

PISTON GROUPS

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Summary

The piston engine group includes a piston, piston rings and a piston pin. The piston is one of the most loaded parts of the engine. It is acted upon by the changes in pressure of hot gases and inertia forces. That is why the piston must have sufficient strength at increased temperature and be as light as possible. The pistons of fast running engines are usually made of light aluminum alloys. The pistons of large diesels are made of steel but sometimes they are made of cast iron. There is a great variety of different types of piston engine constructions including the form of bottom surface, the number of piston rings, the form of side surface of the piston case, the method of piston cooling and others.

Of great importance is the modeling of thermal and stress-strained state of elements when creating a reliable construction of a piston group. In this case effective mathematical models providing an efficient accuracy of computations are based on the method of finite elements. The principal problems connected with particularities of construction and calculation of strength of piston engine group elements are considered below.

1. Introduction

The piston engine group with usual crank mechanism includes a piston, piston rings and a piston pin. The engines with a cross head include a rod fixed stationary to the piston. The piston takes pressure of hot gases in the operating cylinder of the engine and transmits the effort of this pressure through the piston pin and connecting rod to a

connecting rod neck of a crankshaft where there appears a torque as a result. The torque removed from the crankshaft (it depends on the purpose of the engine) is transmitted to the transmission of a car, a tractor, to a screw of the vessel, to a propeller of the airplane, to the electrical generator rotor etc.

The piston is the most typical part of the internal combustion engine realizing its thermodynamic cycle directly.

Apart from the above-mentioned pressure which frequently exceeds 10 MPa, the heat (thermal) loads also act upon the piston. They are connected with the removal of considerable amount of heat from hot gases and heat isolated as a result of friction from piston parts when working. In fast-running engines inertia loads reach a noticeable value due to the reciprocating character of the piston with acceleration changeable in value and direction. For high level of listed loads modern engine pistons must operate reliably alongside with other engine parts within the limits of the given long enough service life. But it is not permitted the appearance of fatigue and thermal fatigue cracks and significant wears of piston ring grooves, lateral area of the piston body and a hole for a piston pin.

Therefore the pistons of modern engines are made of quality materials (mainly of metals) with relatively high mechanical, thermo physical and technological characteristics. The fast-running engine pistons first of all of automobiles (cars), motorcycles, airplanes, tractors and some other types must have light weight and must be usually made of aluminium alloys having rather high strength properties and wear resistance.

However with the increase of mean effective pressure using a turbocharging the high-temperature strength of aluminium alloys appears poor especially in large-size engines. Despite the application of the special cooling system (mainly by means of oil) the temperature in separate places of piston head fails to be kept at a level acceptable to aluminium alloys. In this case for all piston or its most heated parts (crown) much higher temperature resistance materials are used: cast irons, alloy steels. Lately (recently) the interest to non-traditional materials such as structural ceramics, composites, inter-metallic compounds that are superior by some parameters of usually used metal alloys has increased.

The piston (Figure 1) can conventionally be divided into three belts in the direction of the piston axis: an upper heated belt suitable to the piston crown and occupying the place from the upper edge up to the first piston ring, a packed belt - a place for piston rings location; and support belt-suitable to a piston skirt and to the location of a piston pin in engines with usual crank mechanism.

The axial size, mass, inertia forces and many important parameters of engine operation depend upon the extent of indicated belts of the piston. So the approximation of the upper compressive ring to the edge of the piston bottom reduces a dead volume and promotes improving of economy (profitability) and ecological characteristics of the engine. However in this case the working conditions of piston rings become more difficult.

