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EVALUATION OF THE TECHNICAL STATE OF AN ENGINE PRC SYSTEM BY MEANS OF FUMES CONTENTS

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Summary. The paper presents an evaluation of validity of engine fumes contents for a diagnosis of the technical state of the piston – rings – cylinder system (PRC). The most valid for the description of the state of PRC system toxic contents of fumes were selected by statistical methods. Mathematical formulas were worked out to describe changes of the technical state. It was verified experimentally whether the values found out by the formulas agreed with the real ones. The areas were pointed out for the use of the tested method in non-invasive diagnostics and in motor diagnostics.

Key words: diagnostics, PRC system, fumes analysis, working parameters

INTRODUCTION

The processes of wear and regulation parameters change during a vehicle's exploitation, whose total values describe its technical state, are directly reflected in the intensity and character of the accompanying processes. The dominant part among them is played by the output processes, characterized by diagnostic signals parameters and by an engine's work effectiveness indicators. The basis for a vehicle's technical diagnosis is an assumption of a close relationship between physical values of diagnostic signals during an object's work and its inner structure determining a particular technical state [Hebda *et al.* 1984, Merkisz and Mazurek 2002].

Hence there is a need for finding such diagnostic methods which would use the signals of easily accessible output processes. Engine fumes contents are a carrier of diagnostic information available for use mainly for an evaluation of the combustion process, which is significantly affected by its wear. It should be assumed that there is a correlation between PRC system's state, amount of oil used by an engine and fume contents.

THE CONCEPT OF THE DIAGNOSTIC METHOD

The aim of the presented research problem is to describe the correlation between the wear of the piston – rings – cylinder system (PRC) and the changeability in the emission levels of basic fumes contents, assessment of the usefulness of the tested method in the broadly understood diagnostics and verification of the universality and repeatability of the method.

The changeability of hydrocarbons – HC, carbon monoxides – CO and carbon dioxides CO_2 were precisely analysed in fumes at different states of an engine's work. An important aspect of the presented research was to select the fume content of the highest reliability as to an evaluation of the PRC system's wear.

In view of the character of oil consumption in a spark-ignition engine (PRC system and timing gear) additional analyses of fumes contents were carried out to exclude interference due to oil consumption in timing the gear.

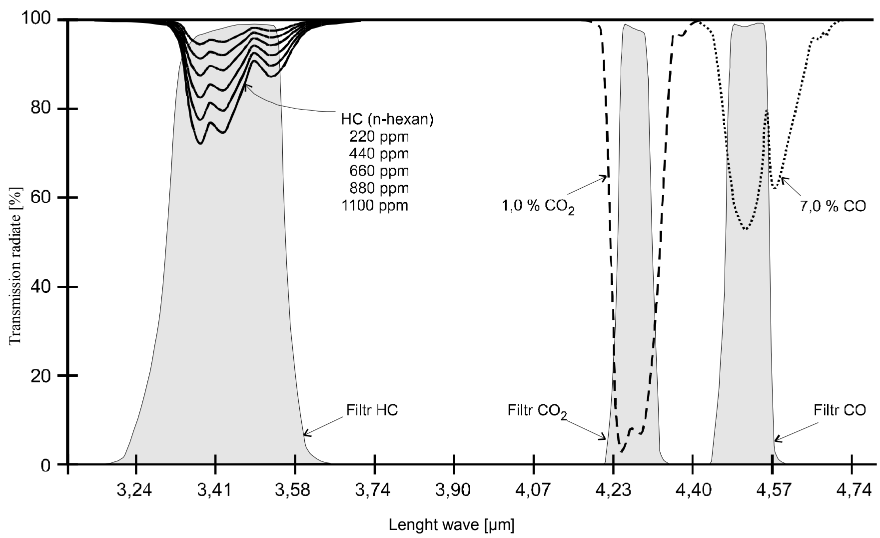

Fig.1. Transmission spectrum of infrared radiation in the analyzer's system

The research involved engines of different, randomly selected working period, of the following types: SKODA781.135, FSO 115C.086, FIAT 170A1.000 and 126A0, testing 30 items of each type.

During research serving to determine parameters of diagnostic signals, assumptions were accepted which maximally reduced interference with PRC system during the fumes contents dependence analysis.

Research on engines involved measurements of parameters of the emitted fumes contents diagnostic signals, compression pressure, relative drop of compressed air pressure in cylinders and compression pressure. Tests on the relative drop of the compressed air pressure in cylinders and compression pressure were carried out in two trials: without oil and with oil injected to the cylinder. Fumes analyses were carried out for three states of an engine's work:

– rotational speed at idle running;
– mean rotational speed – 2000…3000 rpm;
– unstable state, i.e. rotational speed's acceleration to a maximum speed for a particular engine and at sudden throttle close.

