CHANGES IN THE TIGHTNESS OF THE COMBUSTION CHAMBER OF AN DIESEL ENGINE DURING LONG-TERM OPERATION

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Abstract

The paper presents results of research on changes in the tightness of the combustion chamber during long-term operation. The study was conducted on 5 six-cylinder diesel engines with a swept volume of 6.8 dm^3 mounted in medium size trucks. All 5 trucks were used and serviced in similar conditions. The changes in the tightness of the combustion chamber were determined on the basis of the results of periodical measurements of maximum compression pressure in cylinders, drop of pressure during a cylinder leakage test and blowby rate under different conditions of engine operation. The investigation was carried out in the range of vehicle mileage of 0-450,000 km.

The results showed that in the initial period of engine use (0-40,000 km) the tightness of the combustion chamber improved, after which it gradually deteriorated. For mileages of over 40,000 km, the significance of linear correlations between results of all tightness measurements and mileage were confirmed and regression lines were determined. Mean rates of changes in the individual tightness parameters differed considerably among one another. Maximum compression pressure changed the slowest and blowby the fastest together with mileage. Mean value of maximum compression pressure at 440,000 km was only 13% lower than at 40,000 km, whereas blowby rate at full engine load at 2200 rpm was 125% higher.

Keywords: *IC engine, blowby, compression pressure, leak-down test, piston ring, cylinder, wear*

1. Introduction

Wear of elements of an engine, and in particular wear of the cylinder liner and piston rings, which causes increased clearances within the piston-rings-cylinder (PRC) kit, leads to reduced tightness of the combustion chamber. A decrease in the tightness of the combustion chamber has an adverse effect on the engine as it reduces its performance, increases the consumption of fuel and engine oil as well as enhancing wear of components and decreasing start-up performance of a cold engine.

Some commonly used measures of the tightness of the combustion chamber include diagnostic parameters such as maximum compression pressure or rate of blowby into the crank case. In the literature, information on changes of these parameters during actual operation of an engine can seldom be found. Knowledge of the changes of these parameters, especially after correlating with information on the wear of engine components [4], can be useful both from the point of view of engine diagnostics as well as modelling the tightness of the combustion chamber, because such results can be used for verifying mathematical models of the PRC kit [2, 7].

The article presents results of tests of tightness of a combustion chamber of an engine during long-term operation of an automobile under actual conditions. Knowledge of the rate of changes in tightness with increasing mileage will allow one to evaluate the adequacy of the results obtained in simulation studies of the changes in tightness of the combustion chamber done with the application of the analytical model of the PRC kit [3]. As the model of the PRC assembly [2, 3] is a deterministic model, the present study concentrates only on the evaluation of the average trends of changes in the respective diagnostic parameters; the dispersion of measurement results or the differences between the individual test objects (engines and cylinders) have not been analysed.

2. Engine and method

The test object was a six-cylinder compression ignition engine with a swept volume of 6.8 dm^3 and rated power of 110 kW at 2800 rpm. The engine was equipped with wet, cast iron cylinder liners with the nominal inside diameter of 110 mm. The piston travel was 120 mm. The tests involved 5 engines mounted in trucks of medium loading capacity and gross vehicle weight of 12 tons. All the vehicles were the property of one transport provider and were used in similar conditions, with an average monthly mileage of 10,000 km. The engines were lubricated with the same CE/SF SAE 15W/40 class oil.

The following diagnostic methods were used to evaluate the tightness of the combustion chamber:

- measurement of the maximum compression pressure in cylinders,
- measurement of the pressure loss during a leakage test,
- measurement of the blowby rate.

The maximum pressure in the combustion chamber at the end of the compression stroke was measured with a controlled compression pressure tester SPCS-50. During the leakage test the relative drop of pressure of the compressed air supplied to the combustion chamber through the injection inlet, with piston at TDC after the compression stroke was measured. For these measurements, a PSC-2M leakdown tester was used. Measurements of compression pressure and leakage were performed successively in all 6 cylinders of a warmed-up engine. Measurements of the blowby rates were performed at idle run (idle speed) and on an chassis test bench at full load of the engine (maximum position of the accelerator pedal) at the following crankshaft speeds: 1570, 1880, 2200 and 2800 rpm.

Diagnostic measurements were performed periodically. At mileages below 100,000 km, the measurements were done after about every 15,000 km. After reaching 100,000 km, the measurements were done after about every 50,000 km. The frequency of the measurements was connected with the periodic checks-up of the engines. In this way the servicing activity was reduced and disturbances in vehicle operation were minimised. To reduce the error of unique measurement conditions and methods, the measurements were performed by the same people, with the same instruments and at the same location [6].

