UDK 622.243.3

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DESIGN OF PDC DRILL BITS AND THEIR OPERATING MODES USING A NEW METHOD FOR QUANTITATIVE ASSESSMENT OF DYNAMIC ROCK HARDNESS

The efficiency of oil and gas well drilling in Ukraine is critically important amid efforts to achieve energy independence and counter external aggression. PDC (polycrystalline diamond compact) bits dominate the industrial drilling volume, accounting for 75–85% in regions like the Dnieper-Donets Basin, Carpathians, and Black Sea shelf. Their advantages include high wear resistance, penetration rates, and suitability for horizontal drilling in unconventional reservoirs such as shale gas and tight gas. However, initial bit selection based on static geological data often leads to inefficient rock failure, increasing drilling time by 15–25% and costs by up to 10–12 million UAH per well. The core issue is the inaccurate assessment of dynamic rock hardness, a key parameter determining resistance to the cutting-chipping action of PDC cutters. Traditional methods, such as those by Shreiner, Protodyakonov, or OST 41-89-74, focus on static indentation or impact crushing, neglecting the combined axial and tangential forces in real drilling, where rock properties vary by ±2.5% due to anisotropy, fracturing, and hydrostatic pressure [1, 2].

Global market analysis indicates steady growth for PDC bits (>4% annually from 2020 to 2025), driven by exploration and new field development. Onshore drilling, comprising 70% of global oil production, leads the segment, with North America holding the largest market share due to shale activities. Lateral lengths in U.S. unconventional wells have increased by 180% over the past decade. Key trends favor onshore projects for their simplicity and faster startup compared to offshore. Investments in new wells, such as Baker Hughes' 300-well contract in Rajasthan, India, and ONGC's 200 wells in Assam, boost PDC demand but require adaptation to regional conditions. Volatility in oil prices and geopolitical factors restrain growth, emphasizing the need for enhanced tool efficiency to reduce costs [3, 4].

Restraining factors for PDC bit performance include impact loads as the primary cause of wear, necessitating optimization of bottomhole assembly (BHA) and drilling modes. PDC bits excel in cutting-chipping failure, twice as effective as indentation, offering higher penetration and reduced torque via oval-spiral surfaces. However, they demand more energy and precise directional control. In Siberia, PDC bits constitute up to 90% of industrial use, improving footage and reducing failures. Understanding loads at the bit-rock interface is essential: the resultant force R combines axial (P_{is}) and cutting (F_r) components at a tangent angle. If R directs upward, it reduces rock resistance and axial force, decreasing cutting depth from h_k to h_n. The normal force N acts on the compression core, expending R to overcome internal friction [5, 6].

Critical review of rock hardness evaluation methods reveals limitations for PDC drilling. Shreiner's method uses static indentation with a stamp on setups like UMGP-3/4, recording load-deformation diagrams. It classifies rocks as brittle, brittle-plastic, or highly plastic, calculating hardness as P/F (load over stamp area) and plasticity coefficient K_p as total work over elastic work. For brittle rocks, deformation is linear to failure (point A); for brittle-plastic, it includes elastic (OA) and plastic (AB) phases with yield limit P_t. Highly plastic rocks lack brittle failure, setting K_p to infinity. Shreiner's classification tables by hardness and yield strength are effective for static processes but inadequate for dynamic cutting-chipping, as they ignore tangential cutting forces.

For sedimentary and soft rocks, it fails due to low resistance. Samples from core (1.5–2 cm fragments) undergo impact testing in a POK device: 10 drops of a 2.4 kg weight from 0.6 m, sieving through 0.5 mm, and calculating F_d as specific crushing work, K_{ab} as mass loss Q, and $\rho_m = F_d * K_{ab}$. For rotary drilling, ρ_m determines categories; for percussive-rotary, $\rho_{m\_ud} = F_d * K_{ab}^{0.5}$.

Dynamic strength dominates percussive modes, abrasiveness rotary ones. These inform cost estimates and tool selection but overlook full PDC dynamics.

Other methods – Brinell (ball indentation, hardness as load over imprint area), Rockwell (cone indentation, HR=100-kd), Shore (striker rebound height), Leeb (velocity change), Mohs (scratch scale) – suit metals/minerals or roller-cone bits but not PDC, as they consider only vertical forces, excluding cutting. Indirect acoustic methods register emissions from tool-rock interaction, detecting microcracks and failure types (surface, volumetric, fatigue). Combined with gamma or gas logging, software like RSA accounts for in-situ pressures and anisotropy for real-time hardness. However, they lack quantitative criteria for PDC-specific volumetric failure transition. To address these gaps, a new quantitative method for dynamic rock hardness is proposed, linking it to the transition to optimal volumetric failure in cutting-chipping. Implemented on the UMR setup with a fixed cutter (Stratapax/GOST 880-75), it uses rigid cutter fixation on a force-measuring device and sample movement with variable chip thickness. Parameters (rake angle 5–30°, speed, thickness) are adjustable to capture static indentation and dynamic failure stages until volumetric mode. The criterion H_vd, analogous to Shreiner's H_v but for dynamic processes, is a material constant of plastic deformation resistance under combined forces, objective across rock spectra from soft sedimentary to hard.

Verification on UMR yields nomograms for blade count selection and mode recommendations (axial load, RPM, feed), reducing drilling time by 10–15% and footage per bit by 20–30%. The method integrates static/dynamic stages, matching analytical models of resultant R_x, enabling scientifically grounded PDC design, BHA optimization, and 30–40% failure reduction. Practical value lies in implementation at Ukrgazvydobuvannya and private operators, cutting costs by 8–12% and bolstering Ukraine's energy security. In conclusion, the developed method overcomes traditional limitations, providing precise dynamic hardness assessment for PDC bit design and modes, enhancing drilling efficiency in Ukrainian fields.

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