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EFFECT OF THE WORKING TIME OF COMRESSION-IGNITION ENGINE ON CHARGE LOSS

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Summary

In the paper is presented a statistical analysis of the effect of compression-ignition engine working time on the phenomenon of exhaust gas scavenging into crankcase. Characteristics of the crankcase scavenging and pressure variations were made for the start-up speed of SB-3.1 one-cylinder compression-ignition engine as well as micrometric measurements of the cylinder liner were performed after a run of 549 hours of operation on engine test bed. Basing on the analysis of obtained measuring results, it was showed that measurement of exhaust gas scavenging and exhaust gas pressure in crankcase may be used for determination of engine run and life.

***Key words:** scavenging, wear, piston, rings, cylinder*

1. Introduction

Piston with rings is a sliding seal of piston combustion engine working space. As the operational run increases, its units and cooperating parts are getting worn out. This wear brings about worsening of engine technical and operational indicators, the symptoms of which are: power drop, increase of lubricating oil consumption, increase of smokiness and toxic substance emission in exhaust gases, increase of fuel consumption, increase of noise level, difficulties in engine start-up and a considerable decrease of engine reliability. The most important factors that induce changes in shapes, dimensions, quality and properties of engine parts as well as worsening of engine operation properties are first of all tribological processes (friction and accompanying processes), considerable dynamic and heat loads of engine parts and corrosion, erosion and cavitation phenomena. Elements of the piston-rings-cylinder (PRC) system operate in particularly difficult conditions [1, 2, 7].

Determination of the reasons of most intensive wear in the PRC group has a decisive effect on the prolongation of engine operational time and run. As a rule, the wear of these elements determines the necessity of executing engine repair or taking it out of service. Therefore, this tribological pair is required to ensure failure-free operation of engine in as long time as possible and to not limit its usability by engine performance in this time [9]. The course of wear processes in the PRC group as well as its size and character depend on many factors, which can include physicochemical properties of material, quality of cooperating parts, size of unit pressures, speed of the relative displacement of elements, temperature of elements, quality of oil and thickness of oil film as well as course of combustion processes in the working space over piston.

In the PRC group, wear processes take place that are induced by friction phenomena and processes leading to destruction of the surface layer of frictional pair caused by mechanical abrasion of surface irregularities, effect of intermolecular forces, local friction welding and disruption of the tops of surface irregularities (type I and II adhesion), micro-cutting, scratching and ridging caused by the presence of wear bodies and products within the areas of cooperating elements which act as abrasive material or clearly harder surface irregularities of one of the fricative bodies.

2. Description of wear processes in the PRC group

The PRC assembly is characterised by a large variation of the mutual speed between cooperating surfaces. Only in one working cycle there are periods when the relative speed of cooperating frictional pairs is too small for the fluid friction to occur. At that time, an interruption of the oil film occurs and it comes to direct contact of friction surfaces. Such a contact is accompanied by mechanical separation of material particles. Such a phenomenon can take place both in case of the dry friction and through a layer of lubricating oil. The friction surfaces contacting with each other get into contact, due to the effect of load, with the tops of surface irregularities which undergo plastic strain and then tacking bridges develop in result of adhesion. Mutual displacement of spot welded surfaces brings about the pulling of metal particles out of the bottom of metal surface layer with lower strength and their translocation onto the cooperating surface [6].

Separate group is the wear connected with material fatigue due to variable mechanical or heat loads. A result of the fatigue wear is surface layer flaking.

