

UDC: 621.43.016:621.43.038

## THE IMPORTANCE OF EXTERNAL DESIGN AND GEOMETRY IN ENSURING PISTON RELIABILITY

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**Abstract.** This article highlights the importance of a piston's external design and geometric accuracy in ensuring reliable operation of internal combustion engines. It explains how surface quality (scratches, roughness, edge wear) and shape deviations influence friction conditions, oil-film stability, and heat transfer, which directly affect wear rate, mechanical losses, oil consumption, and blow-by. A comparative assessment is provided between traditional cylindrical-conical pistons and modern oval-barrel (barrel/oval) geometries. The study shows that eliminating edge contact and achieving proper thermal-expansion compensation allow reduced clearance, improved lubrication, lower noise, and extended piston service life.

**Keywords:** Piston, piston geometry, surface quality, geometric accuracy, oval-barrel profile, cylindrical-conical piston, thermal expansion, lubrication (oil film), friction and wear, engine reliability.

## ЗНАЧЕНИЕ ВНЕШНЕЙ КОНСТРУКЦИИ И ГЕОМЕТРИИ В ОБЕСПЕЧЕНИИ НАДЁЖНОСТИ ПОРШНЯ

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**Аннотация.** В статье рассматривается значение внешней конструкции и геометрической точности поршня в обеспечении надёжной работы двигателей внутреннего сгорания. Показано, что качество поверхности (царапины, шероховатость, износ кромок) и отклонения формы существенно влияют на условия трения, стабильность масляной плёнки и теплоотвод, что напрямую отражается на скорости износа, механических потерях, расходе масла и прорыве газов в картер. Проведён сравнительный анализ традиционных цилиндрико-конических поршней и современных овально-

бочкообразных профилей. Установлено, что устранение кромочного контакта и правильная компенсация теплового расширения позволяют уменьшить рабочий зазор, улучшить условия смазки, снизить шум и увеличить срок службы поршня.

**Ключевые слова:** поршень, геометрия поршня, качество поверхности, геометрическая точность, овално-бочкообразный профиль, цилиндро-конический поршень, тепловое расширение, масляная плёнка, трение и износ, надёжность двигателя.

**Introduction.** The external shape of a piston plays a critical role in its efficient operation. The evolution of engine design has directly influenced the transformation of piston geometries. In the early stages of engine development, pistons featured extremely simple designs—cylindrical across their entire height—and were typically manufactured from cast iron or steel. This was due to the lower power output and crankshaft speeds of that era, which were 3–4 times lower than modern engines, resulting in significantly lower thermal stress on the piston components.

The Evolution of Piston Geometry and Materials. Throughout the history of engine engineering, increasing power density has been a primary objective. The most effective methods to achieve this are increasing the mean effective pressure within the cylinder and enhancing the crankshaft rotational frequency. Both parameters directly lead to increased thermal and mechanical loads on the piston. Consequently, as engine technology advanced, both the external shape and the materials of pistons evolved.

**The main part.** While low-power, low-speed engines utilized cylindrical cast iron or steel pistons, the shift toward higher power and speed necessitated the transition to “cylindrical-conical” shapes and the use of aluminum alloys. As power increases, the piston temperature rises unevenly; the upper part (crown) heats up significantly more than the lower part (skirt). This thermal gradient

requires the piston to be manufactured with a larger diameter at its “cold” section and a smaller diameter at its "hot" section to account for thermal expansion. This results in a cylindrical-conical geometry. Piston grouping and sizing are typically conducted based on the maximum diameter.

Furthermore, piston materials have become progressively lighter. Using cast iron or steel at high rotational frequencies is problematic due to the substantial increase in inertial forces during the piston's reciprocating motion.

Comparative Analysis of Piston Shapes. Until the 1985–1990s, pistons in tractor engines used in the agriculture of the Republic of Uzbekistan primarily maintained a cylindrical-conical shape. During the same period, international tractor and automotive manufacturers shifted toward oval-barrel (ovate-prolate) geometries. If we analyze the thermal expansion of a cylindrical-conical piston, it results in the configuration shown in Figure 1.