During the fumes analyses the following measurements were taken: HC [ppm], CO[%], CO_2 [%], O_2 [%], γ .

During the fumes analyses were carried out by means of analyzer MULTIGAS PLUS 488.

Fumes analyzer of the type Multigas Plus mod. 488 uses the method based on infrared radiation absorption (NDIR) to measure the concentration of carbon monoxide, carbon dioxide and hydrocarbons. Transmission spectrum of this analyzer's radiation is presented in Figure 1. Oxygen and nitrate oxides contents are measured by the electrochemical method, and the presented analyzer is included in the class I according to OIML (Organization Internationale Metrology Legal).

AN ANALYSIS OF RESULTS

Although the research was carried out on four engine types, due to their analogy, this paper presents the full analysis cycle only for the engine FSO 115C.076 of the Polonez car.

Fig. 2 presents the results of tests on the dependence of compression pressure changeability on hydrocarbons contents in fumes for the rotational speed at idle running; Fig. 3 – the dependence of cylinder tightness on hydrocarbons contents in fumes; Fig. 4 – the relation of compression pressure changeability to carbon monoxide content in fumes; Fig. 5 – the dependence of cylinder tightness on carbon monoxide content in fumes.

Fig. 6 presents the dependence of compression pressure changeability on hydrocarbons contents in fumes tested at the rotational speed 3000 rpm; Fig. 7 – the dependence of cylinder tightness on hydrocarbons contents in fumes; Fig. 8 – the relation of compression pressure changeability to carbon monoxide content in fumes; Fig. 9 – the dependence of cylinder tightness on carbon monoxide content in fumes.

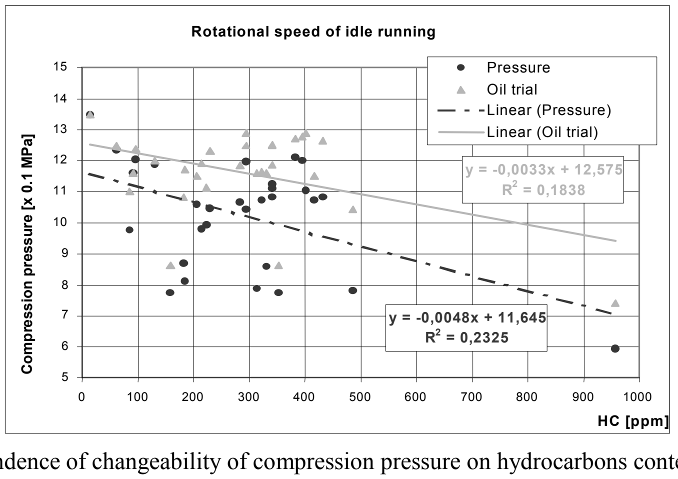

Fig. 2. Dependence of changeability of compression pressure on hydrocarbons contents in fumes

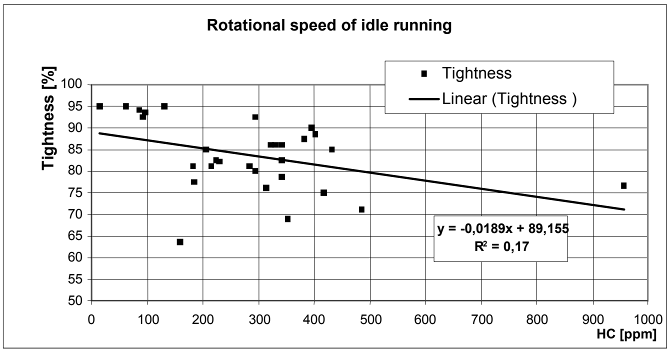

Fig. 3. Relation of changeability of cylinders tightness to hydrocarbons contents in fumes

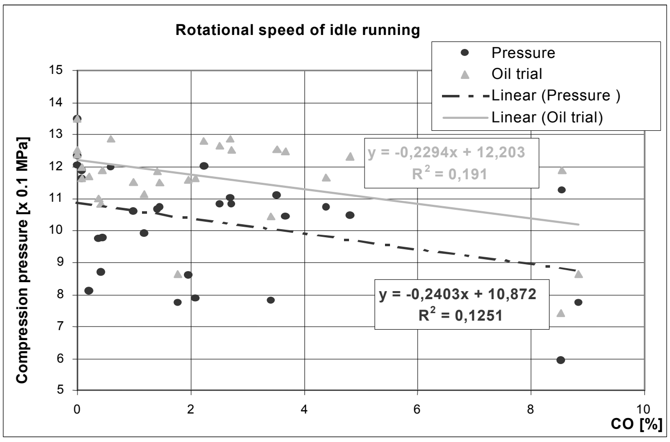

Fig. 4. Dependence of changeability of compression pressure on carbon monoxide content in fumes

