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ANALYSIS OF TOPICAL ISSUES OF RIFLE BARREL FLUTING INFLUENCE ON THERMAL CALCULATION

Designing the barrels of modern weapons—from tank guns and grenade launchers to precision rifles and machine guns—requires comprehensive consideration of the complex thermal and mechanical processes that occur during firing. These processes are associated with extreme heating and pressure conditions, presenting a challenge for designers to accurately analyze the thermodynamic effects on barrel materials. The reliability, durability, and performance of weapons depend on the effective management of these processes, making thermal analysis of barrels an important scientific task.

The main processes occurring in the gun barrel during firing can be divided into several key categories. Firstly, there are the dynamics of gunpowder gas combustion. When gunpowder or other explosives are ignited, large volumes of gases are rapidly produced, expanding and creating high pressure (up to 300–600 MPa) and temperatures (up to 3000–4000 K) in the barrel channel. This rapid thermal surge transfers energy to the inner surface of the barrel, potentially causing localized melting and accelerated metal erosion if there is insufficient protection against overheating. The paper [1] investigates how reducing the tensile strength of a barrel coating under heat affects its service life. The authors developed a model that accounts for fatigue damage to the coating due to cyclic thermal and mechanical stresses, leading to flaking and barrel damage. Traditional models rely on a constant strength assumption without considering the effect of temperature, making their predictions less accurate. Numerical modeling, including the finite element method, has shown that accounting for the temperature dependence of strength significantly improves prediction accuracy, as confirmed by tests.

The barrel cooling process begins immediately after the shot is fired and is achieved through heat transfer to the environment. Convection and heat conduction play a key role here: the barrel gradually cools down, but in the case of multiple shots, such as with automatic weapons, it does not have enough time to cool fully, leading to heat accumulation and reduced strength characteristics. The paper [2] analyzes the causes of failure in the locking block of semi-automatic rifles, focusing on material selection, geometry, and heat treatment. The main failure factors were identified as poor material selection, inadequate heat treatment, and geometric defects causing stress concentrations in critical areas. AISI 4340 steel, hardened and tempered at 450°C, was found to be the optimal material for the block, providing a balanced combination of strength and ductility. To enhance durability, it is recommended to smooth sharp edges of the block and adapt the venting system.

Erosion and mechanical wear are also critical to consider. Prolonged exposure to high temperatures and the friction of the projectile against the barrel walls inevitably lead to both chemical erosion (interaction of powder gases with the metal) and mechanical erosion. This issue is especially relevant for large-caliber rifles and tank guns, where the force of impact and rate of wear are higher.

The article [3] investigates the mechanisms of gun barrel failure under the influence of high temperatures, pressure, friction, and fatigue loads. The primary damage factors include erosion, projectile friction, and fatigue cycles, which lead to the formation and expansion of micro-cracks. Laboratory tests have confirmed the three-phase nature of fatigue failure: stable crack growth, accelerated crack development, and sudden fracture. It is proposed to use deformation sensors on the outer surface of the barrel to monitor its condition, allowing real-time assessment of barrel life and the prevention of failures to ensure operational safety.

Thermal and mechanical deformation of the barrel is another factor affecting gun performance. During cyclic heating and cooling, temporary or permanent deformation can occur, reducing accuracy and potentially necessitating barrel replacement. Thus, thermal analysis can predict the impact of temperature on wear, material fatigue, and resistance to external loads affecting accuracy. To effectively manage thermal processes in the barrel, several design solutions have been developed, among which fluting holds a special place. Fluting involves adding longitudinal grooves to the barrel surface, increasing its surface area, enhancing heat dissipation, and reducing weight, which is important for mobile weapons. The effectiveness of fluting is particularly evident when the weapon is subject to significant thermal stresses, such as with sniper rifles, where fluting helps prevent thermal deformation, maintaining accuracy even after multiple shots.

Automatic weapons and long-range machine guns also benefit from fluting, as it helps reduce heat buildup. Additionally, high-caliber hunting and tactical rifles use fluting to stabilize the barrel, offering advantages for long-range shooting.

Fluting serves several essential functions: increasing surface area for more efficient cooling, reducing weight, and improving structural rigidity. To accurately calculate the optimal fluting parameters, such as groove depth and width, computer modeling tools like ANSYS and SolidWorks are used. These tools enable the creation of barrel models and the analysis of their behavior under thermal stresses, helping to determine which fluting profile will deliver the best results under specific operational conditions.

In conclusion, the thermal analysis of weapon barrels, including the calculation of fluting parameters, is a critical design step aimed at enhancing the durability, performance, and safety of weapons in harsh environments.

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