# APPLICATION OF CORRELATION ANALYSIS IN PROECOLOGICAL EVALUATION OF INFLUENCE OF GABARIT-MASS MODIFICATION IN TRACTOR ENGINE'S PISTON ON VIBRATION DYNAMICS OF A CYLINDER LINER

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**Summary**. In the paper the analysis of correlation is used to estimate the influence of gabarit-mass modification in a conventional piston of S 4002/3 engine on the vibration dynamics in the cylinder liner. The obtained results allow to ascertain a significant influence of gassive force on the vibration dynamics inside of a cylinder liner under considered research conditions.

Key words: agricultural tractor, piston-cylinder system, simulation experiment, vibration dynamics

## INTRODUCTION

The tribological system: piston with piston rings-cylinder liner is one of the basic systems which decide about the exploitation reliability of a tractor engine. The cooperation of piston, rings and cylinder influence its durability, mechanical waste and the level of vibrations generated by the engine block [Cempel 1985, Kozaczewski 1987]. Because of high-speed of spark-ignition engines, the mass forces predominate in the range of nominal rotational speeds. However, the gas forces predominate in the range of maximal efficient pressure. In the engine with self-ignition, as being lower high-speed and having much higher maximal pressure up to 12 MPa, the gass forces have got much contribution in the whole range of its work.

In modern high-speed car engine the low-gabarit pistons with reduced number of piston rings have got more and more application in order to decrease friction resistance of piston rings and friction between piston skirt and cylinder liner as well as to decrease the mass forces [Serdecki 1987, Iskra 1998, Serdecki 1998]. On the other hand there is an opinion that superfluous reducing of piston mass is unjustified because of increasing tendency of the assembly of crank-shaft-piston to vibrate [Kozaczewski 1987].

Such methods of mathematical statistics as correlation analysis, multifactorial analysis of variance or regression are of more and more importance in estimation of influence of exploitation and technical parameters on the dynamic of the engine's work [Burski *et al.* 2003, Hempel and Seidl 1970].

#### THE AIM OF THE PAPER

Because of prevailing traditional constructional solutions for piston and piston rings, the aim of the paper is to try to evaluate the influence of gabarit-mass piston's modifications on cylinder liner vibrations by means of correlation analysis. The researches were done by the method of experimental simulations on a model stand under traditional ratio k = S/D. Proecological aspect of researches was taken into account.

## MATERIALS AND METHODS

The research object was the acceleration of cylinder liner vibrations in the form of linear level (LIN) and amplitude spectrum A(f) in the range of band 31.5 Hz–5 kHz with maximal emission of vibration energy.

The detailed description of research stand as well as applied measuring equipment and research conditions were presented in [Burski and Tarasińska 2005, Burski *et al.* 2003]. The model of acting forces of conventional set P-R-C at the technological (initial) clearance together with measurement points of cylinder liner vibrations in considered planes are given in Fig.1. Two different compression chambers, namely, I ( $P_{max} = 0.5$  MPa) and II ( $P_{max} = 0.26$  MPa) were used. Mass force  $P_b = 0.374$  kN was also considered (in case of nominal piston) [Burski and Tarasińska 2005].

Five size modifications of piston were made: four on the piston's guiding part: "1c" (coefficient of gabarit-mass modification  $\gamma_{M/L} = 9.6$ ); "2c" ( $\gamma_{M/L} = 9.8$ ); "3c"( $\gamma_{M/L} = 9.9$ ); "5c" ( $\gamma_{M/L} = 10.1$ ) and one "4c" ( $\gamma_{M/L} = 10.0$ ) on the sealing part. The original number of piston rings was kept. All measurement results are referred to the nominal piston with  $\gamma_{M/L} = 9.4$  ("0c").