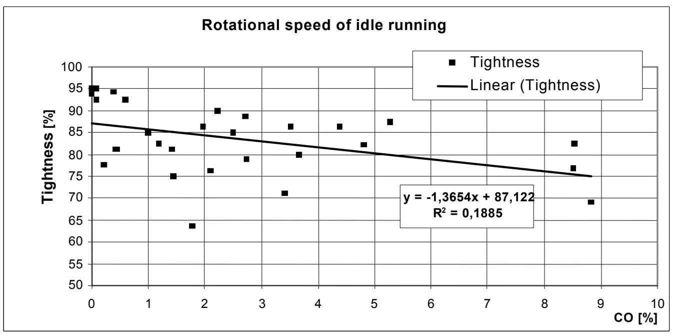

Fig. 5. Relation of changeability of cylinders tightness to carbon monoxide content in fumes

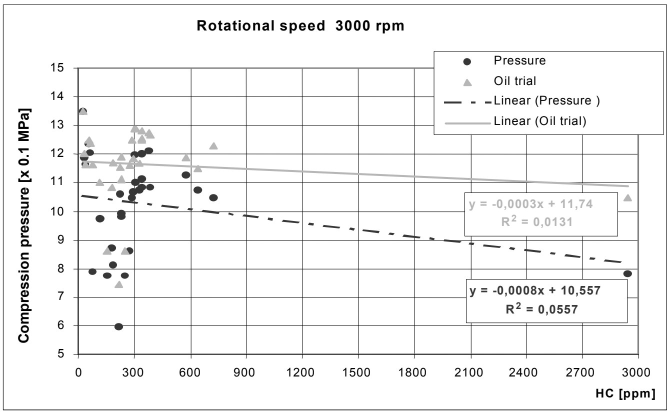

Fig. 6. Dependence of changeability of compression pressure on hydrocarbons contents in fumes

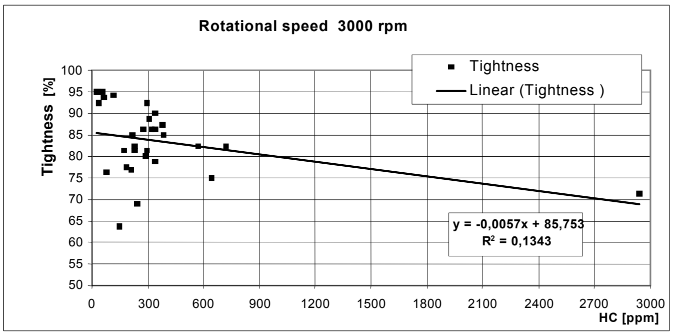

Fig. 7. Relation of changeability of cylinders tightness to hydrocarbons contents in fumes

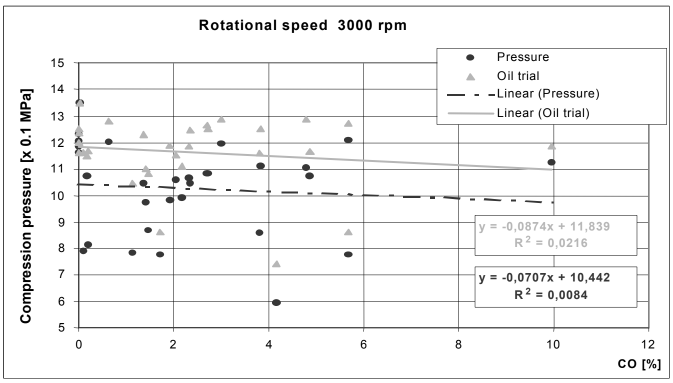

Fig. 8. Dependence of changeability of compression pressure on carbon monoxide content in fumes

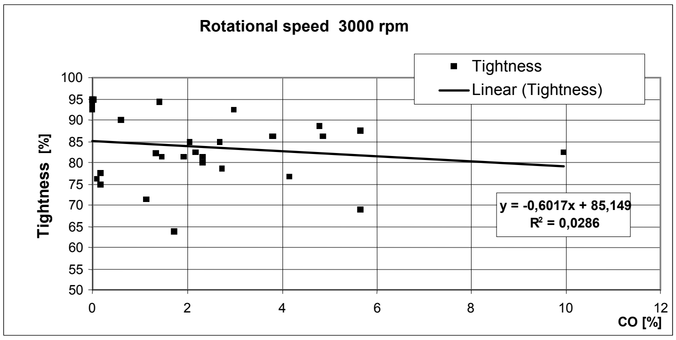

Fig. 9. Relation of changeability of cylinders tightness to carbon monoxide content in fumes

