



Ways to increase the wear resistance of pistons of internal combustion engines (review)

T. V. Dudchak*

Podolsk Agricultural and Technical University, Ukraine

*E-mail: dvp18r@i.ua

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Abstract

The article analyzes the materials from which the piston is made for internal combustion engines. For automobile and tractor engines, in particular, eutectoid mixtures of the AL25 type and eutectoid mixtures containing copper, nickel, magnesium and manganese are used. The chemical composition of aluminum alloys is given. Pistons for high-speed, forced diesel, medium-speed engines are made of gray or malleable cast iron (SCh24-44, SCh28-48, SC32-53), as well as alloyed with additives of vanadium, chromium, titanium, copper (RF45-5). Heat-resistant steels of the 20Kh3VMF type are used for combined pistons. Research work is being carried out on pistons made of titanium and carbon fiber. Pistons with automatic adjustment of the degree of compression can limit the thermal and mechanical stress of the parts of the cylinder-piston group, boost the engine at an average effective pressure of 1.5-2 times, improve starting quality, provide the ability to use different brands of fuel. A combined piston with copper-fluoroplastic inserts is available for internal combustion engines, compressors, pumps and other reciprocating machines. Inserts made of copper-fluoroplastic composition provide the application of a thin film of copper on the friction surface throughout the life of the engine, which significantly accelerates running, reduces burrs and abrasions, increases wear resistance and durability of CNG parts. The main disadvantages and advantages of the performance characteristics of pistons made of different materials. The analysis of designs of pistons is made. The main requirements for the design of pistons are: simplicity of design, and if possible to ensure symmetry about the axis of the cylinder, minimum weight, maximum strength and rigidity, wear resistance of the material, efficient heat dissipation (cooling); minimum cost of production. The main defects of the piston are: the height of the first groove, the diameter of the hole under the piston pin, the diameter of the skirt.

Key words: engine, piston, fluoroplastic, construction, wear resistance, piston skirt, restoration, deformation, remelting, cylinder, strength, rigidity, durability.

Materials for pistons

For the manufacture of pistons, depending on the purpose of the engine and type of construction, use cast iron, steel, aluminum alloys. For automobile and tractor engines, in particular, eutectoid mixtures of AL25 type (11-13% Si) and eutectoid mixtures containing copper, nickel, magnesium and manganese are used. Pistons of these alloys are made by casting into the ground or in the chill mold, the latter method allows you to more accurately withstand the weight of the workpiece, reduce the allowance for machining. Pistons are also stamped from alloys AK-4, AK4-1, AK2, D20, which have high properties at elevated temperatures (300°C). The chemical composition of materials for aluminum-based pistons are shown in table 1.

Pistons for high-speed, forced diesel, medium-speed engines are made of gray or malleable cast iron (CЧ24-44, SCh28-48, SCh32-53), as well as alloyed with additives of vanadium, chromium, titanium, copper (BЧ45-5).

Heat-resistant steels of the 20Kh3MVF type are used for combined pistons. Pistons made of cast iron and steel are characterized by greater strength, wear resistance and lower coefficient of thermal expansion compared to aluminum alloys. Their use reduces the gaps between the piston skirt and the sleeve. The main disadvantages of cast iron and steel pistons are increased wear of the cylinder mirror, low thermal conductivity (3-4 times less than aluminum alloys), greater weight (30-50% more than aluminum pistons).



