THE RESEARCHES ON THE VIBRATIONS OF THE ENGINE UNITS BY THE METHOD OF MULTIFACTOR INTERACTIONS OF VARIANCES UNDER THE CONDITIONS OF WORK ENVIRONMENT POLLUTION

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Summary

The paper presents the results of the researches on the vibration of a cylinder sleeve working under conditions of environmental pollution. The statistical analysis of variance was conducted to prove the influence of chosen factors (the state of PRC, chamber with or without compression, three planes of vibrations, the oil polluted with coaldust) on the values of LIN, PEAK and peak factor C of vibrations.

Keywords: dynamics of tractor's engine, vibrations, statistical analysis of variance.

BADANIA DRGAŃ SILNIKA W WARUNKACH PRACY W ZANIECZYSZCZONYM ŚRODOWISKU METODĄ WIELOCZYNNIKOWEJ ANALIZY WARIANCJI

Streszczenie

Praca przedstawia wyniki badań drgań tulei cylindrowej w warunkach zanieczyszczenia środowiska pyłem węglowym.. Przeprowadzono statystyczną analizę wariancji pozwalającą wykryć wpływ wybranych czynników (stanu TPC, obecności komory ze sprężaniem, trzech płaszczyzn wibracji, zanieczyszczeń oleju pyłem węglowym) na wartości LIN, PEAK i C widma drgań.

Słowa kluczowe: dynamika silnika ciągnikowego, drgania, statystyczna analiza wariancji.

1. INTRODUCTION

The researches on the dynamics of vibrations of high – pressure agricultural machines in their works conditions are extremely difficult and complex. The work enviroment of, e.g. a tractor, by its influence (temperature and humidity of the surroundings, dustiness, vibrations of the ground and co- operating machines) creates the situation in which random phenomena affect to a great extent the evaluation of co-relations between operational factors (type and size of wear, clearances, leak in compression chamber, load) and the symptoms accompanying the work, such as vibrations or noise [1,2,4].

Pro – ecological effects on changes leading to the decrease in emission of vibrations and noise which have already been tried do not seem to match higher and higher expectations of European and world standards. Therefore, there is the need to conduct the researches in the form of experimental or computer simulation which would take into consideration constructional and operational factors in pro – ecological aspect. It is significant and inevitable to make use of modern statistical tests, such as multifactor interactions of variances, in order to conduct the analysis and define the statistical significance of the presence of each of the factors.

2. THE PURPOSE OF THE PAPER

The purpose of the paper is to present the statistical significance of the influence of dustiness of the work surroundings of the S-4002/3 engine with coaldust taking into consideration the influence of the chosen operational factors (the changes in compression pressure, the values of clearances)on the total linear level of vibrations of a cylinder sleeve. The spectral analysis of the influence of the above – mentioned factors, conducted by means of multifactor interactions of variances, is presented in the paper [5,7].

3. THE METODICS OF THE RESEARCHES

The subject of this paper is a multifactor statistical analysis of the interactions of the level of vibrations of the cylinder sleeve in the form of the values: LIN, PEAK and the peak factor C $[\frac{PEAK}{LIN}]$ [3]. During the measurements we checked their dependence on the following factors:

- the state of PRC (new, worn),
- the presence of the compression chamber (with or without),
- 3 planes of the vibrations (t-transverse, l-longitudinal, v-vertical),
- 2 measuring points (N and N'),
- oil pollution (the oil alone, the oil with coaldust 8mg/m^3 , the oil with coaldust 16 mg/m^3).

For each out of 72 combinations of the above – mentioned factors, a few parameters of the vibrations were included. Among the others, those were: the level of amplitudes of the spectrum at 16 frequencies (315 – 10000Hz) and the parameters presenting the linear level of vibrations, e.g. PEAK, LIN, C [6]. In [6] we analysed some of the random variables representing the amplitude spectrum and characterised in details the conditions of the measurement.