3. Results

The values of diagnostic parameters for individual cylinders and engines, obtained in operational tests, were characterised by considerable dispersion and frequent lack of monotone changes in the function of the vehicle's mileage. That is why the results of diagnostic measurements were analysed jointly for all the tested cylinders and engines with the use of statistical methods. Because at the initial stage of vehicle operation an improvement in the tightness of the combustion chamber was observed (see Fig. 1), which should be associated with the run-in of the engines, the statistical analyses presented below take into consideration the results of measurements for mileages higher than 40,000 km. It was assumed that at that mileage the processes of engine run-in had been definitely finished, and that both the wear of the PRC elements [4] and changes in tightness had stabilised.

Firstly, linear correlation coefficients r between the results of diagnostic measurements and vehicle mileage were calculated and the significance of correlation at the level of 0.05 was estimated [5]. The results of the calculations are shown in Tab. 1 (in the case of results of measurements of compression pressure and leakage, where the sample size was greater than 100, additionally other tests recommended for such sample sizes were done [5]; the results of those tests, not presented in Tab. 1, also indicated that the correlation was significant).

Also, the significance of linear regression was tested with the use of statistics described with formula [1]:

$$F = \frac{r^2}{1-r^2}(n-2) \; . \qquad (1)$$

Critical values of $F_{\alpha,k1,k2}$ for the adopted level of significance $\alpha = 0.05$ and $k_1 = 1$ and $k_2 = n - 2$ degrees of freedom were taken from Snedecor's F distribution tables. Because in all the tested cases $F > F_{kr}$, it can be stated that at the adopted level of confidence of 0.95 the effect of linear regression is significant. The results of the calculations are shown in Tab. 1.

Tab. 1. The results of tests of significance of correlation and significance of the effect of linear regression between the results of diagnostic measurements and the vehicle's mileage (for mileages over 40,000 km)

Diagnostic parameter	Significance of correlation (α = 0.05)		Significance of linear regression (α = 0.05)	
	r	r_{kr}	F	F_{kr}
Compression pressure	-0.735	0.195	244.2	3.88
Leakage	-0.704	0.195	174.7	3.89
Blowby at idle run	0.598	0.335	18.34	4.14
Blowby at 1570 rpm	0.768	0.335	47.35	4.14
Blowby at 1880 rpm	0.623	0.335	20.97	4.14
Blowby at 2200 rpm	0.733	0.335	38.31	4.14
Blowby at 2800 rpm	0.639	0.344	22.03	4.15

Because in all the cases the linear correlation could be considered significant at the level of confidence of 0.95, regression lines were subsequently determined together with confidence intervals for the regression lines at the level of significance $\alpha = 0.05$ [5]. The equations of regression lines are shown in Fig. 1-7.

Mean values of results of diagnostic tests of combustion chamber tightness for mileages of over 40 thousand km change with increasing mileage pointing to the deteriorating technical condition of the engine. However, the rate of changes in the individual diagnostic parameters along with increasing mileage varies between each other.

Mean value of maximum compression pressure for mileages over 40,000 km decreased only by 13% relative to the state at 40,000 km (value calculated on the basis of the determined regression line). Mean value of the leakage within the same range of mileages decreased by 28%.

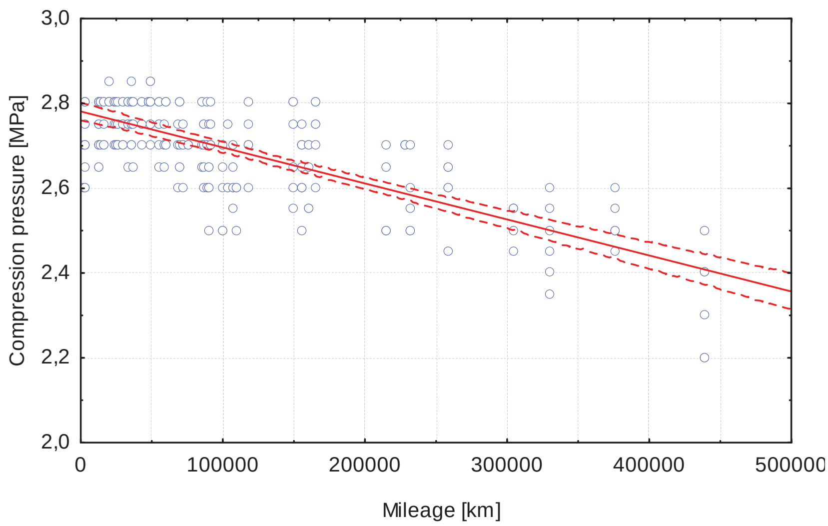

*Fig. 1. Maximum compression pressure as a function of mileage (a linear regression line y = 2.791 – 8.761E-7*x and confidence area for the regression line at α = 0.05 determined for the measurement results obtained for mileages over 40,000 km)*

