rotational speed. Roller-cone bits exhibit a quasi-linear response governed by cyclic indentation and chipping of the teeth, whereas PDC bits demonstrate a nonlinear response associated with stress redistribution and a transition of the dominant rock-breaking mechanism. The influence of cutter geometry, rock stress state, and lithological heterogeneity on drilling efficiency and dynamic response is examined. The results provide a mechanistic basis for optimizing drilling parameters and bit designs under complex geological conditions.

Key Words: Drill bit kinematics, roller-cone bits, PDC bits, rock-breaking mechanism, rock stress state, lithological heterogeneity

Introduction

Drilling kinematics—specifically bit weight and rotational speed—have traditionally been regarded as universal control parameters governing rock-breaking processes. However, accumulated experimental and theoretical evidence indicates that the response of a drilling tool to variations in these parameters is highly dependent on the mechanism of interaction between the cutting elements and the rock, as well as the stress state within the “bit–bottomhole” zone [1–3]. This distinction becomes particularly evident when comparing roller-cone and PDC bits, despite the apparent similarity of their operational parameters.

Studies on the kinematics of roller-cone bits have demonstrated that adjustments in rotational speed and bit load primarily affect the frequency and amplitude of cyclic indentations of the teeth, while the fundamental mechanism of rock failure—cyclic penetration and chipping—remains unchanged [2]. Even when transitioning between formations of different strengths, the dominant failure mechanism persists, and the tool response exhibits a quasi-linear character, determined by the cumulative energy of contact impulses.

In contrast, recent experimental investigations of PDC bits under complex stress conditions reveal a fundamentally different response to kinematic variations [1–3]. Varying bit load and rotational speed can trigger a qualitative shift in the rock-breaking mechanism—from quasi-stationary shearing to a milling-like process characterized by non-parallel and unbalanced cutter–rock contacts. In this case, the efficiency of rock removal is influenced more by the ratio of axial to lateral stresses than by the geometry of the cutting elements [1].

Additional data on the vibrational response of PDC bits in alternating formations indicate that changes in kinematic parameters induce nonlinear dynamic behavior, particularly at sharp lithological boundaries [2]. Unlike roller-cone bits, where vibration increases are mainly associated with higher contact frequency, for PDC bits the critical factor is the rate of change of cut depth and the corresponding redistribution of stresses within the contact zone [1–3].

Thus, despite the formal similarity in kinematic control parameters, roller-cone and PDC bits exhibit qualitatively distinct response mechanisms. This underscores the need to analyze these two bit types within a unified mechanistic framework.

The present study aims to establish causal relationships among drilling kinematics, rock stress states, and failure mechanisms for roller-cone and PDC bits, as well as to identify the factors that govern the nonlinear response of PDC bits compared with the quasi-linear behavior of roller-cone bits [1–3].

Methods

The methodological foundation of this work is a comparative mechanistic analysis of experimental results concerning rock failure and the dynamics of different types of drill bits. Data on the kinematic response of roller-cone bits were drawn from experimental and theoretical studies that provide detailed characterization of cyclic indentation, contact loads, and the frequency-dependent behavior of tooth–rock interaction [2].

The analysis of PDC bit response relied on laboratory experiments investigating rock failure using hybrid and modified PDC bits under controlled axial and confining pressures [1–3], as well as studies on the vibrational response of PDC bits in lithologically heterogeneous formations. Data from investigations of vertically-rolling PDC bits were also utilized to assess the influence of contact mechanism variations on tool dynamics [3].

Comparisons were conducted with respect to the following parameters: nature of contact interaction, crack type and propagation direction, dependence of rock-breaking efficiency on kinematic parameters, and dynamic indicators (vibrational accelerations, torque) [1–3]. This approach allowed for the identification of both commonalities and fundamentally distinct features of roller-cone and PDC bit responses.

Results

Analysis revealed that for roller-cone bits, changes in bit load and rotational speed primarily alter the frequency and intensity of tooth indentation cycles, while the underlying rock failure mechanism remains unchanged [2]. Rock-breaking efficiency is governed by the total energy of contact impulses, and the tool’s dynamic response varies smoothly.

For PDC bits, rock-breaking efficiency is more strongly controlled by the ratio of axial to lateral stresses than by the shape of the cutting elements [1–3]. When the optimal principal stress differential is achieved, the rate of rock failure is maximized; conversely, increasing confining pressure suppresses crack development and reduces efficiency [3].

