Karol Franciszek ABRAMEK **PTNSS–2011–SC–067**

Modelling of elements wear of the piston-rings-cylinder system

Abstract: Evaluation of the processes of wearing out of the piston-rings-cylinder system (PRC) can be introduced by the use of functional dependency of blowthrough intensity of the working substance to the engine's crankcase, as the flow of gases between elements of this system. Many structural and exploitation factors affect the tightness of the PRC arrangement. In the report only exploitation factors having the direct impact on the value of the summary field of the leakage , through which the flow of the medium to the crankcase of the piston combustion engine can take place. The impact of wear of cylindrical sleeve, wear the rings in the radial and axial direction and the wear of the groove in the piston were modelled. The leakage of the PRC system in experimental studies, during the tests on blowthrough was analysed with the presence of the lubricating oil. It has been showed, that the greatest impact on the intensity of blowthrough has increase of the width of the lock of the sealing ring, which is bound up with the wear of the external cylindrical surface of the ring. It was found that the measurement of the clearance value of the lock only on the first sealing ring, growing larger as a result of the exploitation can be used to the evaluation of the summary field of leakage, as a wear of piston-rings-cylinder system.

Key words: *piston, rings, cylinder, wear, blow-by, combustion engine*

Modelowanie zużycia elementów systemu tłok-pierścienie-cylinder

Streszczenie: Ocenę procesów zużywania się systemu tłok-pierścienie-cylinder (TPC) można przedstawić za pomocą zależności funkcjonalnej natężenia przedmuchów czynnika roboczego do skrzyni korbowej silnika, czyli jako przepływ gazów pomiędzy elementami tego systemu. Na szczelność układu TPC ma wpływ wiele różnych czynników konstrukcyjnych i eksploatacyjnych. W referacie analizowano tylko czynniki eksploatacyjne mające bezpośredni wpływ na wartość sumarycznego pola nieszczelności, przez które może następować przepływ czynnika do skrzyni korbowej tłokowego silnika spalinowego. Modelowano wpływ zużycia tulei cylindrowej, zużycie pierścieni w kierunku osiowym i promieniowym oraz zużycie rowka w tłoku. Nieszczelność układu TPC w badaniach eksperymentalnych, podczas badań przedmuchów, analizowano z obecnością oleju smarującego. Wykazano, iż na intensywność przedmuchów największy wpływ ma przyrost szerokości zamka pierścienia uszczelniającego, który związany jest ze zużyciem zewnętrznej powierzchni walcowej pierścienia. Dowiedziono, że pomiar wartości luzu zamka jedynie pierwszego pierścienia uszczelniającego, powiększający się w wyniku eksploatacji, może służyć do oceny sumarycznego pola nieszczelności, jako zużycia układu tłok-pierścienie-cylinder.

Słowa kluczowe: *tłok, pierścienie, cylinder, zużycie, przedmuchy gazów, silnik spalinowy*

1. Introduction

In the piston combustion engines the working space from one side is situated between the head and the sides of the cylinder on the other. The piston together with the rings states a closure of this space. It is the piston which transfer the pressure force of combustion gases on the connecting rod. Therefore, the loss of charge between the piston, rings and cylinders should be as small as possible in order to achieve the stated parameters of engine operation (e.g. power, torque, fuel consumption, emission of toxic substances in the exhaust gases, lubricating oil consumption). As a result of operation the wear in the group piston-rings-cylinder (PRC) follows, which leads to the deterioration of its integrity, and thus to growth of the phenomenon of gases blowthrough from the cylinder to the crankcase [2,3,4]. The largest wears take place on the working surfaces of cylindrical face and the rings [6]. The ring thanks to the resilience force, is attached with its external surface to the cylindrical face. Hence the wear of the cylindrical face and the surface of the ring appear in large part by the growth of its lock. According to the literature [7] the greatest impact on the occurring blowthrough phenomenon has wear of the external cylindrical surface of the sealing rings, displayed by the growth of the lock.

2. Formulation of the research problem

In order to assess the impact of the clearance of the lock of the sealing rings on the phenomenon of blowthrough gases to the crankcase, the measurements of the sealing rings have been made regarding their width and their resilience force as well as the lock's clearance in its free state and in the state corresponding to its normal arrangement in the cylinder. The piston-rings were derived from the piston combustion engines of 359 type: one was exploited in normal conditions the another has been used in the engine test house. The radial thickness of a piston ring was measured in five points (introduced in fig.1): in the opposite point of lock slit (3), from two sides under the angle of 90º to the direction of the first (2 and 4), and from two sides under the angle of 30º to the axis cross-out (1 and 5). The measurements have been carried out with the use of the time sensor. Subsequent numbers of rings were counted from the bottom of the piston. While the measurement of the gap in the lock of the ring was made with the use of feeler gauge for the ring inserted into model adapter with the diameter equal to the nominal diameter of the cylinder 0,11m. The measurements of the springiness of rings were made with the use of the instrument which acts on the principle of girding the ring with tape. The size of tangent forces were determined through clenching rings all the way to the moment, when gaps in locks achieved values equal to the gaps of rings inserted to cylinders.