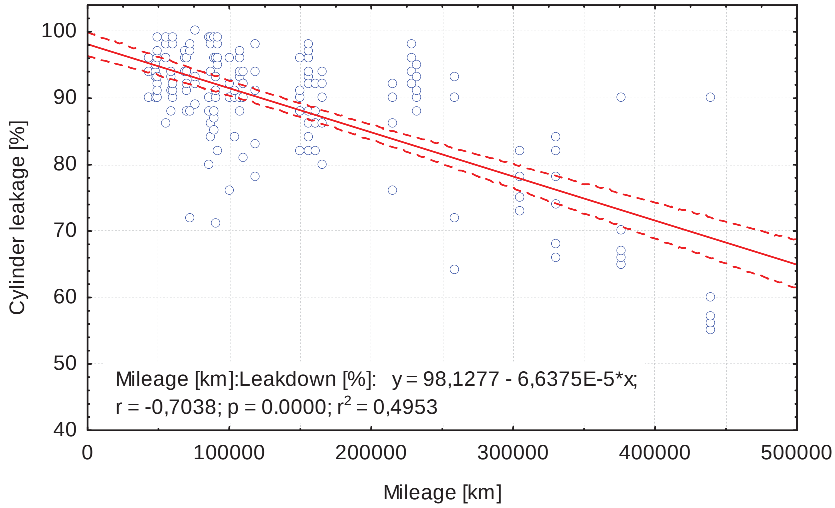

Fig. 2. Cylinder leakage as a function of mileage (a linear regression line and confidence area for the regression line at $\alpha = 0.05$ were plotted)

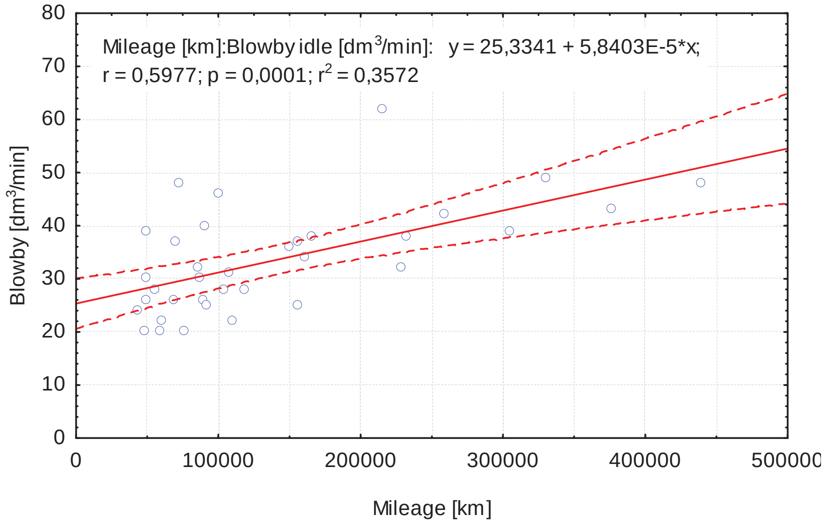

Fig. 3. Blowby rate at idle run as a function of mileage (a linear regression line and confidence area for the regression line at $\alpha = 0.05$ were plotted)

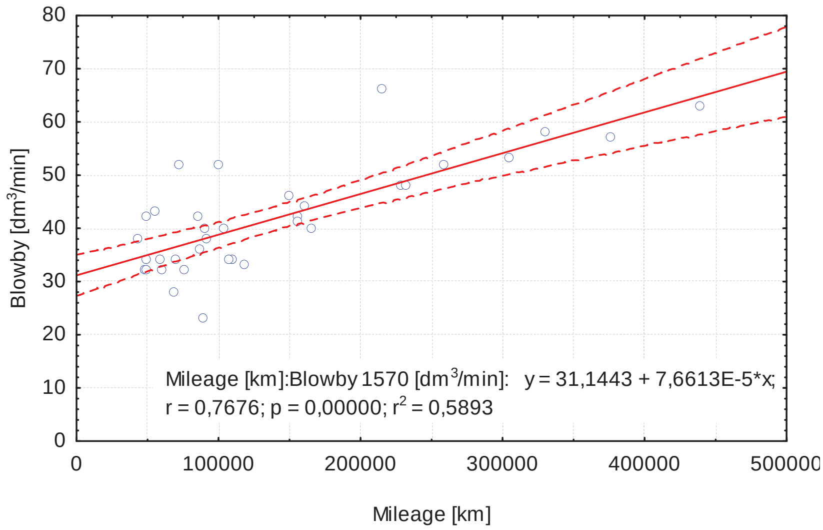

Fig. 4. Blowby rate at full engine load and rotational speed of 1570 rpm as a function of mileage (a linear regression line and confidence area for the regression line at $\alpha = 0.05$ were plotted)