#### **RESULTS OF RESEARCH**

Table 1 presents the correlation coefficients between two measurement points for amplitude spectrum of vibrations (n = 24) and p-values for these coefficients. They are presented under three different conditions of acting forces: only mass force ( $P_b$ ) with pressure  $P_s = 0$ , maximal  $P'_{max}(P_b + P_g)$  with experimental compression chamber II and  $P''_{max}$  with compression chamber I. Correlation coefficients in case of nominal piston (0c) and modifications "1c" and "2c" are considerably diversified ( $r = -0.70 \div 0.98$ ). Only under compression pressure of chamber I (0.309 $\div$ 0.22 MPa) correlation coefficients are in a narrower range 0.63 $\div$ 0.97. It means that there is essential influence of compression pressure (force  $P_g$ ) on the level of amplitude vibrations between analyzed

measurement points in all planes. In considered simulation conditions with lower compression pressure or only mass force ( $P_b$ ) the differentiation of correlations coefficients is considerable.

For succeeding modifications  $(3c \div 5c)$  there exists strong positive correlation in emission of amplitude spectrum vibrations, regardless of compression pressure value ( $r = 0.63 \div 0.97$ ). It points at little contribution of nominal force ( $N_{\text{max}}$ ) connected with holding down of piston to cylinder bearing surface at transversal piston's movements.

In evaluation of determination coefficient  $(100 - r^2 [\%])$ , influence of normal force

 $(N_{max})$  for  $\gamma_{max} = 9.9$ , under mass force  $(P_b)$  alone is 46% and under  $P''_{max}$  (chamber I) only 17%. A similar result for determination coefficient appears for the rest piston's modification coefficients  $\gamma_{M/L} = 10.0$  and  $\gamma_{M/L} = 10.1$ .

Figures 2–7 present exemplary changes of correlation coefficients (between two research conditions) as a function of piston's modifications for different planes and measurement points.



Fig. 1a, b. Localization for vibrations measurements of a cylinder liner and the model for acting of basic forces in unit p-r-c

In evaluating the influence of piston rings and skirt's friction on the vibration of cylinder liner (with participation of  $N_{\rm max}$ ), the measurements of the vibrations in verti-

cal plane in points P5 and P6 (Fig. 1) were taken into account. From Table 1 we can see that the correlation coefficients for these points, in case of nominal piston work ( $p_s = 0$ ), are the lowest – with minus sign. It is the effect of large difference for piston rings and skirt friction as a result of transversal movements of piston under force  $N_{\rm max}$ . From succeeding modification "2c" the power of correlation between both measurement points increases and the influence of normal force  $N_{\rm max}$  does not exceed 14%.

Piston's modification $\gamma_{_{M/L}}$		Plane and point of measurement		
		transversal	longitudinal	vertical
		1/2	3/4	5/6
$\begin{array}{c} \text{Oc} \\ \gamma_{_{M/L}} = 9.4 \end{array}$	$P_{i}=0$	$0.79^{1}$	0.94	-0.70
		$0.00^{2}$	0.00	0.00
	chamber II	0.62	0.79	0.75
		0.00	0.00	0.00
	chamber I	0.63	0.88	0.77
		0.00	0.00	0.00
$\frac{1c}{\gamma_{M/L}} = 9.6$	$P_{i}=0$	0.12	0.21	0.96
		0.56	0.32	0.00
	chamber II	0.90	-0.56	-0.69
		0.00	0.00	0.00
	chamber I	0.95	0.85	0.89
		0.00	0.00	0.00
$2c \\ \gamma_{M/L} = 9.8$	$P_{i}=0$	0.95	0.28	0.94
		0.00	0.17	0.00
	chamber II	0.95	0.98	0.95
		0.00	0.00	0.00
	chamber I	0.93	0.97	0.92
		0.00	0.00	0.00
$3c \\ \gamma_{M/L} = 9.9$	$P_{i}=0$	0.74	0.95	0.96
		0.00	0.00	0.00
	chamber II	0.92	0.91	0.96
		0.00	0.00	0.00
	chamber I	0.91	0.96	0.95
		0.00	0.00	0.00
$4c \\ \gamma_{M/L} = 10.0$	$P_{i}=0$	0.93	0.96	0.92
		0.00	0.00	0.00
	chamber II	0.94	0.92	0.91
		0.00	0.00	0.00
	chamber I	0.96	0.92	0.93
		0.00	0.00	0.00
$5c \\ \gamma_{M/L} = 10.1$	$P_{i}=0$	0.97	0.63	0.93
		0.00	0.00	0.00
	chamber II	0.92	0.96	0.96
		0.00	0.00	0.00
	chamber I	0.96	0.96	0.94
		0.00	0.00	0.00