The engine 359 operated in normal condition achieved the course of 281742 km. After that mileage the measurement of the rings have been made, and in the engine the cylinder liner and pistons were exchanged, but the "old" piston rings were left. It enabled the assessment of the impact of only rings wear (growth of the lock's size) on the phenomenon of blowthrough of gases. This same has been done to the engine operated in the engine test house. After the period of 573 working hours in the engine test house, the measurements of the rings were made, and in the engine the cylindrical liners and pistons were changed (leaving the old piston rings). After that change, the measurements of the blowthroughs were made and both engines continued to operate.

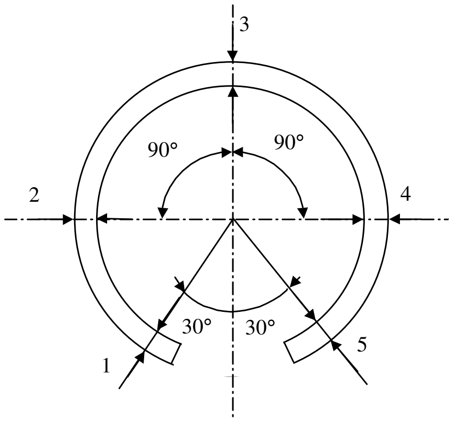

Fig.1. Directions of measurement of the thickness of a piston ring: 3- opposite point of the lock, 2 and 4 - 90° angle to first direction, 1 and 5 - 30° angle to axis' slit.

Rys. 1. Kierunki pomiaru grubości pierścienia tłokowego: 3-punkt przeciwległy zamka, 2 i 4-kąt 90° do kierunku zamka, 1 i 5-kąt 30° do osi przecięcia

According to the author's opinion, the measurement of the size of the lock of the first sealing ring is sufficient for setting the supplementary coefficient of wear of the PRC system, which can provide the general measure of wear and tear of this system. The first ring was chosen (counting from the bottom of piston), because in that ring the most intensive processes of wear take place. Assigning the transitional diameter of the piston-cylinder system μF is very difficult and requires the use of specialist apparatus. Also the interference in the arrangement of the engine is necessary in order to install the specific sensors. Mentioned value can be calculated with the help of the indicator graph of the medium mass flow value to the crankcase G_{sk} and the pressure in the p_{sk} crankcase. Moreover, the temperature of the gases in T cylinder should be measured, to determine the R gas constant and the adiabatic exponent of k gas flow. In such a way, μF can be determined from the following dependency [5]:

$$\mu F = \frac{G_{sk}}{a \int_0^{720} \frac{p \cdot y}{\sqrt{T}} d\alpha_{\omega k}} \tag{1}$$

where constant a determined with following:

$$a = \frac{\sqrt{2R}}{6 \cdot n \cdot 8314} \tag{2}$$

and y function as:

$$y = \left(\frac{p_{sk}}{p} \right)^{\frac{1}{k}} \sqrt{\frac{k}{k-1} \left[1 - \left(\frac{p_{sk}}{p} \right)^{\frac{k-1}{k}} \right]} \tag{3}$$

where:

p – pressure of gases in cylinder,
T – temperature of gases in cylinder,
R – gas constant,
$\alpha_{\omega k}$ – angle of rotation of the shaft,
n – rotational speed of the shaft,
p_{sk} – pressure of gases inside crankcase,
k – adiabatic exponent of gas flow.

Therefore, it seems to be well-founded to search certain, simpler method for evaluation of substitute coefficient of PRC system wear. Analyzing wear of the cylindrical face surface and the thickness of the ring in radial direction and taking under consideration the springiness of the ring, which presses the ring against cylinder surface, that wears can be with certain simplification evaluated as increase of the size of the ring's lock.

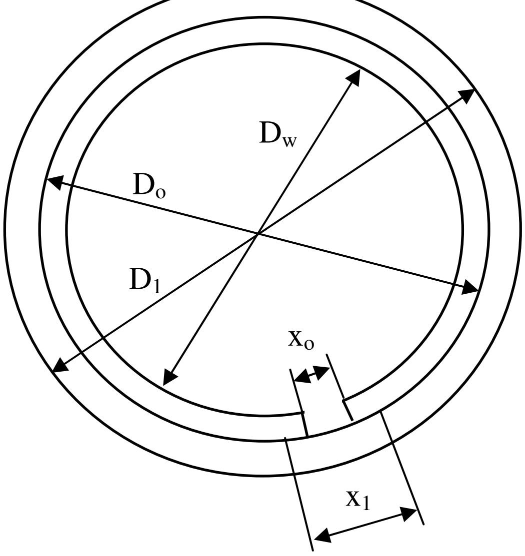

Fig. 2. Indication marks of cylindrical funne's wear and increase of the lock's size providing that the processes of wearing for rings do not take place.