4. THE METHODICS OF STATISTICAL CALCULATIONS OF THE SIGNIFICANCE OF THE CHANGES IN DYNAMICS OF THE VIBRATIONS

The analysis of variances (ANOVA) was conducted for the variables PEAK, LIN, C in order to discover the significance of the influence that each of the factors exerts upon the variable. Only one value of the variable in each subclass (i.e. for every combination of the factors) which was considered to be the nominal one (taking into consideration the 3% error of repeatability), was observed. This, however, does not allow for the complete evaluation of the error present in calculations. Therefore, the analysis was conducted in 2 stages:

1. every possible 4 – factors ANOVA analysis was conducted, getting rid of one factor after another until the model with the least mean error was chosen[7].
2. the further reduction of the model took place (eliminating more factors) if any of the factors and its interactions that were chosen in point 1. turned out to be insignificant.

The eliminated factor in the first stage for all considered variables was the measuring point. In the case of the variable PEAK in the second stage the planes were eliminated.

It turned out to be necessary to subject the variables to logarithmic transposition, because a very important condition of the analysis of variances concerning the lack of co-relation between the means and standard deviations in groups was not completed. It is stabilized together with variances in groups by the logarithm.

All the calculations were conducted is STATISTICA programme. Table 1 presents the names of the factors used in ANOVA [5].

Table 1. The explanations of factors used in ANOVA

The name of the factor	PRC	Chamber	Plane	Point	Oil
the number of levels	2	2	3	2	3
the explanation of the levels	new worn	with or without compression	t-transverse, l-longitudinal, v-vertical	N N'	oil alone, oil+coaldust 8mg/m^3, oil+coaldust 16 mg/m^3

5. THE STATISTICAL ANALYSIS OF PEAK

Table 2 presents the results of the 3 – factors ANOVA for the variable Ln (PEAK). As it shows, the main effect of the chamber proved to be insignificant. However, the factor is involved in interactions of the second and third order and, hence, cannot be omitted.

Table 2. The results of the 3-factors ANOVA for the variable Ln (PEAK)

1– PRC 2 – Chamber 3 – Plane 4 – Oil						
effect	df effect	MS effect	df error	MS error	**F**	p-value
1	1	16,02	60	0,348	46,07	0,0000
2	1	0,02	60	0,348	0,05	0,8296
3	2	4,83	60	0,348	13,89	0,0000
12	1	5,79	60	0,348	16,65	0,0001
13	2	6,63	60	0,348	19,08	0,0000
23	2	2,02	60	0,348	5,82	0,0049
123	2	7,33	60	0,348	21,09	0,0000

Figure 1 shows diagram of the 3 - directional interaction PRC x CHAMBER x OIL with vertical bar which denotes the size of LSD (Least Significance Difference) on 0,05 significance level. LSD is used for finding significant differences between means of cells with fixed levels of other factors.

In order to check the statistical significance of differences of the variable PEAK on different levels of oil pollution, so called, analysis of contrast was carried out on 0,05 significance level. The results of that analysis are shown in Table 3. It contains the observed significance levels for all the differences. Comparison „1-2" indicates the difference between the oil alone and the oil + 8mg/m^3 of coaldust „2-3" the oil + 8mg/m^3 and the oil + 16mg/m^3 of coaldust, „1-3" the oil alone and the oil + 16mg/m^3 of coaldust. Table 4 presents the differences between the new and worn PRC and the chambers with or without compression.

Fig.1 The interaction PRC x Chamber x Oil

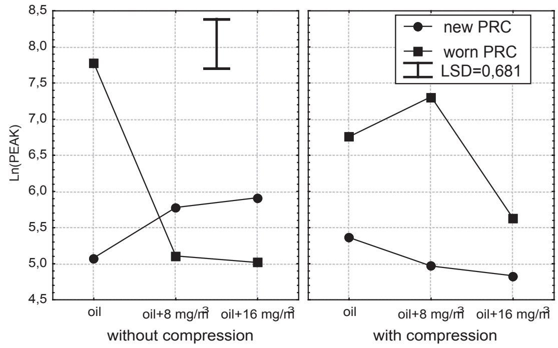

Table 3. The differences between levels of oil pollution

Effect		comparisons between oil pollution		
PRC	Chamber	1-2	1-3	2-3
new	with compr.	ins.*	ins.	ins.
	without	0,045	0,017	ins.
worn	with	ins.	0,002	0,000
	without	0,000	0,000	ins.