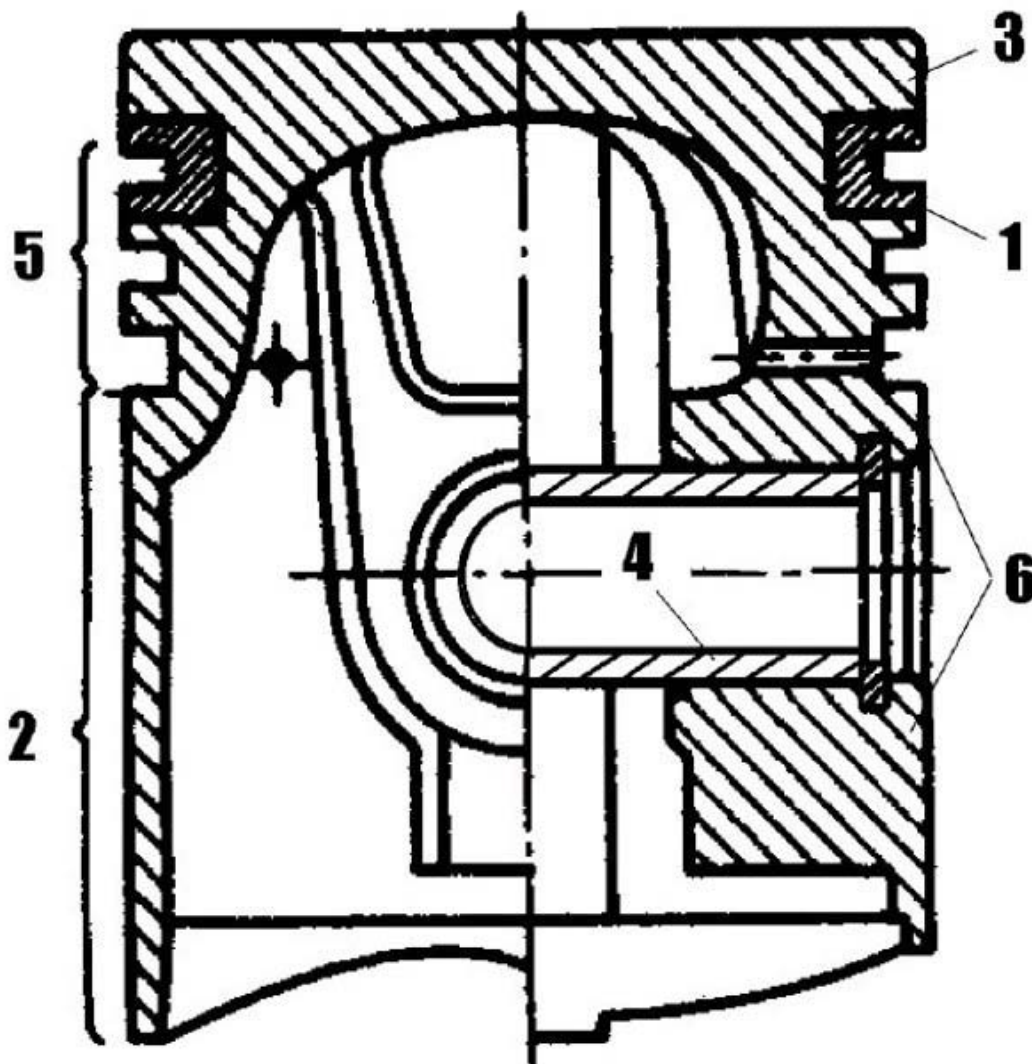


Figure 1. Piston group

The reductions of length of packed and support belts leads to the decreasing of piston height and the engine as a whole. But in case of an excessive reduction of strips between ring grooves the strength of these strips can appear poor. The reduction of length of the support belt can worsen the working conditions of conjugation of a piston skirt with the cylinder thereby increase specific loads, vibration level, leading to the increasing of the lubrication oil consumption. The shape of a skirt surface is as important as the extension of the support belt i.e. length of a skirt.

The cylindrical shape of a piston skirt especially in the case of the piston made of aluminium alloy is not favourable for conjugation action of a piston - cylinder. The pistons of modern engines are designed with different profiles of a lateral area: stepwise consisting of some conjugated cones (we speak about the deviations from the straight line generator in the 100-th of mm), curve lined with barrel shaped profile in particular. The pistons with the barrel shaped profile of lateral area have a number of advantages: possibilities of reduction of a radial gap in the directing belt, the reduction of intensity of piston impacts against the cylinder wall while resetting, which in its turn reduces the

danger of cavitation on a cooled surface of the cylinder and noise level of the operating engine.

In the plane perpendicular to the cylinder axis the optimal shape of a piston skirt differs from the round one designed with some ellipticity. The large axis of the cylinder is perpendicularly directed to a piston pin, that compensates the higher expansion of the piston along a piston pin from heating and pressure of gases on the piston head when the engine is running.

For reduction of gas escapes from the cylinder to the casing the compressive rings are set in the upper grooves of a packed belt of the piston. For removal of lubrication surpluses from the lateral area of the cylinder to prevent lube oil to get into the combustion chamber oil scraper rings are set after setting compressive rings. The number of compressive and oil scraper rings as well as the arrangement of the latter depends on the type and purpose of the engine [1]. So in modern fast-running engines as in automobiles, pistons with two compressive rings and one oil scraper ring are usually used. The piston rings being split are in the oblate state when the piston is in the cylinder.

It provides sealing between working surfaces of rings and a wall of the cylinder due to an elastic forces and additional contraction by gases. In the perfect case gas leakage from the above-piston space into the casing happens only through the ring lock - a gap formed while splitting the ring and it is hardly limited when the ring is in the working position in the cylinder of the engine. Being about 0.15 mms this gap must always be kept, otherwise when heating up the ring can be wedged in the cylinder. In the grooves the ring are arranged with a small gap in the direction of the cylinder axis, which ensures necessary mobility of a ring while the engine is running. The loss of mobility of a ring in the groove results in a loss of compression. Frequently this dangerous phenomenon is connected with the excessive temperature growth of the piston in the zone of rings arrangement, which in its turn leads to the modification of lube oil properties with the formation of lacquers and resins resulting in ring hanging. The excessive mobility of rings in the axial direction is also undesirable.