Table 1

Chemical composition of aluminum alloys for pistons of tractor engines

Brand of alloys	Chemical composition of the main components									
	AL	Mg	Si	Mn	Cu	Ni	Ti	Cr	Fe	Zn
AL-1	basis	1,25-1,75	–	–	3,7-4,5	1,75-2,25	–	–	–	–
AL -11	basis	0,1-0,3	6,0-8,0	–	–	–	–	–	0,8-1,2	10-14
AL 24	basis	1,5-2,0	–	0,2-0,5	–	–	0,1-0,2	–	–	–
AL 25	basis	0,8-1,3	11,0-13,0	0,3-0,6	1,5-3,0	0,8-1,3	0,05-0,2	–	–	–
AL 30	basis	0,8-1,3	11,0-13,0	–	0,8-1,5	0,8-1,3	–	–	–	–
AL 21	basis	0,8-1,3	–	0,15-0,25	4,6-6,0	2,6-3,6	–	0,1-0,2	–	–
VKZLS -2	basis	0,2-0,5	20,0-22,0	0,20-0,40	2,2-3,0	2,2-2,8	0,1-0,3	0,2-0,4	–	–
AK4	basis	1,4-1,8	0,5-1,2	–	1,9-2,5	0,8-1,3	–	–	0,8-1,3	–
AK4-1	basis	1,2-1,8	–	–	1,9-2,7	0,8-1,4	0,02-0,1	–	0,8-1,4	–

Noteworthy is the research work on titanium and carbon fiber pistons. So in the USA [1] the patented engine with pistons, piston rings, cylinder liners and cylinder blocks is made of carbon fiber. The engine significantly reduces the thermal gaps between the parts of the CNG, which in turn reduces the impact when relocating the pistons, the breakthrough of gases from the combustion chamber, emissions of unburned carbohydrates. In Germany [2] a piston made of carbon is proposed. The method of manufacturing carbon structural material involves pressing carbon granules under high pressure at high temperature. The carbon piston has a low coefficient of friction and thermal expansion, can work reliably in some modes in dry friction. The weight of the piston is much less than the weight of the metal pistons. The design of the piston with the use of carbon inserts in the walls of the piston skirt, receiving lateral loads, is also proposed.

Piston designs.

The piston of internal combustion engines is the most loaded part, as the temperature of the gases can reach 2500°C, and mechanical loads are close to shock. Temperature differences along the length of the piston cause thermal stresses that contribute to its deformation. The piston consists of the upper part (sealing) and lower (guide). The sealing part has piston rings that ensure the tightness of the working part of the cylinder, the guide (skirt) receives lateral loads. Basic requirements for the design of pistons:

1. Simplicity of a design, and if possible maintenance of symmetry concerning an axis of the cylinder;
2. Minimum weight, maximum strength and rigidity, wear resistance of the material;
3. Effective heat dissipation (cooling);
4. Minimum cost of production.

Pistons for carburetor engines are usually made of lightweight aluminum alloys with T-shaped and U-shaped slots (Fig. 1). Slots in the pistons reduce the gap between the piston and the sleeve, which significantly reduces shocks and vibrations during transfers and reduces the likelihood of jamming. In these pistons, the cross section is made in the form of an oval, the major axis of which is in the plane of oscillation of the connecting rod. Pistons with slots are used in engines with small cylinder diameters. Cast alloy pistons made of aluminum alloys with an annular cavity are also used for cooling (Fig. 2) with oil supplied through a nozzle [3]. These pistons are used in engines with a crankshaft speed of more than 2000 min⁻¹.

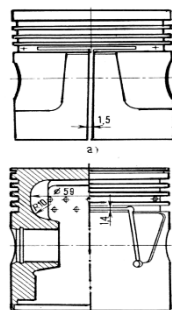


Fig.1. Monometallic pistons of carburetor engines: a) T-shaped; b) U-shaped form

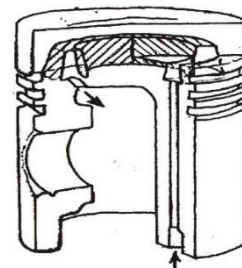


Fig. 2. The scheme of cooling the piston head

In forced diesels, the piston rod is stamped from an aluminum alloy, and the head is made of heat-resistant material (cast iron or alloy steel) [3]. In the engine 16ЧН48 / 58 with a decrease in the thickness of the steel head of the piston, the temperature in the area of the first annular groove decreased by 40 ° C. In fig. In Fig. 3 shows

the design of the combined piston. In the construction of combined pistons use thermal insulation between the piston head and the cutting (Fig. 4).