* insignificant

Table 4. The differences between new-worn PRC and the chamber with-without compression

		levels of pollution		
	differences	oil alone	oil + 8 mg/m^3	oil + 16 mg/m^3
Without compr.	new PRC - worn PRC	0,000	ins.	0,011
With compr.	new PRC - worn PRC	0,000	0,000	0,002
new PRC	With compr. - Without	ins.	0,021	0,002
worn PRC	With compr. - Without .	0,004	0,000	ins.

CONCLUSIONS:

1. The effect of the worn PRC:
   - with the compression chamber, the worn PRC leads to the significant increase in PEAK on all pollution levels,
   - without the compression chamber, the worn PRC leads to the significant increase in PEAK with the oil alone and to the significant decrease in PEAK in the case of 16 mg/m^3 pollution.
2. The effect of the presence of the compression chamber:
   -with the worn PRC, the compression in the chamber lowers PEAK in the case of pure oil and raises PEAK in the case of 8 mg/m^3 pollution,
   -with new PRC, the compression in the chamber decreases PEAK when oil is polluted.
3. The effect of the oil pollution:
   - with the new PRC and the chamber without compression, the oil pollution leads to the increase in PEAK,
   - with the new PRC and the chamber with compression, there is no significant influence of pollution on PEAK value,
   - with the worn PRC and the chamber with compression, in the case of 16 mg/m^3 pollution PEAK is significantly lower than in the case of 8 mg/m^3 pollution or the oil alone,
   -with the worn PRC and the chamber without compression the pollution of oil leads to decrease of PEAK.

6. THE STATISTICAL ANALYSIS OF LIN

Table 5 presents the significant effects at 0,05 level in 4-factors ANOVA for the variable Ln (LIN)

As Table 5 shows, the interactions between the factors create the situation that is difficult in evaluation. The 4-directional interaction PRC x Chamber x Oil x Plane is insignificant but the effect of the plane is involved in the effects of PRC (PRC x Plane interaction) and the chamber (Chamber x Plane). Therefore, the diagram of 4-directional interaction indicating the least significant difference (LSD) at 0,05 level is shown in Figures 2and 3 (4-directional interaction can't be shown on a single figure). Table 6 presents the results of the test for the differences between the levels of pollution in particular groups. Table 7 presents the differences between the new and the worn PRC and the chambers with or without compression at the specified level of oil pollution.

Table 5. The results of 4-factors ANOVA for the variable Ln(LIN)

1-PRC, 2- Chamber, 3- Plane, 4-Oil						
effect	df effect	MS effect	df error	MS error	F	p-value
1	1	16,54	36	0,080	206,3	0,0000
2	1	17,33	36	0,080	216,1	0,0000
3	2	0,62	36	0,080	7,8	0,0016
4	2	1,46	36	0,080	18,2	0,0000
13	2	0,42	36	0,080	5,2	0,0105
23	2	0,54	36	0,080	6,8	0,0032
14	2	0,88	36	0,080	10,9	0,0002
24	2	0,94	36	0,080	11,7	0,0001
124	2	0,75	36	0,080	9,3	0,0006

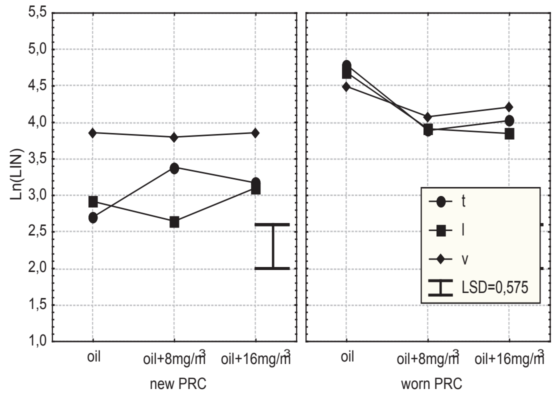

Fig.2 The diagram of 4-directional interaction PRC×Chamber×Oil×Plane, chamber without compression