The PRC group is also exposed to corrosive destruction (chemical and electrochemical corrosion as well). Chemical corrosion occurs first of all in exhaust gas atmosphere, in particular at raised temperatures and in fluids, which can be fuels. In practice, a fuel composed of organic compounds containing carbon and hydrogen is applied to all engines with internal combustion. In this connection, a basic combustion product is water and carbon dioxide. In case of normal operation conditions, water vapour produced in combustion is condensed on very effectively cooled cylinder parts only. Condensation can occur only where the partial pressure of water vapour is higher from the saturation pressure, i.e. in places where the dew-point has been reached. In case of combustion products which do not contain sulphur, the dew-point at a pressure of 0.2 MPa is between 323 and 333 K and increases together with pressure buildup [8]. Decrease of the temperature of combustion products being found on cylinder walls or in piston ring ducts below the dew-point exerts a considerable influence on corrosive wear of all PRC assembly elements. Particularly large influence on the wear is exerted by sulphur contained in fuel and air. This sulphur undergoes combustion producing sulphur dioxide SO_2, with part of SO_2 undergoing subsequently a change into SO_3. Sulphur compounds can work corrosively in different way. Three temperature areas of the effect of sulphur compounds produced during fuel combustion are conventionally accepted. The first zone corresponds to intensive electrolytic corrosion occurring at water vapour condensation. The second zone is characterised by the lowest wear and corresponds to temperatures at which water vapour condensation does no longer occur. The third zone corresponds to high-temperature corrosion. Intensive increase of high-temperature corrosion occurs only when temperature of the surface of elements exceeds 573 K. Since such high temperatures do not occur in piston engines on friction surfaces, therefore this corrosion is of minimal importance. Out of the PRC group, only some areas of the piston head can be subject to it. The presence of sulphur compounds, SO_2 and SO_3, in combustion products increases the dew-point by 80 to 115 K above the dew-point of pure water vapour. This is why sulphurous acid H_2SO_3 and sulphuric acid H_2SO_4 are formed due to dissolution of SO_2 and SO_3 in condensate. The corrosive effect of sulphuric acid depends on its concentration. The most dangerous is its concentration ranging from 20 to 60%. Attention should be paid to the fact that corrosive wear is also dependent on engine high-speed because water vapour condensation process takes place not immediately but requires some time. This causes that considerably less condensate is formed in high-speed engines than in low-speed ones, where in addition it stays considerably longer.

With the intensive flow of fluids or exhaust gases in the form of scavenging through clearances in the PRC system, also erosion processes take place that leave marks on metal surfaces [6].

3. Formulation of research problem

The presented wear processes occurring in the PRC assembly are inevitable. Nevertheless, the most intensive is the wear induced by friction phenomena and processes [5]. Material losses in the cooperating parts cause development of greater and greater clearances between PRC elements. This favours an increase of the exhaust gas scavenging into crankcase, destruction of oil film layer and development of more intensive erosion processes. Therefore, there is a large probability of the intensification of wear phenomena.

In principle, many authors have been examining wear processes in the PRC group [4, 6, 7, 8, 9, 12]. However, there is not much studies directly connected with the loss of medium in the form of exhaust gas scavenging into crankcase through ring sealing assembly [1, 5, 12], hence follows the interest of the author in statistical description of the effect of wear processes and cylinder liner wear size on the value of exhaust gas scavenging intensity. In particular, there are not any results of scavenging tests for the speed of engine crankshaft during start-up. Also an attempt was taken up to explain whether measurements of exhaust gas scavenging into crankcase could be used for evaluation of the technical condition of the PRC kinematic pair and, in particular, whether they are correlated with cylinder liner wear and engine operational run.

In order to evaluate and examine changes in the course of wear intensity in the PRC group and their effect on the loss of medium, studies were carried out consisting in measurement of the intensity of exhaust gas scavenging into crankcase for the start-up speed for a warm (lubricating oil temperature of 333 K) and cold engine (285 K), every ninth hour after replacement of cylinder liner, piston and rings, and for a worn-out SB-3.1 engine. Measurement of the diameters of piston, cylinder liner and rings for new and worn-out elements after the service life eliminates an undesirable effect of the measurements of these values during the service life which can affect engine operation parameters and medium loss. The scavenging values given are arithmetic mean from three measurements. Diameter measurements were taken with an inside micrometer caliper in horizontal planes being distant from cylinder liner end face by 20 mm, which corresponded to the piston position in the upper dead centre (UDC). It is well-known that circularity of cylinder becomes deteriorated in result of wear and resembles an oval. Its larger diameter (measured in the B-B plane) corresponds to a plane perpendicular to the axis of engine crankshaft (it results from the dynamics of crankshaft-pistons-connecting rods system), while a smaller one (measured in the A-A plane) occurs in a plane parallel to the axis of engine crankshaft. A clearance that develops then between a piston and rings is the main reason of scavenging.

4. Test results

Test results for cylinder liner micrometric measurements in the function of operational run for a run of 549 hours worked in engine test bed are presented in Table 1.

Tab. 1. Test results of micrometric measurements for SB-3.1 engine

Measurement direction	l_1=20 [mm]		
	Before test	After test	Wear [μm]
A-A	-4	+21	25
B-B	-2	+39	41

It can be seen that cylinder liner wear processes are not the same in each plane. Larger wear occurs in the plane perpendicular to the axis of engine crankshaft since there are larger normal strengths occurring in this plane that have effect on cylinder liner and induce larger unit pressures and more intensive action of wear processes through friction.

Examination of the scavenging characteristics for the start-up speed (i.e. for engine crankshaft speeds obtained with starter drive) was performed for lubricating oil temperature of 333 K, determining it as a warm engine, and for temperature of 285 K, determining it as a cold engine. Dependence of the scavenging intensity on engine operational run, expressed in operation hours on engine test bed, was obtained using a scavenging intensity test bench presented on Fig. 1 designed and made at the Department of Automotive Vehicle Operation of the Szczecin University of Technology.