It is connected with the reinforcement of grooves wearing in particular of the upper compressive ring, which leads to excessive vibration of the ring groove and to its breakage in the end. For fast-running engines the axial gap of the ring in the groove is about 0,15 mms. To prevent the groove wear the piston material must have sufficient hardness in working temperature range.

Figure 2 shows some types of compressive rings. When the piston is moving from the dead point, a thin oil layer is formed under a working surface of the ring. If the value of this layer exceeds the value of micro-unevenness on working surfaces of a ring and cylinder face, the hydrodynamic operating mode is ensured that is always desirable. Shown in Figure 2 the inclination of working surface generator as well as convex shape of this surface promote the formation of oil layer under the working surface of a ring. The inclination of the end surfaces in a radial direction promotes the increase of ring mobility in the groove. Such shape of a ring called trapezoidal and is applied for the first and sometimes for the second ring of boosted diesel engines.

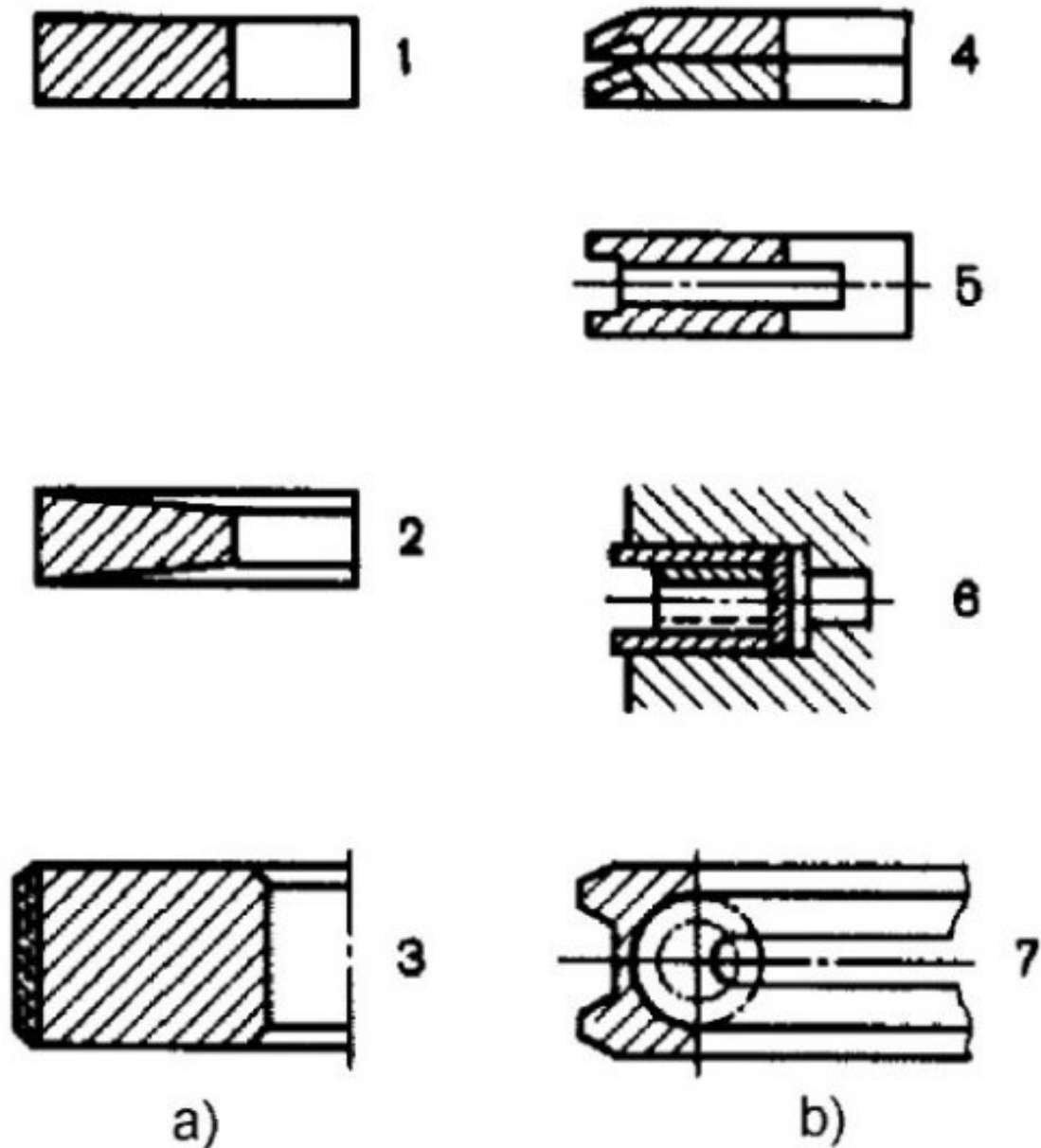


Figure 2. Types of piston rings

For decreasing the lube oil amount falling into the combustion chamber (while the engine is running) and hence for improving ecological parameters and reduction of oil consumption due to burning loss, one or several oil scraper rings are set on pistons after compressive rings. There are scraper, box-shaped or composite oil scraper rings. In all cases higher pressure is required on the working surface of an oil scraper ring for improving removal of an excessive volume of oil from a cylinder face. In case of composite rings a good agreement of working surface profile of ring elements with a deformable surface of a cylinder wall is ensured. It promotes better picking up oil from a cylinder wall.

For increasing ring pressure from the interior of the ring, special expanders in the groove are set. They exert additional pressing of rings to the cylinder wall. In

overwhelming majority of cases ring are made of perlite cast iron. The presence of graphite ensures high tribological properties in the cast iron. In some boosted diesel engines the upper compressive rings are made of steel. To increase ring wear-resistance special abrasive resistant coating of ring working surface is used. The coating including chromium and molybdenum are wide spread. To improve running-in and corrosion protection tinning and phosphating of ring working surface are applied in a number of cases. The fastest ring wear process occurs in the cut area-so-called lock. The preservation of ring sealing ability promotes maintenance of an irregular, quite definite form of pressure distribution over ring to the circumference on the cylinder wall with pressure growth in the lock area.

The construction and production process of piston rings is an important moment in designing of an engine piston group. The basic parameters of engine work depend on an effective work of piston rings: fuel and oil profitability, ecological characteristics, and resource. The friction losses in modern engines rings reach 25 per cent of all mechanical losses of a working engine.