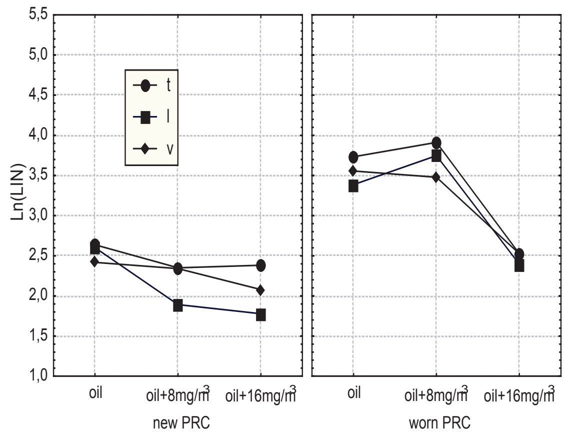

Fig.3 The diagram of 4-directional interaction PRC×Chamber×Oil×Plane, chamber with compression

Table 6. The results of testing the differences in the variable LIN with different stages of oil pollution at 0,05 level of significance

PRC	Cham-ber	Plane	comparisons in oil pollution		
			1-2	2-3	1-3
new	without	t	0,022	ins.	ins.
		l	ins.	ins.	ins.
		v	ins.	ins.	ins.
	with	t	ins.	ins.	ins.
		l	0,017	ins.	ins.
		v	ins.	ins.	ins.
worn	without	t	0,003	ins.	0,011
		l	0,010	ins.	0,006
		v	ins.	ins.	ins.
	with	t	ins.	0,000	0,000
		l	ins.	0,000	0,001
		v	ins.	0,002	0,001

Table 7. The results of testing the differences in the variable LIN for the analysed operational factors

	differen-ces	plane	pollution		
			oil alone	oil + 8 mg/m^3	oil + 16 mg/m^3
with compr.	new PRC – worn	t	0,000	ins.	0,005
		l	0,000	0,000	0,013
		v	0,031	ins.	ins.
without	new PRC – worn	t	0,000	0,000	ins.
		l	0,009	0,000	0,036
		v	0,000	0,000	ins.
new PRC	with compr. – without	t	ins.	0,001	0,008
		l	ins.	0,011	0,000
		v	0,000	0,000	0,000
worn PRC	with compr.– without	t	0,000	ins.	0,000
		l	0,000	ins.	0,000
		v	0,002	0,040	0,000

CONCLUSIONS:
1. The effect of the wear of the unit:
   -worn PRC generally increases the value of LIN, regardless of the level of oil pollution, especially in longitudinal plane,
2. The effect of compression chamber:
   -is mostly visible in the case of 16 mg/m^3 coaldust when compression leads to decreasing of LIN.

7. THE STATISTICAL ANALYSIS OF THE VARIABLE C

Table 8 presents the significant effects (on 0,05 level) of 4-factors ANOVA for Ln (C), where C=$\frac{PEAK}{LIN}$. Figure 4 presents the plane effect and Figure 5 the diagram of PRC x CHAMBER x OIL interaction. Both diagrams contain the LSD value on 0,05 level.

Table 8. The results of 4-factors ANOVA for the variable Ln(C)

1-PRC, 2- Chamber, 3- Plane,4-Oil

effect	Df effect	MS effect	Df błąd	MS błąd	F	p-value
2	1	18,46	36	0,428	44,15	0,0000
3	2	1,54	36	0,418	3,67	0,0354
12	1	5,48	36	0,418	13,10	0,0009
14	2	3,11	36	0,418	7,44	0,0020
124	2	4,18	36	0,418	9,99	0,0004