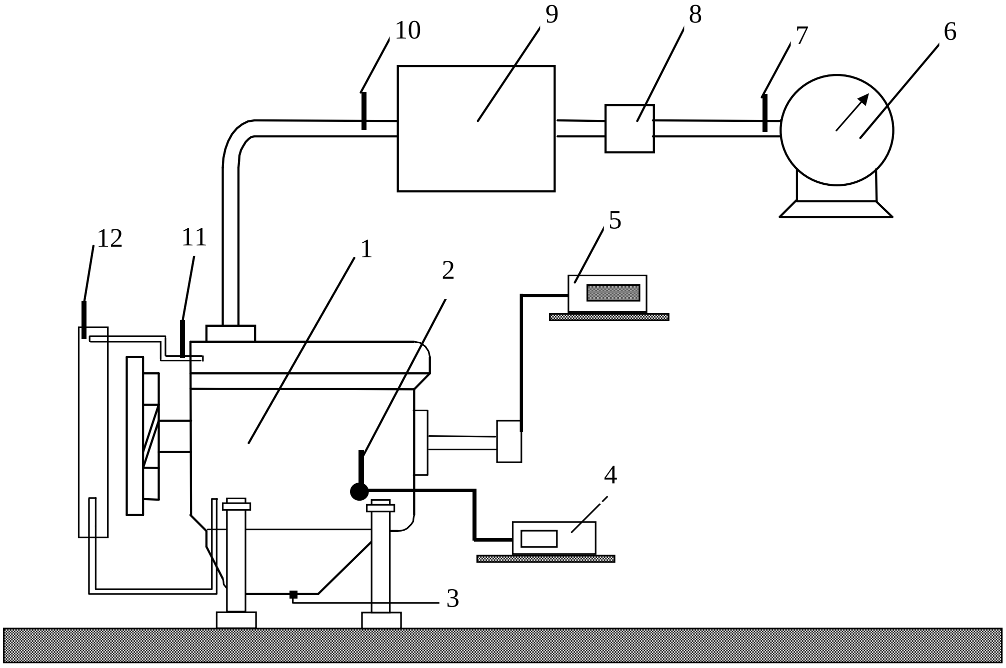

Fig. 1. Diagram of a test bench for examining exhaust gas scavenging into crankcase [3]
1 – tested engine, 2 – crankcase exhaust gas concentration pressure meter, 3 – oil temperature meter, 4 – oil pressure meter, 5 – engine-speed meter, 6 – laboratory gas meter, 7 – exhaust gas temperature meter, 8 – filter, 9 – equalising tank, 10 – exhaust gas temperature meter, 11 – engine port water temperature mete, 12 – cooler water temperature meter

Measurement of the scavenging intensity consisted in that that measuring instrument (6) was connected to the crankcase of tested engine (1) by means of a rubber hose inserted into the oil inlet hole. The pressure produced in crankcase during engine operation induced a flow of exhaust gases into the equalising tank (9), which was filled with steel chips in order to eliminate pulsation and pre-treat exhaust gases from oil mist. Thereafter, exhaust gases went through a filter (8) where they were thoroughly cleaned and went into a laboratory gas meter (6). Additional device, i.e. crankcase exhaust gas concentration pressure meter (2), served as control of the resistance of exhaust gas flow, showing the value of pressure concentration in crankcase [3].

Figure 2 presents the characteristics of exhaust gas scavenging in the function of operational run expressed in operation hours on engine test bed for warm engine, while that for cold engine is presented on Fig. 4.

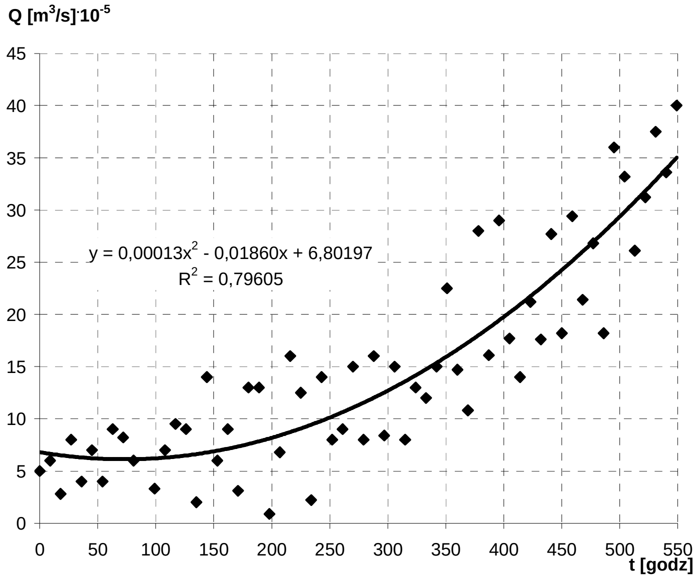

Fig. 2. Dependence of the intensity of exhaust gas scavenging into crankcase on the operational run of warm engine SB-3.1 operated on engine test bed for the start-up speed