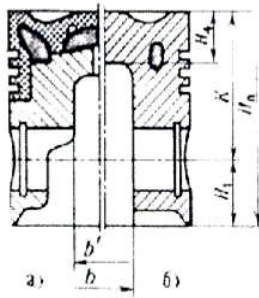


Fig. 3. Piston of forced diesels: a) combined; b) all-metal

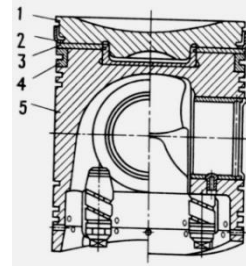


Fig. 4. Piston with heat pad and inseparable heat ring: 1 - head; 2 - inseparable heat ring; 3 - thermal insulation; 4 - ring holder; 5 - piston

For two-stroke high-power engines from Sulzer, in order to prevent overheating and trapping of the piston, forced rotation of the piston around its axis was used during engine operation [4]. With the help of a gear wheel, which is located in the middle of the piston body and two ratchets, which are located in the connecting rod, the movement of the connecting rod was converted into angular (cyclic) movement of the piston (Fig. 5). The ratchet wheel is connected to the piston by a plate spring, which ensures smooth rotation of the piston around the axis (about 10 min-1 at 500 revolutions of the crankshaft per minute). The connecting rod and the piston are connected by a ball bearing. To preserve the shape of the skirt of diesel pistons set compensating inserts in the form of ribbons (Fig. 6), which cover a significant part of the skirt [3].

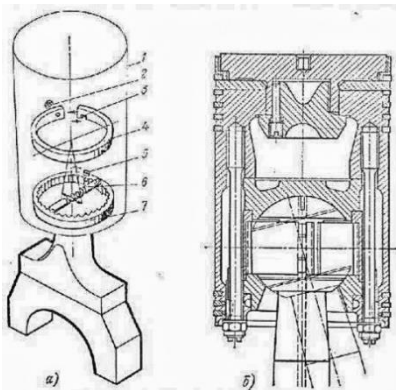


Fig. 5. Piston of the Sulzer engine: a) a sketch of the mechanism of rotation of the piston; b) piston design

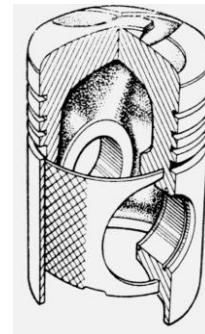


Fig. 6. Piston with thermostatic insert

Diesel pistons of diesel engines work in difficult conditions. There are a large number of different designs that differ in the shape of the head, the method of its attachment to the piston cutting, the type of cooling, the brand of material. The piston of the two-stroke diesel locomotive is presented in fig. 7. Its design feature is that instead of pins there is a snap ring, which is located in the light part of the skirt [3].

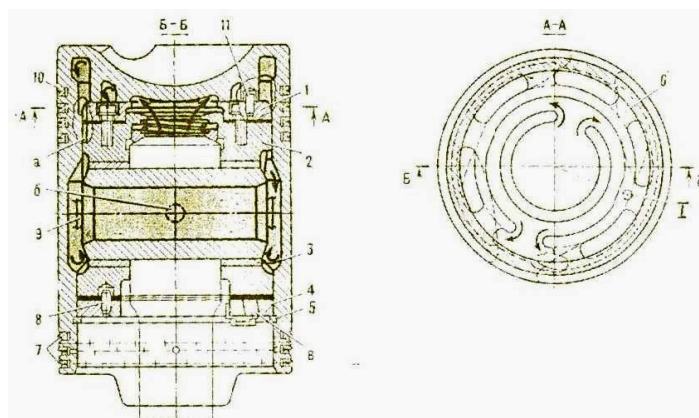


Fig. 7. The piston of the two-stroke diesel engine 2D100: a, b, c - a groove and openings for oil exit from a head and a piston insert; 1 - top plate; 2 - insert; 3 - bushing; 4 - bottom plate; 5; 6 - radial rib; 7 - oil removal ring; 8, 11 - pin; 9 - finger stops; 10 - compression ring

During the modernization of the engine L-V42M (ЧН42 / 45), as a result of which the cylinder power was increased to 625 kW, the company "MITSUI" used a lightweight piston, which consists of three parts (Fig. 8). The cast steel piston head is made with thinner walls and carries two of the three compression rings (there were four). Below the head is the main part, made of cast iron with ball-shaped graphite, on which is the third compression ring, as well as a bearing for the piston pin. The main part is a skirt made of aluminum alloy. The weight of the piston was reduced by 27%.