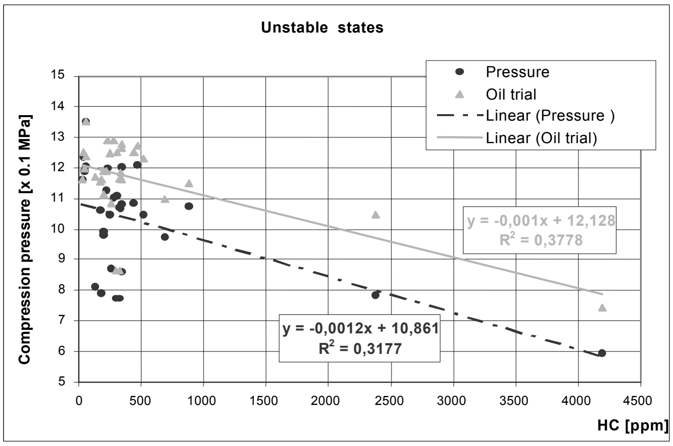

Fig. 10. Dependence of changeability of compression pressure on hydrocarbons contents in fumes

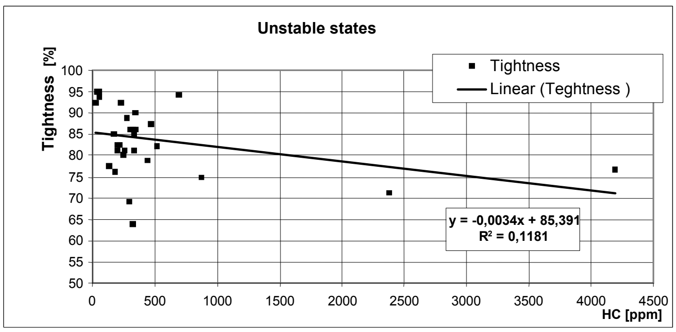

Fig. 11. Relation of changeability of cylinders tightness to hydrocarbons contents in fumes

Fig. 10 presents the dependence of compression pressure changeability on hydrocarbons contents in fumes for unstable engine's states; Fig. 11 – the dependence of cylinder tightness on hydrocarbons contents in fumes.

Aiming at the determination of diagnostic signals for border states, an additional analysis of the obtained measurements results was carried out accepting the maximum value and then the minimum one as the significant parameters of cylinder tightness [Hebda et al. 1984].

The minimum parameters

Coefficient R^2 got improved for the dependence of minimum compression pressure changeability on HC contents in fumes for the rotational speed at idle running (Fig. 12). The improvement also concerns the compression pressure in oil trial.

A much better compatibility was also obtained for the parameter of cylinder tightness (Fig. 13).

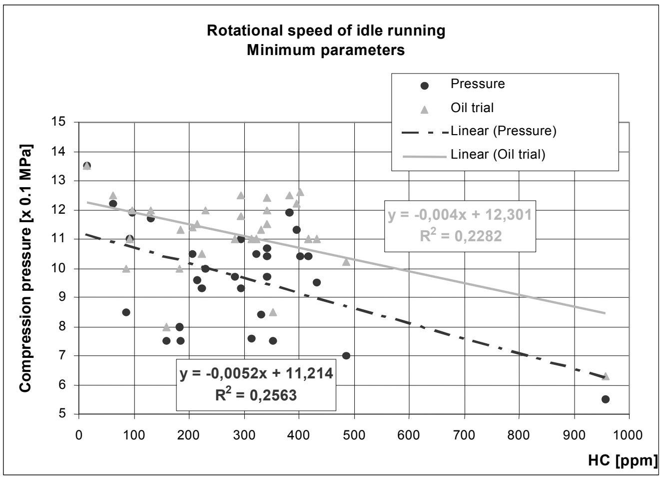

Fig. 12. Dependence of changeability of minimum compression pressure on hydrocarbons contents in fumes

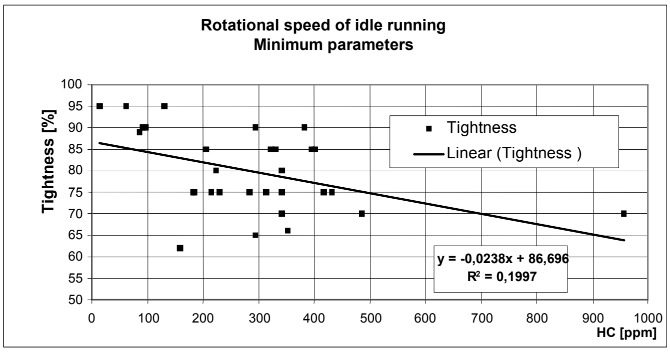

Fig. 13. Dependence of changeability of minimum cylinder tightness on hydrocarbons contents in fumes