Figures 3 and 5 present the dependencies of exhaust gas pressure in crankcase on the operational run of engine SB-3.1 for warm and cold engine, respectively.

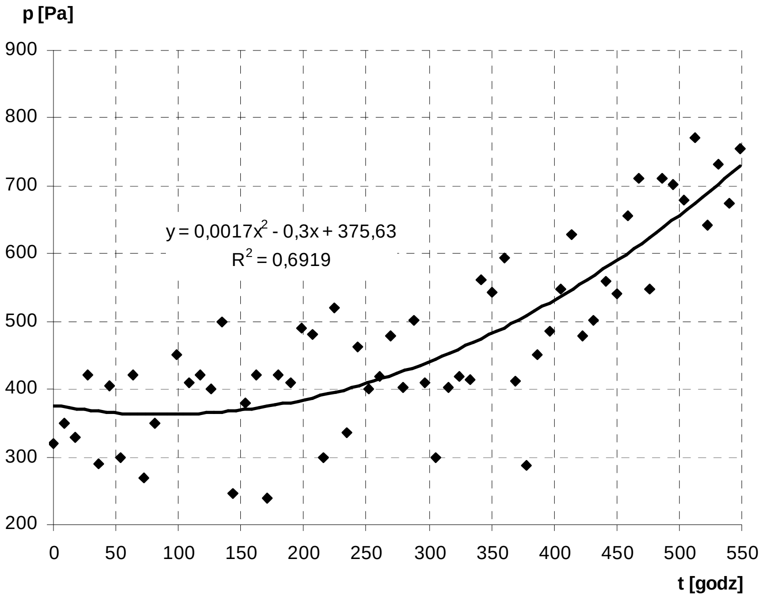

Fig. 3. Dependence of the pressure of exhaust gas in crankcase on the operational run of warm engine SB-3.1 operated on engine test bed for the start-up speed

It can be seen that the value of lost charge intensity in the form of exhaust gas scavenging into crankcase and of exhaust gas concentration changes and increases in result of operational wear (run). This is caused by that that during operation the wear of piston-rings-cylinder group elements increases and a free section, through which a loss of charge takes place in the form of exhaust scavenging, enlarges. The diameter of cylinder section increases, as well as clearances in the joints of respective piston rings (piston packing rings and piston oil control ring) [12].

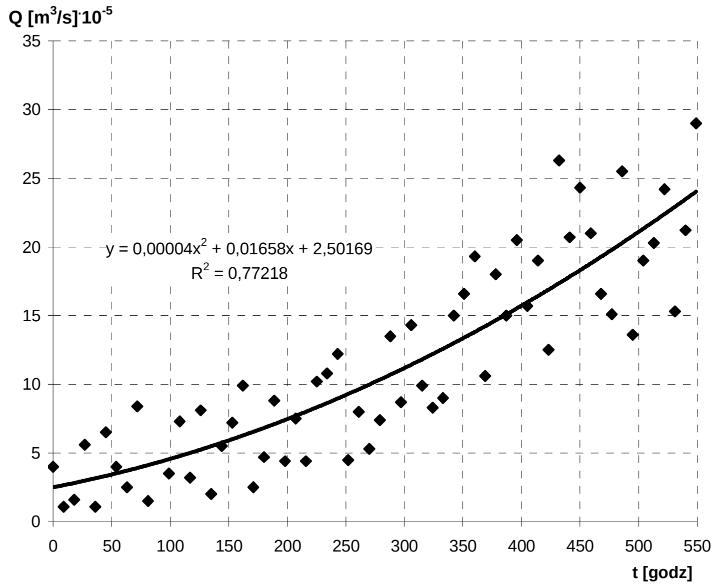

Fig. 4. Dependence of the intensity of exhaust gas scavenging into crankcase on the operational run of cold engine SB-3.1 operated on engine test bed for the start-up speed