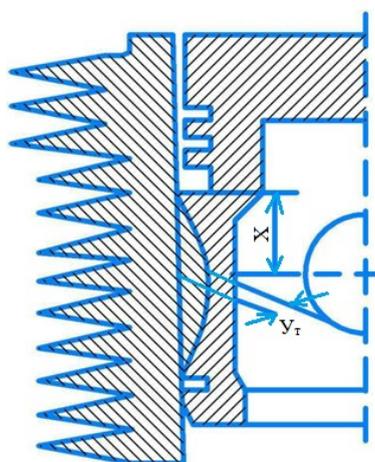


Figure 1. Profile of a cylindrical-conical piston under thermal expansion.

Such a shape creates “edge contact” with the cylinder wall. In its heated state, a cylindrical-conical piston establishes contact with the cylinder only at the upper and lower edges of the skirt. This type of contact: Accelerates piston wear; Increases the piston-to-cylinder clearance; Leads to higher mechanical losses.

An increased clearance results in higher oil consumption (burning) and “blow-by” (leakage of combustion pressure into the crankcase), which ultimately reduces engine power.

**Methods.** A comparative and analytical approach was used to evaluate the influence of piston external geometry on operational reliability. Traditional cylindrical-conical pistons were compared with modern oval-barrel geometries in terms of thermal expansion behavior, contact conditions with the cylinder wall, and load distribution. Relevant scientific literature on friction, wear, lubrication, and heat transfer in the piston–cylinder assembly was also reviewed. The assessment criteria included wear resistance, oil-film stability, mechanical losses, and piston-to-cylinder clearance.

**Advantages of Modern Oval-Barrel Geometry.** Leading international piston manufacturers have abandoned the simple cylindrical-conical design in favor of shapes that eliminate these deficiencies. Organizations specialized in manufacturing pistons for engine repair must adopt modern global practices and transition to oval-barrel (barrel-shaped) production. The advantages of the oval-barrel shape include:

**Reduced Wear:** Since there is no “edge contact” with the cylinder, wear is significantly minimized.

**Surface Contact:** The barrel shape ensures contact over a specific surface area rather than a sharp line. This distributes the load, reducing friction and localized wear. **Optimal Clearance:** It allows for a reduction in the initial piston-to-cylinder clearance. For example, in D-144 engines, the clearance was reduced from 0.20–0.24 mm to 0.11–0.12 mm.

**Results.** The analysis shows that cylindrical-conical pistons tend to create edge contact with the cylinder wall under thermal expansion, leading to increased wear, higher mechanical losses, and greater oil consumption. In contrast, oval-barrel geometry provides more uniform load distribution and surface contact instead of line contact. This improves lubrication conditions, stabilizes the oil film,

and allows reduced operating clearance. As a result, piston durability increases, engine noise decreases, and overall engine reliability is enhanced.

**Improved Lubrication and Acoustics:** The transition from edge contact to surface contact improves oil film stability and reduces engine noise (piston slap). The specific "barrel" profile is determined based on the thermal characteristics and construction of each specific engine. Furthermore, if the longitudinal profile is made "barrel-shaped" and the cross-section is made "oval," the advantages regarding compensation for thermal expansion and mechanical stability are further enhanced.

**Conclusion.** The study confirms that the external design and geometric accuracy of a piston play a decisive role in ensuring the operational reliability of internal combustion engines. Surface quality, dimensional precision, and proper compensation for thermal expansion significantly influence friction behavior, oil-film stability, heat transfer, and wear characteristics. Comparative analysis demonstrates that traditional cylindrical-conical pistons are more prone to edge contact under thermal loading, which increases wear and mechanical losses. In contrast, modern oval-barrel geometries provide improved load distribution, reduced friction, and enhanced lubrication conditions. As a result, optimized piston geometry contributes to extended service life, lower oil consumption, reduced noise, and improved overall engine reliability. The adoption of advanced geometric designs is therefore essential for achieving higher durability and performance in modern engines.

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