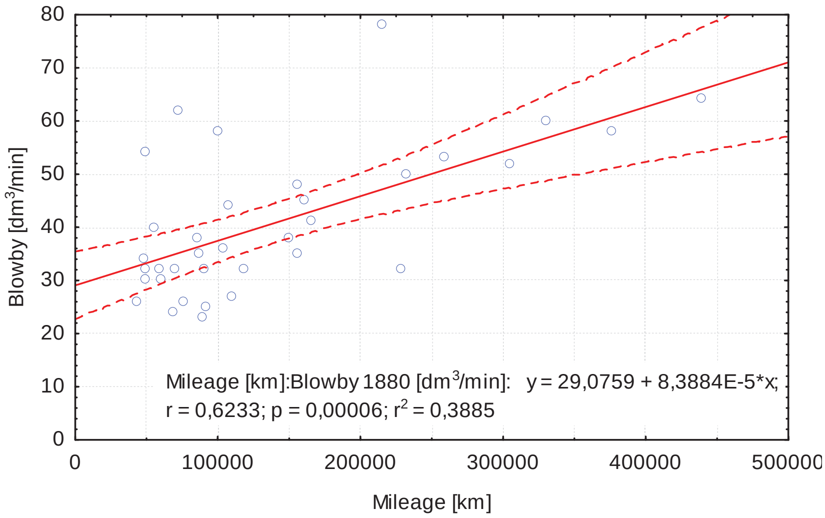

Fig. 5. Blowby rate at full engine load and rotational speed of 1880 rpm as a function of mileage (a linear regression line and confidence area for the regression line at α = 0.05 were plotted)

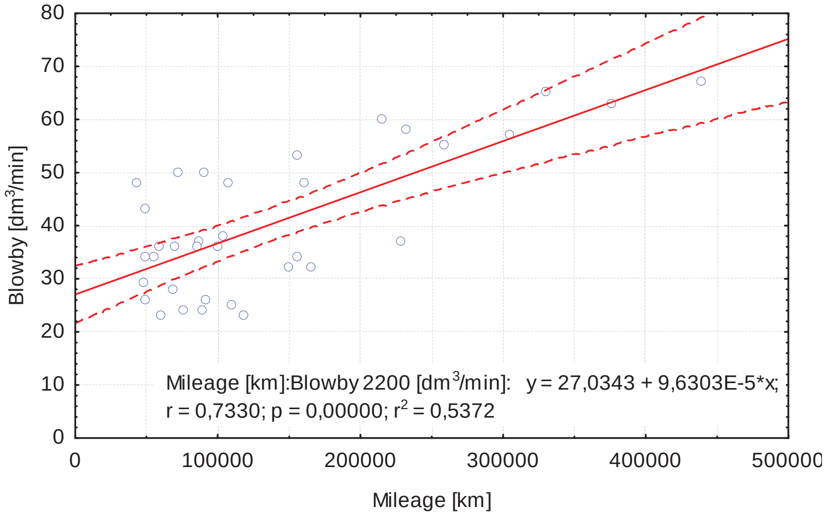

Fig. 6. Blowby rate at full engine load and rotational speed of 2200 rpm as a function of mileage (a linear regression line and confidence area for the regression line at α = 0.05 were plotted)