Table 1. Correlation coefficients and their p-values for amplitude spectrum of acceleration vibrations of a cylinder liner in the adopted study conditions

<sup>1</sup>correlation coefficient, <sup>2</sup>*p*-value



Fig. 2. Spectrum amplitude's correlation coefficient value changes in transversal plane vibrations of a liner (P1) in case of acting mass force (O) and gas force (I.II)



Fig. 3. Spectrum amplitude's correlation coefficient value changes in vertical plane vibrations of a liner (P5) in case of acting mass force (O) and gas force (I.II)



Fig. 4. Spectrum amplitude's correlation coefficient value changes in longitudinal plane vibrations of a liner (P3) in case of acting mass force (O) and gas force (I.II)



Fig. 5. Spectrum amplitude's correlation coefficient value changes in transversal plane vibrations of a liner (P2) in case of acting mass force (O) and gas force (I.II)



Fig. 6. Spectrum amplitude's correlation coefficient value changes in vertical plane vibrations of a liner (P6) in case of acting mass force (O) and gas force (I.II)



Fig. 7. Spectrum amplitude's correlation coefficient value changes in longitudinal plane vibrations of a liner (P4) in case of acting mass force (O) and gas force (I.II)

#### CONCLUSIONS

So far in the design of combustion engine the subject of design engineers' interest was the choice of the most important geometrical parameters: among others, the cylinder's diameter (D) and piston stroke (S). A proper choice of their values allows to form an engine's dimensions, mass and basic parameters of its work. However, there is lack of information on gabarit-mass connections with values characterizing the quality of engine's work or its influence on environment.

In spite of that, experimental tests by simulation method were conducted on a single set of real objects. They proved the influence of gabarit-mass modifications of conventional piston on the vibrations of cylinder liner in respective planes. The gas force is of great importance here. It reduces an influence of normal force in transversal plane of piston movements so that the "object" of correlation between the analyzed points increases. The greater modification is  $(3c \div 5c)$ , the more similar the amplitude spectrums for different research conditions become.

Researches are being continued on next objects in order to confirm statistically obtained dependences. TOB exploitation wear of a set will be also taken under consideration.

## REFERENCES

- Burski Z., Tarasińska J. 2005: Testing an influence of the piston mass and height on the vibrations dynamics in the cylinder Liner of an agricultural tractor in proecological aspect. TEKA Comm. Mot. Power Ind. Agricult. Polish Academy of Science Branch in Lublin, 16–24.
- Burski Z., Tarasińska J., Sadkević R. 2003: The methodological aspects of using multifactoral analysis of variance in the examination of exploitation of engine sets. TEKA Comm. Mot. Power Ind. Agricult. Polish Academy of Science Branch in Lublin V–III., 45–54.
- Burski Z., Tarasińska J., Reichenbach J. 2006: Ocena wpływu modyfikacji tłoka na dynamikę drgań tulei cylindrowej silnika ciągnika w warunkach luzu granicznego zuzycia. Inż. Roln. 5/80, 95–103.
- Cempel Cz. 1985: Diagnostyka wibroakustyczna maszyn. Wyd. Polit. Poznańskiej.

Hempel W.. Seidl T. 1970: Statistische Erhebung über Dieselmotorengeräsche. ATZ 31, 153-156.

- Iskra A. 1998: Straty tarcia powierzchni bocznnej tłoka-weryfikacja modelu obliczeniowego. TEKA KN-PM. PAN o/Kraków, 2–15, 20–25.
- Kozaczewski W. 1987: Konstrukcja złożeń tłok-cylinder silnika spalinowego. WKiŁ Warszawa.
- Serdecki W. 1987: Wpływ liczby pierścieni tłokowych na straty tarcia w silniku spalinowym. J. KONES. Bielsko-Biała, 395–402.
- Serdecki W. 1998: Wpływ ukształtowania elementów układu korbowo-tłokowego w fazie rozruchu. Symp. "Rozruch silników spalinowych". Polit. Szczecińska, 191–197.
- Ustrzycki A. 1999: Wpływ uwzględniania zmian gęstości paliwa na dokładność modelu matematycznego układu wtryskowego z pompą rządową. Konf. SAKON'99, 163–171.