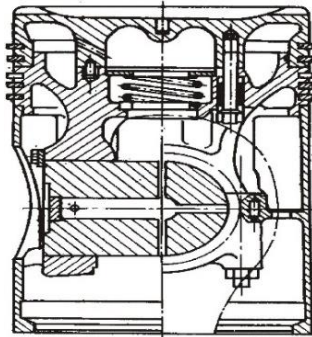


Fig. 8. Composite piston company "MITSUI"

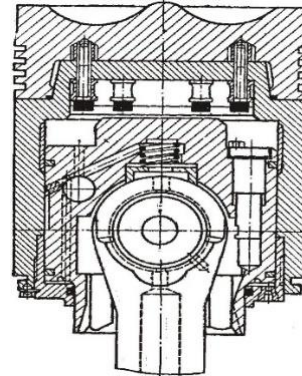


Fig. 9. Diesel piston with varying degrees of compression

The combined piston for the diesel with high forcing which provides a variable degree of compression at work is presented in fig. 9 [5]. Pistons with automatic adjustment of the degree of compression (Fig. 10) can limit the thermal and mechanical stress of the parts of the cylinder-piston group, boost the engine at an average effective pressure of 1.5-2 times, improve starting quality, ensure the use of different brands of fuel [6].

One of the promising methods of reducing the stress state and strengthening the pistons is the use of matrix inserts made of ceramic fibers, which are filled with molten magnesium alloy. In fig. In Fig. 11 shows a diagram of the piston where the head is reinforced with fibers 1 of Al_2O_3 , and under the compressor rings filled with an insert of niresist 2.

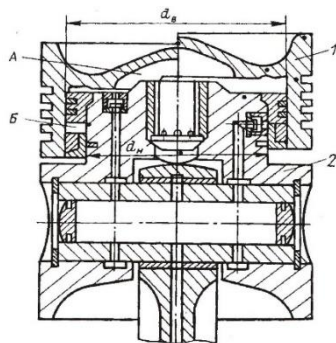


Fig. 10. Structural diagram of the piston with automatic adjusting compression ratio: 1 - piston shell; 2 - housing; A and B - respectively, the upper and lower hydraulic cavities

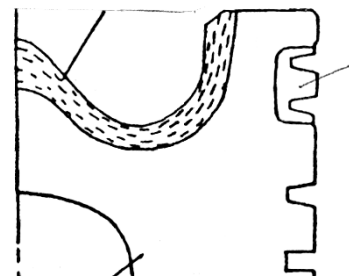


Fig. 11. Combined piston: Al_2O_3 fibers; niresist; piston (aluminum alloy)

In the United States [7], a piston is patented that has a wide outer annular non-metallic insert in the area of the piston pin lugs, which prevents direct contact of the skirt with the cylinder mirror. The insert is made of heat-resistant polymeric material with graphite filler and has a low coefficient of friction.

For internal combustion engines, compressors, pumps and other reciprocating machines, a combined piston [8-9] with copper-fluoroplastic inserts is offered (Fig. 12).

In the standard piston of a diesel engine with a wall thickness of 4 mm and more in the guide part (skirt) drilled two grooves in the form of a "swallowtail", in which inserts of composite polymeric material based on fluoroplastic F4.

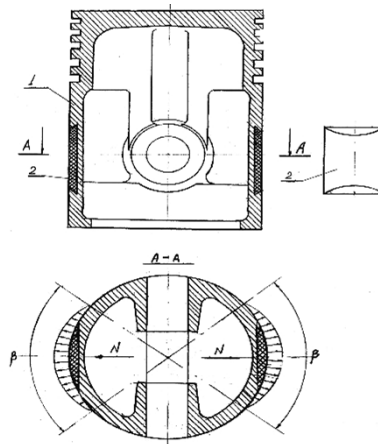


Fig. 12. Combined piston: 1 - piston; 2 - insert

Inserts of copper-fluoroplastic composition provide a thin film of copper on the friction surface throughout the service life (before overhaul) of the engine, which significantly speeds up running time, reduces burrs and abrasions, increases wear resistance and durability of CNG parts. The experimental sample of the piston of the YaMZ-236 engine is presented in fig. 13.