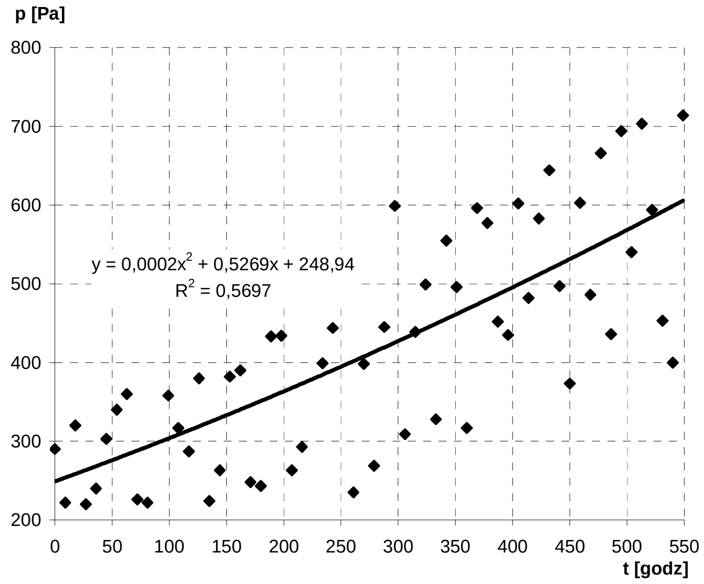

Fig. 5. Dependence of the pressure of exhaust gas in crankcase on the operational run of cold engine SB-3.1 operated on engine test bed for the start-up speed

When analysing the obtained results of exhaust gas scavenging measurements for the start-up speed and cylinder liner wears due to operation of SB-3.1 engine on engine test bed, it can be observed that the amount [quantity] of exhaust gases scavenged into crankcase increases in result of the PRC system wear. The study showed that evaluation of the technical condition of piston engine, in particular of the PRC kinematic pair, can be accomplished by measuring the intensity of exhaust gas scavenging into engine crankcase for the start-up speed. It was observed that characteristics of the intensity of exhaust gas scavenging for warm engine reaches larger values. This is due to the effect of changes in lubricating oil density and its effect on the caulking of the PRC space [2, 5].

Conclusions

When evaluating the usefulness of exhaust gas scavenging measurements for forecasting the service life, the fact should be taken into consideration that examination of medium losses ought to be correlated with operational run. The following coefficients of correlation were obtained: $r^2=0.796$ for warm engine and $r^2=0.772$ for cold one. It is well-known by experience that achievement of such an appreciable value of the coefficient of correlation in case of diagnostic tests is rather difficult and requires great repeatability of measurements conditions. Slightly worse were measurements of the concentration of exhaust gases in crankcase. The following results were obtained for exhaust gas concentration: $r^2=0.691$ for warm engine and $r^2=0.569$ for cold one. In both cases, it is better to carry out examinations for warm engine because coefficient of correlation reaches then higher values. Taking into account difficulties connected with taking measurements of exhaust gas scavenging in relation to those of exhaust gas pressure in crankcase, the pressure measurement itself seems to be reasonable as well. However, it has been observed by experience that all leaks have greater effect on measurement “falsification” and error as far as the pressure in crankcase is concerned than on exhaust gas scavenging intensity error.

The presented dependencies of exhaust gas scavenging intensity (Figs 2 and 4) are a second order polynomial and a change in the value of exhaust gas scavenging illustrates the 2nd period of changes (normal wear period) being described by the Lorenz curve.

Also the dynamics of signal change in both cases is possibly large and can be calculated from the following formula [4]:

$$d_p = \frac{X_m - X_o}{X_o} \tag{1}$$

where:

X_m – signal boundary value, indicating the necessity of performing a repair or taking the object out of service; in our case it is a run of 549 hours on engine test bed,

X_o – signal initial value, characterising a new object after termination of the running-in period.

For exhaust gas scavenging measurements, the value of signal change dynamics for warm engine is $d_p = \frac{40-5}{5} = 7$, whereas for cold one $d_p = \frac{25-2.5}{2.5} = 9$.

Slightly lower values are reached by signal change dynamics for the measurements of exhaust gas pressure in crankcase. They are as follows: for warm engine $d_p = \frac{750-350}{350} = 1.1$, whereas for cold one $d_p = \frac{600-250}{250} = 1.4$.

Summing up, it is possible to conclude about wear [and tear] degree, and the same about the run of piston combustion compression-ignition [Diesel] engine, basing on the examination of exhaust gas pressure in crankcase. The advantage of measurements of exhaust gas scavenging into crankcase is that that they are carried out on actually operating engine as well as that they can be performed within the whole range of engine crankshaft rotational speed. This gives the full picture of PRC assembly cooperation quality and may serve as indication of leak-tightness loss for a specific range of engine rotational speed.

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