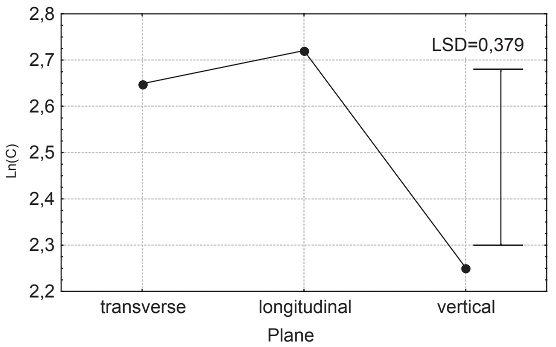

Figure 4. The diagram of the plane effect

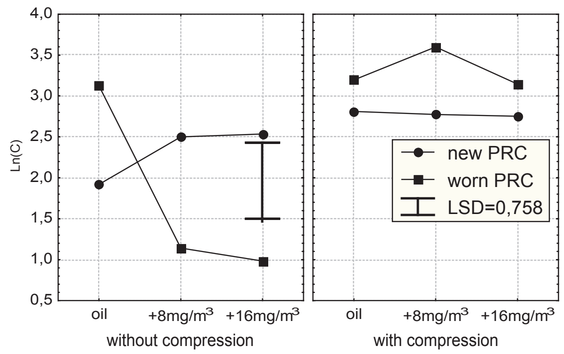

Figure 5 the diagram of PRC x CHAMBER x OIL interaction.

Table 9 shows the differences between oil pollution levels. Table 10 shows the significant differences between the new and the worn PRC and the chambers with and without compression on the specified level of oil pollution.

Table 9 The influence of the level of oil pollution on the value of C

Effect		comparisons in oil pollution		
PRC	Chamber	1-2	1-3	2-3
new	without	ins.	ins.	ins.
	with	ins.	ins.	ins.
worn	without	0,000	ins.	0,000
	with	ins.	ins.	ins.

Table 10 The influence of worn PRC and the influence of compression on the value of C

	differences	levels of pollution: oil alone	oil + 8 mg/m^3	oil + 16 mg/m^3
Without compr.	new PRC - worn PRC	0,0027	0,0009	0,0002
With compr.	new PRC - worn PRC	ins.	0,0338	ins.
new PRC	With - Without compression	0,0222	ins.	ins.
worn PRC	With - Without compression	ins.	0,0000	0,0000

CONCLUSIONS:

1. The plane effect: the influence of the vibrations in the form of the peak factor C in vertical plane is significantly smaller than in transverse and longitudinal plane.
2. The effect of the worn PRC:
   - with the compression chamber, the worn PRC causes the increase in the value of the peak factor C in the case of 8 mg/m^3 pollution,
   - without the compression chamber, the worn PRC causes the increase in the value of the peak factor C in the case of the oil alone and decrease in the case of oil pollution.
3. The effect of pollution: the differences in pollution levels do not have influence of the value of the peak factor C, apart from 2 cases: in the worn PRC without the compression chamber, the peak factor C is significantly higher in the case of oil alone than in the cases of 8 and 16 mg/m^3 pollution.
4. The effect of the chamber with compression.
   - the presence of the chamber with compression in the worn PRC leads to the higher value of the peak factor C, in the case of 8 and 16 mg/m^3 pollution,
   - the presence of the chamber with compression in the new PRC leads to the higher value of the peak factor C, in the case of the oil alone.

BIBLIOGRAPHY

[1].Burski Z.: The researches on the symptoms of consumption and the possibilities of their usage in the field exploitation of a tractor. Scientific Disquisitions no. 173. The Academy of Agriculture Publishers. Lublin 1994.
[2].Burski Z.: The simulation researches on the vibrations of a cylinder sleeve of a tractor's engine in the model position in tribological aspect. Scientific Symposium SYMROZ'2000. Szczecin – Ystad, June 2000.
[3].Cempel Cz., Tomaszewski F.: Diagnostyka maszyn. Wyd. MCNEMT. Radom 1992.
[4].Dziubak T., Tylicki H.: Wyznaczanie terminów obsługiwania filtrów powietrza pojazdów mechanicznych. Problemy Eksloatacji. 1. 2000. Zeszyty naukowe ITE. Radom 2000.
[5].Statistica PL dla Windows, Statsoft Inc., 1997.

[6]. Tarasińska J., Burski Z., Sadkiewicz R.: Application of analysis of variance in the simulation researches on the dynamics of the vibrations of a kinematic pair an engine under the conditions of air dustiness.Polish Akademy Sciences Branch in Lublin. Volume II. Commission of Motorization and Energetics in Agriculture. 2002.
[7]. Yandell B. S.: Practical data analysis for designed experiments. Chapman & Hall, London 1997.

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