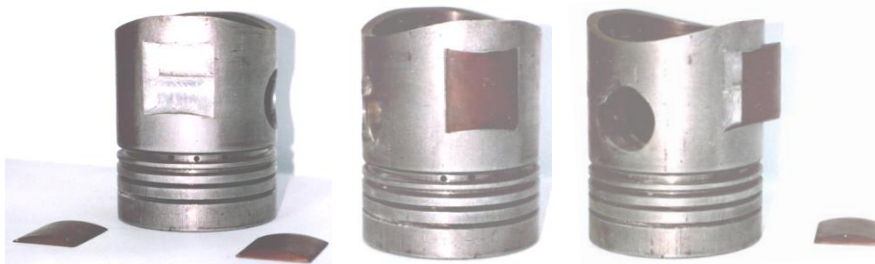


Fig. 13. Combined piston with copper-fluoroplastic inserts

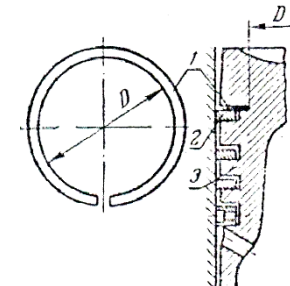


Fig. 14. Scheme of restoration of the coupling ring-piston groove: 1 - clamping ring; 2 - piston ring; 3 - piston

Ways to restore the pistons

The main defects of the piston are: the height of the first groove, the diameter of the hole under the piston pin, the diameter of the skirt.

Coupling - the first piston ring - the groove of the piston wears out the most. It was found [10] that 75% of worn pistons made of aluminum alloys have a defective defect of the upper groove, which is restored by boring, installing a ring of aluminum alloy, welding it with subsequent boring under the ring of nominal size. The holes for the piston pins are restored by boring to the repair size using a finger of increased diameter.

In individual production, the coupling "piston groove - upper piston ring" can be restored by the method of auxiliary repair dimensions, developed by prof. K.A. Achkasov. To do this, in the pre-drilled groove of the piston (Fig. 14) install a spring ring complete with a piston ring of nominal size. Spring rings are made of steel tape steel U-7 or U-8 by winding, followed by thermofixation. The thickness of the tape should be in the range of 0.75-1 mm, and the width should be equal to the size of the auxiliary groove above the first ring. Thermofixation temperature 400 °C.

The method of electron rubbing [11] is used to restore the piston skirt and holes in the lugs under the piston pin. Restore the piston with skirt wear up to 0.15 mm.

The process of electron rubbing of the piston takes place at high current densities, which provides high productivity of the process. Iron-zinc electrolyte is used to restore pistons made of aluminum alloys. The anode is made of zinc. When using an iron-aluminum electrolyte, the anode is made of steel.

Technological process of restoration of pistons is carried out in the following sequence: after washing, cleaning from a deposit of pistons degrease in the electrolytic way at the following modes: current density - 0,4-0,6kA / m², electrolyte temperature 40 °C, processing time - 1-1,5 min. After rinsing in water, the piston is clarified in nitric acid (7-9 s).

In the bath ACS 1513 spend zinc treatment by immersing the pistons in a solution of zinc sulfate with a holding time of 1.5-2 min at 45-50 °C.

Modes of electrofriction: piston speed - 30-40 min⁻¹, current density - 60-80 kA / m², electrolyte temperature - 45-50 ° C, pH acidity - 2.5-3, cooling rate - 0.01 mm / min.

The method of plastic deformation for the restoration of the piston skirt is proposed in [12]. We offer a special landing and leveling tool (Fig. 15) in the form of a roller knurler, which displaces the metal from the surface of the piston skirt and gives an increase in diameter of more than 0.2 mm. Profile notches form a rhombic grid, which is aligned by machining.

