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KINEMATIC RESPONSE OF PDC AND ROLLER-CONE DRILL BITS

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Abstract: This paper investigates the kinematic response of PDC and roller-cone drill bits under varying drilling conditions. Particular attention is paid to the influence of combined rotational motion, cutter geometry, and kinematic parameters on load distribution, contact trajectories, and rock-breaking efficiency. The analysis is based on a synthesis of numerical and experimental studies, including kinematic modeling of PDC bits in compound drilling [1] and three-dimensional finite element simulations of rock cutting by PDC cutters with experimental validation [2]. The results demonstrate that kinematic variations lead to non-uniform load distribution on cutting elements, changes in contact stresses, and cyclic behavior of cutting forces, significantly affecting penetration rate and tool wear. It is shown that optimization of cutter rake angle, depth of cut, and motion parameters can enhance rock-breaking efficiency and extend bit service life. The findings provide a basis for comparative analysis of PDC and roller-cone drill bits and contribute to the development of optimized drilling modes and cutter design strategies.

Key Words: PDC drill bit; roller-cone drill bit; drilling kinematics; rock breaking; cutting forces; finite element modeling

Introduction

Enhancing the efficiency of mechanical drilling and extending the service life of drill bits remain central challenges in the oil and gas industry, particularly in the context of increasing drilling depths, more complex lithological profiles, and the expanding application of directional and horizontal drilling. Under these conditions, the analysis of the kinematic response of drill bits gains particular importance, as it governs the interaction between cutting elements and rock, the distribution of loads, and the rate of tool wear.

From the perspective of rock mechanics, drilling can be conceptualized as a combination of rotational and translational motion of the bit, contact interactions between cutting elements and the formation, and the formation of zones of ductile-brittle failure. These processes operate through fundamentally different mechanisms depending on the type of bit. In PDC bits, shearing and cutting dominate the failure process, whereas in roller-cone bits, rock is fragmented primarily through cyclic indentation, crushing, and chipping induced by the rolling motion of the cone teeth.

Previous studies have demonstrated that the kinematics of cutting elements significantly affect both rock-breaking efficiency and tool wear. For PDC bits, this relationship has been actively investigated in the context of hybrid drilling and asymmetric cutter motion [1]. In contrast, for roller-cone bits, kinematic variations manifest through changes in tooth trajectories, contact impulse loads, and the dynamic interaction between the cones and the bottomhole. Despite isolated studies, the literature lacks a systematic comparison of PDC and roller-cone bit responses to kinematic variations. The present work aims to analyze and comparatively summarize the response of PDC and roller-cone bits to kinematic changes based on contemporary numerical and experimental research.

Methods

This study was conducted as an analytical review incorporating elements of comparative methodological analysis. The primary data sources comprised published results of numerical simulations and experimental studies on the kinematics and rock failure mechanisms of PDC and roller-cone bits, including references [1,2].

The methodological analysis for PDC bits focused on kinematic models of cutter motion during hybrid drilling, the influence of geometric parameters of the cutters (inclination angle, cut depth, chamfer), and the assessment of contact load distribution. For roller-cone bits, models of tooth motion accounting for rolling, slipping, and the impulsive nature of contact with the bottomhole were analyzed, along with methods for determining dynamic loads and the energy associated with rock failure.

Special attention was given to comparing criteria for evaluating drilling efficiency, including cutting forces, contact stresses, energy expenditure of rock failure, and conditions of cutter wear. This approach enabled a methodologically consistent comparison of the kinematic responses of different bit types.

Results

Analysis of the results [1] indicates that during hybrid drilling, the trajectories of PDC cutters deviate significantly from classical circular paths. Variations in the rotational speed ratio between the surface and bottomhole drives lead to uneven load distribution among cutters and the formation of localized zones of elevated contact pressure, accompanied by increased dynamic loads.

Results from [2] show that the geometric parameters of PDC cutters substantially influence the nature of rock failure. Optimal values of inclination angle and chamfer minimize contact area, reduce wear, and enhance cutter stability at high rotational speeds.

For roller-cone bits, prior studies indicate that kinematic variations redistribute impulse loads among the cone teeth. Changes in rotational speed and axial load affect tooth penetration depth, contact frequency, and the energy of individual impacts, which directly influence mechanical drilling rate and the rock-breaking pattern. Therefore, for both bit types, kinematic parameters play a decisive role in load distribution and drilling efficiency.

Discussion

Comparison of the reviewed studies reveals that the kinematic response of both PDC and roller-cone bits is nonlinear and determined by the combined effects of motion parameters and cutting-element geometry. In PDC bits, enhanced drilling efficiency is often achieved through localized increases in contact stress on individual cutters, whereas in roller-cone bits, a similar effect arises from increased impulse loads on the teeth.

Contrary to traditional models assuming uniform load distribution, contemporary approaches emphasize the need to account for the actual kinematics of cutting elements. For PDC bits, this is expressed in asymmetric cutter contact, while for roller-cone bits, it appears in complex tooth trajectories and variable contact behavior with the bottomhole.

The findings indicate that optimization of drilling parameters must consider the specific kinematic response of each bit type. Universal approaches that ignore differences in rock-breaking mechanisms may reduce drilling efficiency and accelerate tool wear.

Limitations

A limitation of this study is the uneven level of detail in available data for PDC and roller-cone bits. PDC bits benefit from more advanced numerical models and experimental methodologies, whereas many studies of roller-cone bits are limited to macroscopic drilling parameters [1–5].

Additionally, most experimental data were obtained under laboratory conditions, which do not fully account for formation heterogeneity, drill-string dynamics, or the non-stationary drilling conditions typical of field operations.

Conclusion

The analysis demonstrates that kinematic variations significantly influence the response of both PDC and roller-cone bits, shaping load distribution, rock failure mechanisms, and the rate of cutter wear. For PDC bits, motion parameters and cutter geometry play a central role, while for roller-cone bits, tooth trajectories and the impulsive nature of contact with rock are dominant.

These conclusions provide a theoretical foundation for further research aimed at quantitatively comparing the kinematic responses of PDC and roller-cone bits and developing adaptive drilling regimes that account for the specific characteristics of each bit type.

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