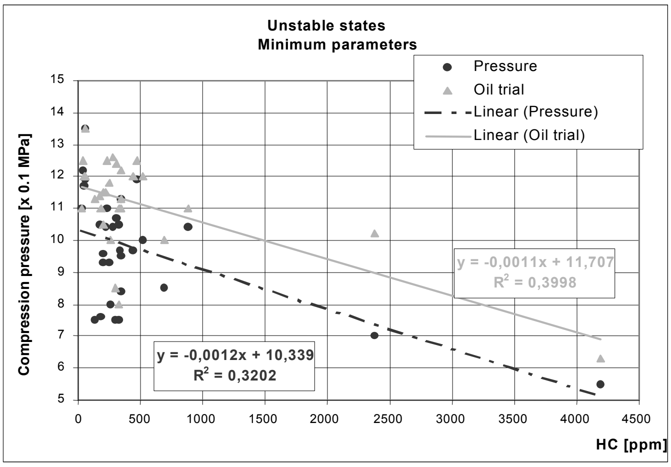

Fig. 14. Dependence of changeability of minimum compression pressure on hydrocarbons contents in fumes

Moreover an improvement of R^2 was obtained for the dependence of minimum compression pressure and tightness on hydrocarbons contents in fumes for the measurements results obtained in the unstable states (Fig. 14); for the oil trial the above-mentioned improvement of coefficient R^2 was slightly more significant

The maximum parameters

There was no improvement of coefficient R^2 for any of the considered dependencies accepting values equal to or much worse than those for mean parameters. This supports the fact of a very significant influence of the technical state of a single cylinder in the condition of border wear on mean toxicity of an engine's fumes.

An analysis of the tests results shows that there exist dual mechanisms of the drop in the above-piston space tightness [Korematsu 1990]:

– PRC system's wear,
– wear of timing gear (sockets and valves connections).

Thus, it is inspiring to consider a quantitative evaluation of an influence of particular factors on the drop in the above-piston space tightness and to correlate the obtained dependencies with fumes contents.

In connection to this aspect of the problem, for each engine type, compression pressure difference was calculated for all the tested items in oil trial and during the measurement of compression pressure without oil trial. The obtained differences from the measurements of compression pressure were presented in the function of toxic elements content in fumes from engines working in particular states.

The dependence of compression pressures difference in oil trial and without oil for an engine of the Polonez car in the function of hydrocarbons contents in fumes for the rotational speed at idle running is presented in Fig. 15, whereas the dependency of the above-mentioned parameters on carbon monoxide content in fumes in fig. 16.

A statistical analysis was carried out to determine the dependencies: mean compression pressure (without oil), mean compression pressure (oil trial), mean tightness (group

I, explained variables) on: HC, CO, CO_2, O_2 contents in fumes and on the coefficient γ at the rotational speed at idle running, at mean rotational speed and in unstable states (group II, explaining variables).

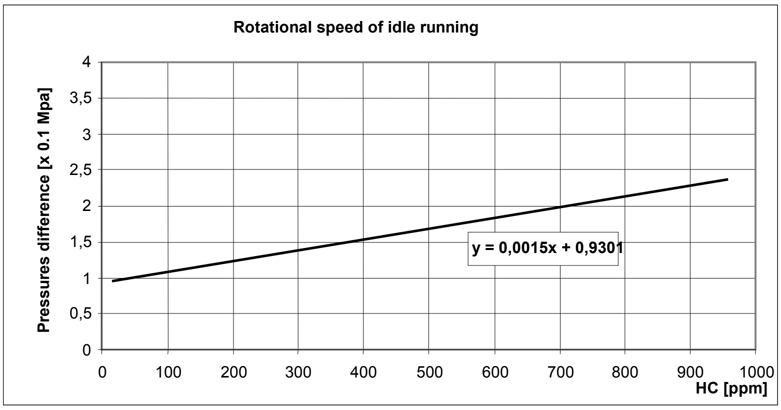

Fig. 15. Dependence of changeability of compression pressures difference in oil trial and without oil on hydrocarbons contents in fumes

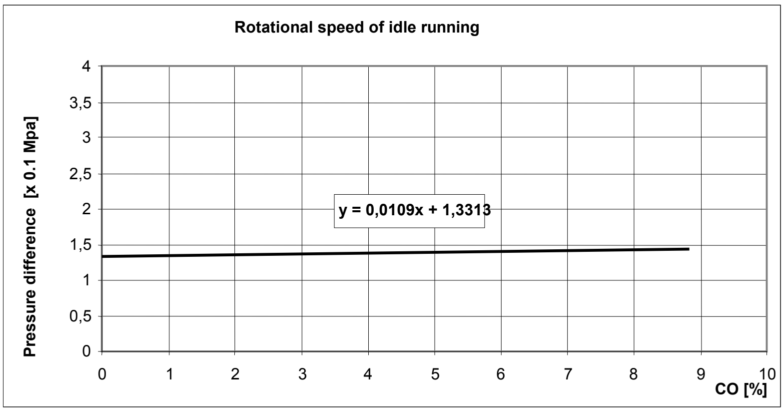

Fig. 16. Dependence of changeability of compression pressures difference in oil trial and without oil on CO content in fumes

The statistical method of the analysis of multiple regression was used. For every variable from group I progressive stepwise regression was carried out, appointing all the variables from group II as the set of independent variables. Then, standard regression was carried out for the statistically significant group II variables.