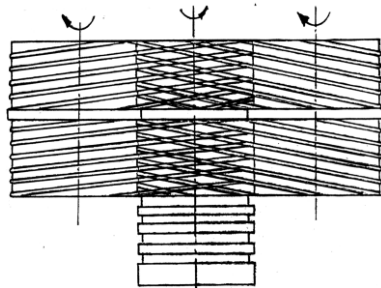


Fig. 15. Scheme of restoration of the piston skirt by plastic deformation

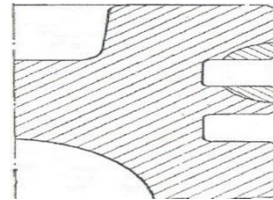


Fig. 16. Sealing of the upper groove of the piston by remelting by doping

Notches on the rollers of planting material provide the most favorable conditions for lubrication of friction surfaces.

The method of plasma remelting to restore and strengthen the piston grooves is that in the environment of argon gas melts part of the aluminum alloy with the simultaneous introduction of filler wire, which contains alloying elements (Fig. 16).

In the process of remelting, the alloying material interacts with the aluminum alloy with the formation of solid thermostable aluminides. Depending on the chemical composition of the piston and the number of alloying elements, the remelting strength increases by 1.2-1.3 times, hardness by 1.3-2 times, resistance by 1.5-4 times [13].

Conclusions

1. The analysis of materials from which pistons for internal combustion engines are made is made. The chemical composition of aluminum alloys is given.
2. For internal combustion engines, compressors, pumps and other reciprocating machines, a combined piston with copper-fluoroplastic inserts is offered.
3. The analysis of designs of pistons is made. The basic requirements for the design of pistons are presented. The main defects of the piston are presented.
4. The analysis of ways of restoration of pistons is made.

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Дудчак Т.В. Шляхи підвищення зносостійкості поршнів двигунів внутрішнього згорання (огляд)

В статті зроблен аналіз матеріалів, з яких виготовляють поршні для двигунів внутрішнього згорання. Для автомобільних і тракторних двигунів, зокрема, застосовують евтектоїдні суміші типу АЛ25 і заевтектоїдні, які містять мідь, нікель, магній та марганець. Приведений хімічний склад алюмінієвих сплавів. Поршні для швидкохідних, форсованих тепловозних, середньооберткових двигунів виготовляють з сірого або ковкого чавуну (СЧ24-44, СЧ28-48, СЧ32-53), а також легованого присадками ванадію, хрому, титану, міді (ВЧ45-5). Для комбінованих поршнів застосовують жаростійкі сталі типу 20Х3МВФ. Проводяться дослідні роботи над поршнями з титану і вуглепластиків. Поршні з автоматичним регулюванням ступеню стиску дозволяють обмежити теплову і механічну напруженість деталей циліндро-поршневої групи, форсувати двигун по середньому ефективному тиску в 1,5-2 рази, покращити пускові якості, забезпечити можливість використання різних марок палива. Для двигунів внутрішнього згорання, компресорів, насосів та інших поршневих машин пропонується комбінований поршень з мідно-фторопластовими вставками. Вставки з мідно-фторопластової композиції забезпечують нанесення тонкої плівки міді на поверхні тертя на протязі всього ресурсу роботи двигуна, що значно прискорює припрацювання, зменшує задири і натири, збільшує зносостійкість і довговічність деталей ЦПГ. Дані основні недоліки і переваги експлуатаційних характеристик поршнів, виготовлених з різних матеріалів. Зроблен аналіз конструкцій поршнів. Представлені основні вимоги при конструюванні поршнів, це: простота конструкції, і по можливості забезпечення симетричності відносно осі циліндра; мінімальна маса, максимальна міцність і жорсткість, зносостійкість матеріалу; ефективний відвід тепла (охолодження); мінімальна собівартість виготовлення.

Ключові слова: двигун, поршень, фторопласт, конструкція, зносостійкість, юбка поршня, відновлення, деформування, циліндр, міцність, жорсткість, довговічність.