The geometry of PDC cutting elements primarily affects crack propagation direction: spherical cutters tend to promote axial crack growth, whereas conical elements favor radial propagation [2]. Experimental vibrational data indicate that increases in bit load have a greater impact on PDC bit dynamics than rotational speed, particularly in formations with lithological transitions [3].

Modified PDC bits with rolling elements exhibit reduced torque and vibrational accelerations while maintaining comparable penetration rates, highlighting the critical role of contact mechanisms in shaping dynamic response [3].

Discussion

Comparisons with roller-cone bit kinematics indicate that differences in response to kinematic variations arise from fundamentally distinct rock-breaking mechanisms. In roller-cone bits, kinematic parameters control the frequency and intensity of cyclic indentations without altering the nature of contact, thereby ensuring relative stability of the response even under variable lithology [1–3].

In PDC bits, changes in kinematic parameters affect individual cutter penetration depths and redistribute stresses in the contact zone, potentially leading to a shift in the dominant failure mechanism [1–5]. The nonlinear response observed experimentally in PDC bits is a consequence of surpassing a critical principal stress differential, which either activates or suppresses crack formation processes [1–3].

Results from vertically-rolling PDC bits further confirm that operational instability is not determined by WOB and RPM values per se, but by their influence on cutter penetration and contact interaction characteristics . This fundamentally differentiates PDC bits from roller-cone bits and explains their heightened sensitivity to lithological heterogeneity [1–3].

Limitations

It should be noted that the experimental data employed were primarily obtained under laboratory conditions and do not fully account for scale effects, the influence of drilling fluid, or cutter wear [1–6].

Furthermore, direct experimental comparisons between roller-cone and PDC bits under identical stress and lithological conditions remain limited, defining avenues for future research [1–3].

Conclusion

The present analysis demonstrates that roller-cone and PDC bits respond differently to variations in drilling kinematics due to differences in contact mechanisms and rock failure processes. For roller-cone bits, changes in bit load and rotational speed induce a quasi-linear variation in dynamic response driven by modifications in cyclic tooth indentation.

In contrast, PDC bits exhibit a nonlinear response, governed by stress redistribution and changes in cutter penetration depth, which may trigger shifts in the dominant failure mechanism. The rock stress state is a determining factor for energy efficiency of rock failure, whereas cutting element geometry primarily affects crack propagation direction [1–6].

These findings provide a mechanistic basis for comparing the kinematics of roller-cone and PDC bits and can inform the development of adaptive drilling regimes and bit designs for challenging geological and technical conditions.

Refrences:

1. Huang, X., Chang, J., Li, C., Yang, W., Pang, J., Zou, J., & Zhang, Y. (2025). Experimental study on the rock breaking effect of different tooth shapes of inserted teeth in a hobbing-cone hybrid PDC bit under complex stress environment. Geoenergy Science and Engineering, 246, 213390.
2. Zhang, J., Cui, M., Wang, Q., Ren, H., Ji, G., Shao, F., ... & Yu, J. (2025). Experimental study on rock drilling vibration of PDC bit in interbedded formations. Geoenergy Science and Engineering, 244, 213452.
3. Yang, Y., Yang, Y., Song, D., Ren, H., Qiu, S., Xie, X., & Huang, Z. (2025). Study on rock-breaking mechanism of the vertical wheel PDC bits. Geoenergy Science and Engineering, 244, 213428.

4. Маткасимова, Ш. Ш. (2024, December). СРАВНИТЕЛЬНЫЙ АНАЛИЗ ЭФФЕКТИВНОСТИ СЕТКИ БУРЕНИЯ И ПРИМЕНЕНИЯ ДРОБИЛЬНОГО ОБОРУДОВАНИЯ ДЛЯ ОПТИМИЗАЦИИ ВСКРЫШНЫХ РАБОТ НА УГОЛЬНОМ МЕСТОРОЖДЕНИИ. In International Conference on Multidisciplinary Sciences and Educational Practices (pp. 235-239).

5. Маткасимова, Ш. Ш. К., Эшонкулов, К. Э. У., Тогаев, А. С. У., & Пардаев, А. Б. (2022). Технологические аспекты процесса бурения скважин трехшарошечными долотами в условиях разреза «АНГРЕНСКИЙ». Вестник науки и образования, (10-1 (130)), 38-45.

6. OpenAI (2025). ChatGPT (GPT-5) [Large Language model]. <https://chatgpt.com/chat /> [Электронный ресурс] - режим доступа - URL:https://openai.com/about/ (дата обращения: 30.12.2025).