Rys. 2. Oznaczenia zużycia tulei cylindrowej i wzrostu wielkości zamka przy założeniu, iż nie zachodzą procesy zużycia dla pierścienia.

If the marks shown in Fig.2 are to be accepted, it means, the nominal diameter of the cylinder D_o as well as internal diameter of the ring D_w mounted in the cylindrical liner with nominal dimension, then the value of the clearance of the lock's sealing rings equals to x_0, and the circumference of external surface of the ring adjacent to the cylindrical face enlarged by the clearance's value of the lock x_0 comes to πD_o. As a result of the wear and tear the diameter of the cylinder changes its value to D_1. The sealing ring because of the springiness force presses on the cylinder face. Assuming that no processes of wearing on the surface of the sealing ring take place then the circumference of the ring's external surface, also adjacent to the cylindrical face increased by the value of the clearance of the ring's lock x_1 , comes to πD_1. Since the size of the lock changes only because of the wear of the cylinder liner, hence increase of the clearance /gap/ of the ring's lock is equal to:

$$\Delta x_{o1} = \pi D_1 - \pi D_o = \pi(D_1 - D_o) \quad (1)$$

However assuming the situation, that as a result of engine exploitation only the sealing ring wears, and the liner's diameter doesn't change and equals D_0, then the increase of the lock's size Δx_{o2} depends on the wear of ring's width z (marks as in Fig.3):

$$\Delta x_{o2} = \pi D_z - \pi D_w = \pi(D_z - D_w) \quad (2)$$

$$D_z - D_w = 2z \quad (3)$$

$$\Delta x_{o2} = \pi(D_z - D_w) = 2\cdot\pi\cdot z \quad (4)$$

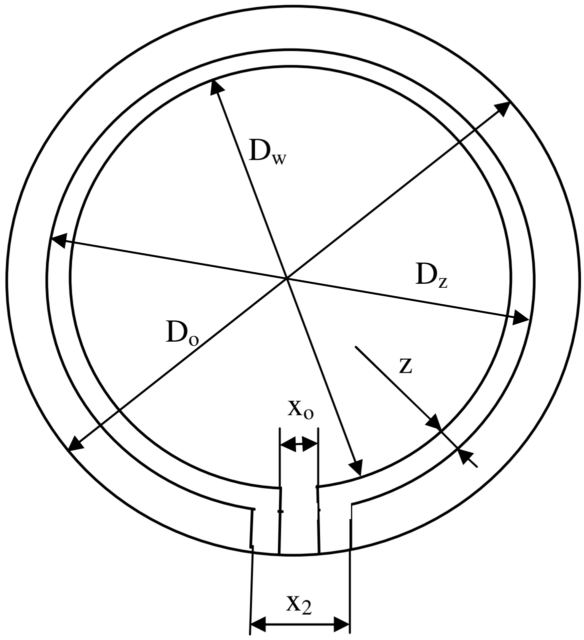

Fig.3. Indication marks of the sealing ring's wear and the size of the lock providing, that the processes of wearing of the cylinder liner do not take place.

Rys. 3. Oznaczenia zużycia pierścienia uszczelniającego i wielkości zamka przy założeniu, iż nie zachodzą procesy zużycia tulei cylindrowej.

3. Tests results

The results of the wear of the sealing rings for engine 359 operated under normal conditions after mileage of 281742 km were as follows:

The average of the maximum wear of the rings' width:

- for the first sealing rings – 0,295 mm,
- for the second sealing rings – 0,257 mm,
- for the third sealing rings – 0,197 mm.

The average wear of the rings' width:

- for the first sealing rings – 0,253 mm,
- for the second sealing rings – 0,214 mm,
- for the third sealing rings – 0,175 mm.

The average size of the lock's clearance /gap/ in all sealing rings after inserting them into the master holder with the diameter equal to the cylinder's nominal diameter is larger than the output gaps /clearances/ by:

- 1,89 mm for the first sealing rings,
- 1,58 mm for the second sealing rings,
- 1,24 mm for the third sealing rings.

For the analysis of the decrease of the rings' springiness the static forces have been measured when the rings were closed to the size of the locks measured after inserting them to the master holder with the diameter equal to the cylinder's nominal diameter and comparing them with the output values. The average drop of springiness (resilience) was as follows:

- for the first sealing rings – 11,9 N,
- for the second sealing rings – 8,7 N,
- for the third sealing rings – 5,6 N

While the results of the measurements of wear of the sealing rings for 359 engine operated in the engine test house after 573 working hours were as follows:

The average of the maximum wear of the rings' width:

- for the first sealing rings – 0,237 mm,
- for the second sealing rings – 0,194 mm,
- for the third sealing rings – 0,125 mm.