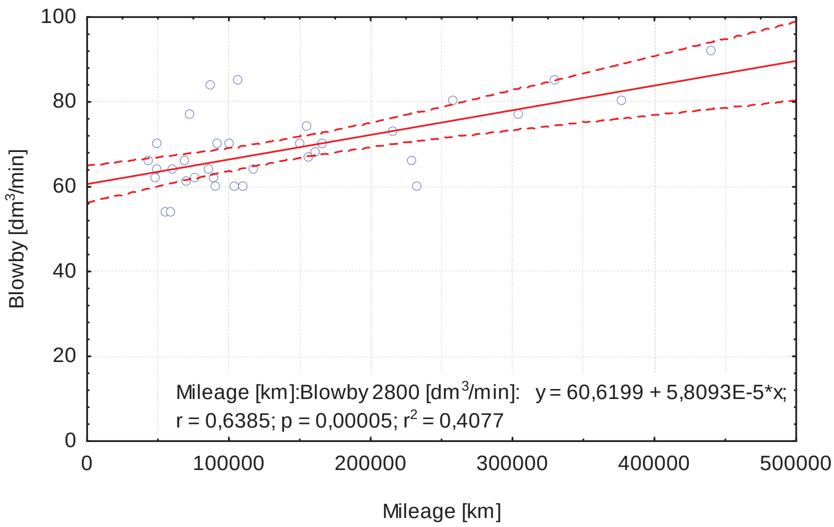

Fig. 7. Blowby rate at full engine load and rotational speed of 2800 rpm as a function of mileage (a linear regression line and confidence area for the regression line at α = 0.05 were plotted)

Much larger increases with growing mileage were observed for blowby flow rates, where, however, the relative changes were affected to a great extent by the operating conditions of the engine during measurement. Mean values of the blowby rate within the mileage range of 40 to 440 thousand km increased by 84% at idle run, while at full engine load blowby rates increased by 90% at 1570 rpm, 103% at 1880 rpm, 125% at 2200 rpm, and 37% at 2800 rpm. The considerably lower relative increase in the blowby rate at full engine load and crankshaft rotational speed of 2800 rpm was connected with approximately twice as large absolute values of blowby in these conditions of engine operation compared to the blowby rates under the other measurement conditions. The differences in the absolute changes (direction coefficients of regression lines) are not as large and range from 5.8 dm^3/min/(100,000 km) at full load and 2800 rpm to 9.6 dm^3/min/(100,000 km) at 2200 rpm.

4. Conclusion

An analysis of results of diagnostic measurements of the combustion chamber tightness, performed periodically in 5 vehicles during their long-term operation, was carried out. The values of diagnostic parameters were characterised by considerable dispersion and sometimes lack of monotone changes in the function of a vehicle's mileage. The statistical methods were assessed to find some general trends. Because it was noted that at the initial stage of vehicle operation (0 to 40 thousand km) the values of the diagnostic parameters pointed to an improvement in the tightness of the combustion chamber, the results of measurements obtained for mileages within this range were not considered in the present analysis of correlations and linear regression.

For mileages over 40,000 km, the linear correlation between the results of the diagnostic measurements and mileage was found to be significant at a level of confidence of 0.95. Mean rates of changes in the individual diagnostic parameters specified on the basis of the determined regression lines differed considerably from one another. Maximum compression pressure showed the slowest and blowby flow rate the fastest changes with mileage. The relative drop of compression pressure within the mileage range of 40 to 440 thousand km was only 13%, while the blowby rate at full load and 2200 rpm within the same mileage range increased by as much as 125%.

The established changes in the diagnostic parameters characterizing the tightness of the combustion chamber will be used for the assessment of results of simulations made with the use of a mathematical model of the PRC kit.

References

[1] Godziszewski, J., Mania, R., Pampuch, R., *Zasady planowania doświadczeń i opracowywania wyników pomiarów*, Wyd. AGH, Kraków 1987.

[2] Koszałka, G., *Modelling the blowby in internal combustion engine, Part 1: A mathematical model*, The Archive of Mechanical Engineering, Vol. LI, No. 2, pp. 245-257, 2004.

[3] Koszałka, G., *Application of the piston-rings-cylinder kit model in the evaluation of operational changes in blowby flow rate*, Eksploatacja i Niezawodnosc – Maintenance and Reliability, No. 4 (37), pp. 71-80, 2010.

[4] Koszałka, G., Niewczas, A., *Wear profile of the cylinder liner in a motor truck diesel engine*, Journal of KONES Powertrain and Transport, Vol. 14, No. 4, pp. 183-190, 2007.

[5] Krysicki, W., and others, *Rachunek prawdopodobieństwa i statystyka matematyczna w zadaniach, Część II: Statystyka matematyczna*, PWN, Warszawa 1994.

[6] Niewczas, A., Drożdziel, P., Ignaciuk, P., Koszałka, G., Krzywonos, L., *Trwałość tribologiczna silników spalinowych w warunkach obciążeń regularnie zmiennych i losowych*, Report on research project No. 9 S604 047 06, maszyn., Lublin University of Technology, Lublin 1997.

[7] Wolff, A., *Numerical analysis of piston ring pack operation*, Combustion Engines 2 (137), pp. 128-141, 2009.