Tables were given with regression results (coefficients and their significance levels) tab.1, 3, 5, 7 as well as tables of the variance analysis for regression and values pointing at the assessment 'goodness' tab. 2, 4, 6, 8. Also, graphs of the scattering of the explained variable in relation to each of the explaining variables were given.

The explained variable: mean compression pressure

Table 1. Regression results for mean compression pressure

	Coefficients	Standard coefficient error	Test function value t(28)	Level p
W. free	10.86122	0.313531	34.64165	1.55E-24
$HC_{M/M}$	-0.0012	-0.0012	0.000334	0.001181

Table 2. Variance analysis for mean compression pressure

	Total root square	Independence levels	Mean root square	F	Level p
Regression	28.19173	1	28.19173	13.46324	0.001181
Error	60.55443	28	2.162658		
Total	88.74617				

Regression equation

$$\text{mean compression pressure} = 10.861 - 0.001 \cdot HC_{M/M}$$

Where:

$HC_{M/M}$ – hydrocarbons contents in fumes in unstable states

Figures 17, 18, 19, 20 present a graphic interpretation of statistical analysis for the explained variable of mean compression pressure

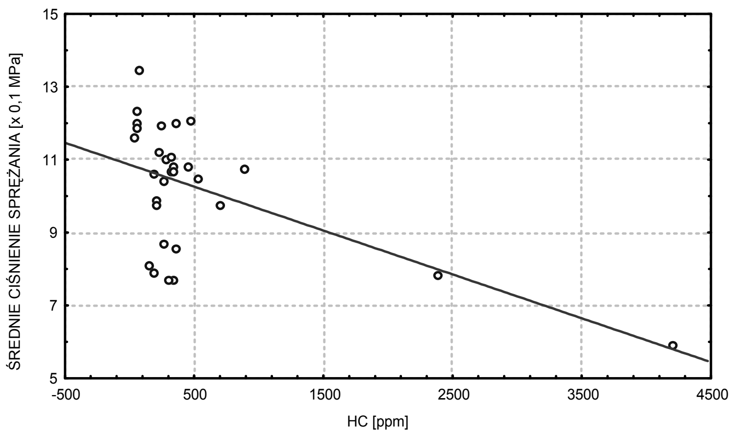

Fig. 17. Chart of the scattering of dependence changeability of mean compression pressure on hydrocarbons contents in fumes for unstable states

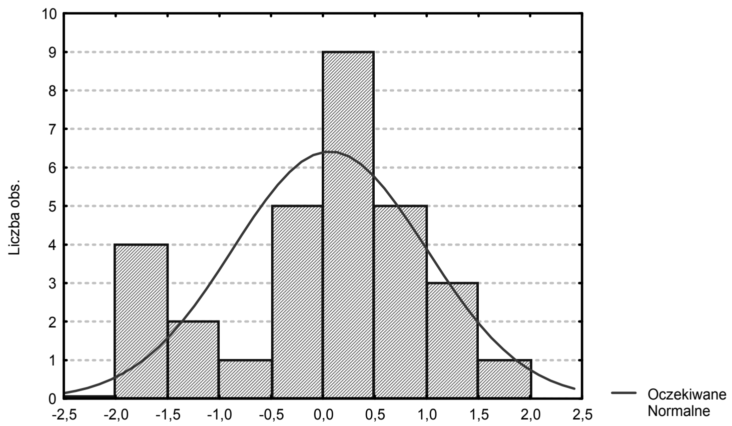

Fig. 18. Distribution of the standardized remainder for the analysis of mean compression pressure

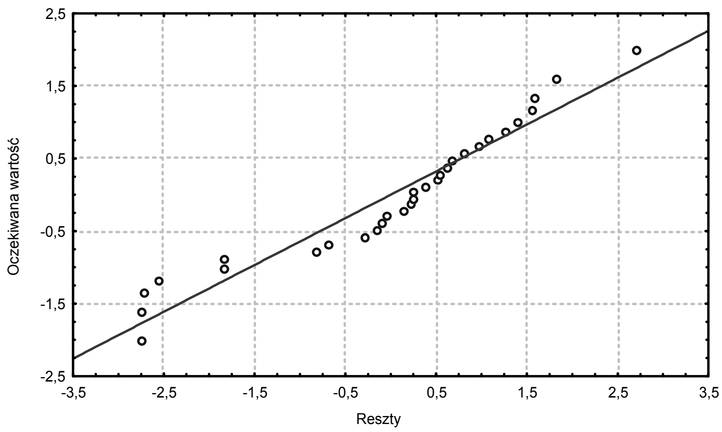

Fig. 19. The standard chart of remainders probability for the analysis of mean compression pressure