The third basic element of piston group is a piston pin (PP) 4 Figure 1. It is an axis and executes a link connection with a connecting rod, transmitting to the latter the efforts from gas pressure and inertia. In four-stroke engines the pin is acted upon by a sign variable, but in two-stroke engine the load is close to pulsating. During the operation process PP is being heated owing to the heat transmission from the piston crown through bosses and also due to friction of the pin. Depending on a kind of fitting by which PP is set in the piston and connecting rod, it can either be stationary conjugated with one of the mentioned parts or turn through with regard to both a piston and connecting rod (floating pin).

In the latter case a relative velocity in a place of contact of surfaces of the pin and conjugated details is decreased. But in this case the pin requires fixing in the axial direction realized by means of special lock rings and sometimes by means of end-caps. Besides reciprocating motion together with the piston the pin also makes rotational motion. In fast-running engines the gaps in the pairs-boss-pin, connecting rod-pin make accordingly from 0.01 to 0.04 and from 0.01 to 0.03 mms. Small gaps in movable conjugation of the pin and high specific loads prevent the supply of a hydrodynamic lubrication of the pin. The pin works in conditions of boundary friction by heat release and wearing. Therefore the pin surface must be polished and have higher hardness. At the same time high dynamic loads cause significant flexural stresses in the pin changing by a turn stresses angle of the crankshaft. To ensure sufficient fatigue resistance the material of the pin must be elastic enough. Engine piston pins are made medium-carbon steels alloyed by chromium, low carbon steels alloyed by a chromium, nickel and molybdenum. The cementation of from 0.5 to 1.5 mms depth is applied in this case. At some time nitration is also applied.

The piston pin made of steel is a noticeable part of total mass of a piston group. Therefore a significant attention is given to mass reduction of PP especially in case of fast-running engines. The hollow pins with internal diameter (from 0.5 to 0.7) from external pin diameter d_{pp} are applied for this purpose. The diameter itself d_{pp} is about

(from 0.24 to 0.28) for petrol engines and for diesel engines (from 0.34 to 0.38) from diameter of the cylinder D .

Of great importance is the position of PP in the piston. During the working cycle the piston makes several movements in the plane of swinging of a connecting rod accompanying by the turn of the piston with regard to a piston pin. These movements are called transpositions and their intensity influences upon cylinder vibration, to some extent promoting the origin of a cavitation in engines with liquid cooling. To decrease the piston action on the cylinder wall during transportation special contouring of piston lateral surface is applied and the pi axis is placed near to the centre of gravity of a piston group

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Biographical Sketch

Chainov N.D. born in 1937, graduated from the Bauman Moscow Higher Technical School in 1960. Doctor of Technical Sciences, Professor of Power Engineering Department, Moscow State Technical University, Russia. The author has more than 140 publications in the field of designing and strength analysis of reciprocating and combined engines.