The average wear of the rings' width:

- for the first sealing rings – 0,199 mm,
- for the second sealing rings – 0,149 mm,
- for the third sealing rings – 0,098 mm.

The average size of the lock's clearance in all sealing rings after inserting them into the master holder with the diameter equal to the cylinder's nominal diameter is larger than the output gaps /clearances/ by:

- 1,51 mm for the first sealing rings,
- 1,26 mm for the second sealing rings,
- 0,93 mm for the third sealing rings.

For the analysis of the decrease of the rings' springiness the static forces have been measured when the rings were closed to the size of the locks measured after inserting them to the master holder with the diameter equal to the cylinder's nominal diameter and comparing them with the output values. The average drop of springiness (resilience) was as follows:

- for the first sealing rings – 9,7 N,
- for the second sealing rings – 7,3 N,
- for the third sealing rings – 5,5 N

In Fig.4 the has been introduced the relation of measured, real quantities of the lock's sealing rings as a function of wear of the rings' width. The results are the arithmetic average taken from six measurements of eighteen rings (six-cylinder engine, three sealing rings on piston). The measurements have been averaged successively for the first, second and third sealing rings counting from the bottom of the piston.

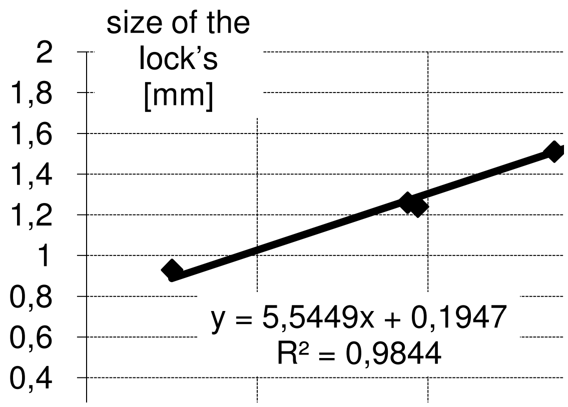

Fig. 4. Measured size of the lock's sealing rings vs the wear of the ring's width.

Rys. 4. Zmierzone wielkości zamka pierścieni uszczelniających w funkcji zużycia szerokości pierścienia.

In Fig. 5 introduced the influence of the quantity of the lock's ring on the intensity of gases blowthrough to the crankcase for the engine 359.

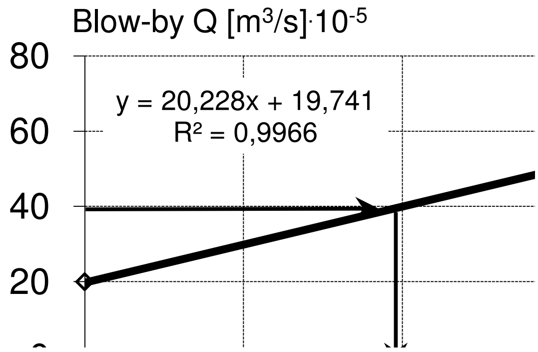

Fig. 5. Influence of the quantity of the lock's sealing rings on the value of the blowthrough intensity

Rys. 5. Wpływ wielkości zamka pierścieni uszczelniających na wartość natężenia przedmuchów

3. Conclusions

By analyzing the results of the measurements of wear of the ring's width and their influence on the size of the sealing ring, it can be stated, that the results meet the relation (4). Some errors may result from the unevenness of wear of the ring's surface. By setting for a given type of the engine (in this case, the engine 359) standard dependency of impact of the size of the lock's sealing rings on the value of blowthroughs' intensity, one can later during operation on the basis of blowthroughs' measurements tell, what the wears of the sealing ring are. For example, in Fig.5 with the use of the arrows marked, if the intensity of gases' blowthrough to the crankcase is $39 \cdot 10^{-5}$ m^3/s then the size of the lock's sealing ring is approximately 0.95 mm. Based on the conducted studies it can be unambiguously stated, that the size increase of the lock's sealing ring linearly influence on the quantity of the blowthroughs' gases to the crankcase.

Nomenclature/*Skróty i oznaczenia*

PRC Piston-Rings-Cylinder System/*układ tłok-pierścienie-cylinder (TPC)*

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Mr Karol Franciszek Abramek, PhD., MEng. – doktor in the Faculty of Mechanical Engineering and Mechatronics at West Pomeranian University of Technology in Szczecin.

Dr inż. Karol Franciszek Abramek – adiunkt na Wydziale Inżynierii Mechanicznej i Mechatroniki Zachodniopomorskiego Uniwersytetu Technologicznego w Szczecinie.