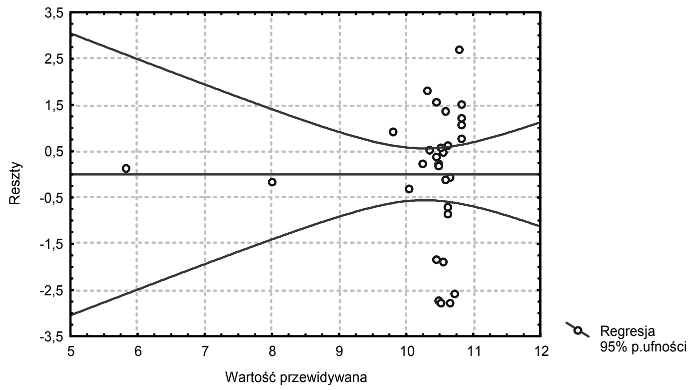

Fig. 20. Predictability in relation to the remainder values for an analysis of mean compression pressure

The explained variable: mean compression pressure (oil trial)

Table 3. Regression results for mean compression pressure (oil trial)

	Coefficients	Standard coefficient error	Test function value t(28)	Level p
W. free	12.57466	0.437663	28.73136	2.54E-22
HC_W	-0.00329	0.001309	-2.51077	0.018097

Table 4. Variance analysis for mean compression pressure (oil trial)

	Total root square	Independence levels	Mean root square	F	Level p
Regression	9.736858	1	9.736858	6.303975	0.018097
Error	43.24764	28	1.544559		
Total	52.9845				

Regression equation:

$$\text{mean compression pressure oil trial} = 12.575 - 0.003 \cdot HC_w$$

Where:

HC_w – hydrocarbons contents in fumes for the rotational speed at idle running

Figures 21, 22, 23, 24 present a graphic interpretation of the statistical analysis for the explained variable of mean compression pressure in the oil trial

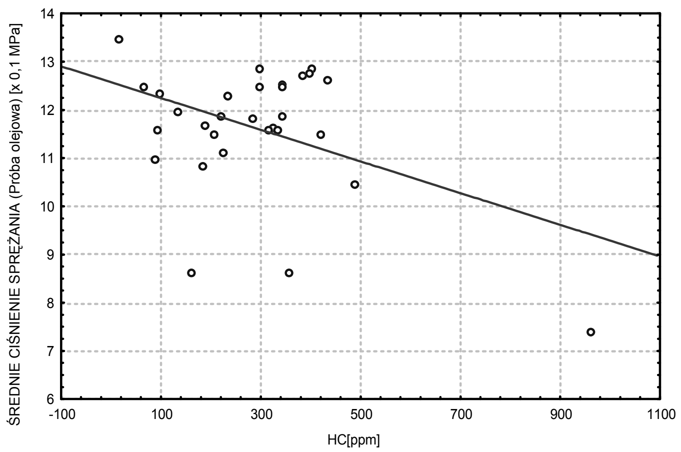

Fig. 21. Chart of the scattering of dependence changeability of mean compression pressure in the oil trial on hydrocarbons contents in fumes for the rotational speed at idle running

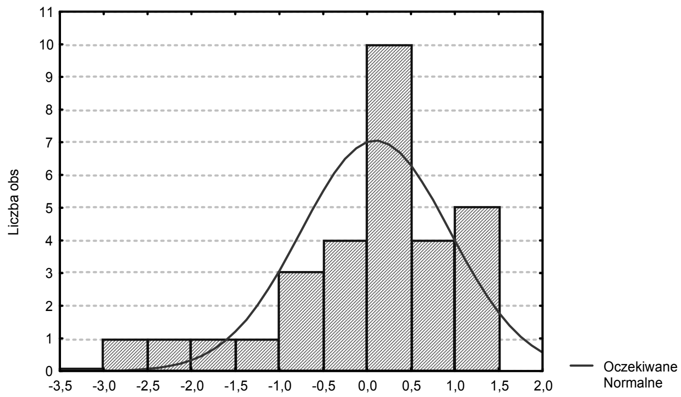

Fig. 22. Distribution of the standardized remainder for the analysis of mean compression pressure in oil trial

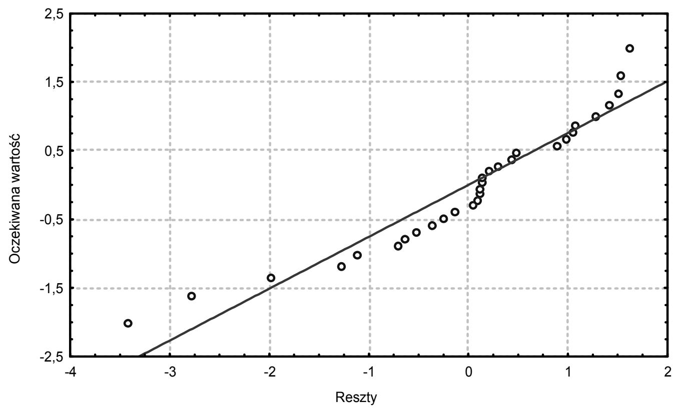

Fig. 23. The standard chart of remainders probability for the analysis of mean compression pressure

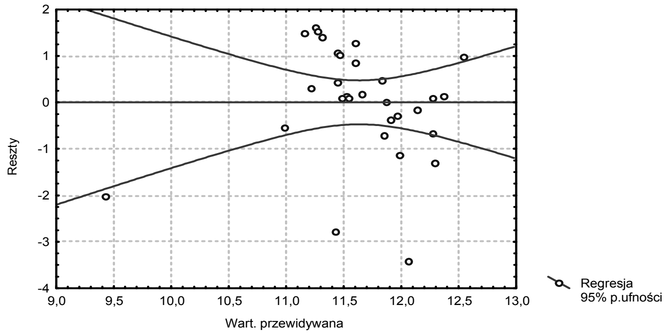

Fig. 24. Predictability in relation to the remainder values for an analysis of mean compression pressure in oil trial

The explained variable: mean tightness

Table 5. Regression results for mean tightness

	Coefficients	Standard coefficient error	Test function value t(28)	Level p
W. free	89.155	2.643518	33.72589	3.23E-24
HC_W	-0.01894	0.007908	-2.39475	0.023566

Table 6. Variance analysis for mean tightness

	Total root square	Independ-ence levels	Mean root square	F	Level p
Regression	323.1534	1	323.1534	5.73482	0.023566
Error	1577.782	28	56.34936		
Total	1900.935				

Regression equation:

$$\text{mean tightness} = 89.155 - 0.019 \cdot HC_w$$

where:

HC_w – hydrocarbons contents in fumes for the rotational speed at idle running

Table 7. Regression results for mean tightness

	Coefficients	Standard coefficient error	Test function value t(27)	Level p
W. free	83.88395	2.941943	28.51311	0.000000
O_{2W}	1.13713	0.384695	2.95593	0.006399
HC_W	-0.01757	0.007015	-2.50447	0.018604

Table 8. Variance analysis for mean tightness

	Total root square	Independence levels	Mean root square	F	Level p
Regression	708.908	2	354.4538	8.028548	0.001836
Error	1192.028	27	44.1492		
Total	1900.935				

Regression equation

$$\text{mean tightness} = 83.884 + 1.137 \cdot O_{2w} - 0.018 \cdot HC_w$$

where:

HC_w – hydrocarbons contents in fumes for the rotational speed at idle running
O_{2w} - oxygen content in fumes for the rotational speed at idle running

CONCLUSION

On the basis of the carried out research and analyses supported by theoretical science the following general conclusions can be formulated:

1. PRC system's wear is connected with an increased oil consumption in an engine and change of cylinder space tightness. Due to oil combustion, toxic contents level rises in fumes. During tests on a 115C.076 engine of the Polonez car in unstable states it was found out that the compression pressure drop by 42% (from 1.35 to 0.78) is accompanied by the 38 times increase of hydrocarbons HC contents in fumes (from 60 to 2380 ppm). However, a further drop of compression pressure from 0.78 to 0.59 MPa i.e. by 24% is accompanied by an increase of hydrocarbons HC contents in fumes by 76% (from 2380 to 4190 ppm). This confirms the correlation of PRC system's wear, described by the drop of compression pressure, with oil consumption and the emitted fumes contents.
2. There exists a strict correlation between the level of toxic contents in fumes and PRC system's wear. In the case of a 115C.076 engine the following exemplary dependencies take place – compression pressure drop from 1.35 to 0.78 MPa causes a 340 times increase of CO contents in fumes in the conditions of an engine running with the rotational speed 3000 rpm (from 0.02 to 1.14% CO).
3. Fume contents fulfill all the requirements for diagnostic signals and may be exploited for a diagnosis of PRC system's technical state, being an exceptionally easily accessible diagnostic parameter. What is more, the dependencies pattern for the parameters of PRC system's parameters on toxic contents in fumes is described by linear regression, consequently, the pattern is clear and linear, which fulfills the requirements for diagnostic signals.
4. An evaluation of an engine's technical state by fumes' analysis can be used within the broadly understood motor diagnostics. There are premises for the use of the presented method in a continuous self-evaluation of the PRC system's state, realized by the systems of deck diagnostics in vehicles, due to easy accessibility of fumes contents diagnostic signal.
5. The most valid fume content for the description of the PRC system's wear are hydrocarbons HC, which is a natural consequence of the thermal process of oil consumption in the combustion chamber.

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