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The testing of the influence of the roughness of the crankshaft journal upon the durability of the crankshaft bearing in engines of agricultural machines

Key words

Tribological tests, linear wear, durability, reliability, roughness.

Słowa kluczowe

Badania tribologiczne, zużycie liniowe, trwałość, niezawodność, chropowatość.

Summary

In the process of the operation of agricultural tractors and harvesters, it is necessary to perform periodical technical service related to the repair of the crankshaft bearings in Diesel engines. The solutions applied in machine finishing of crankshaft journals regenerated by grinding, make it necessary to run the same in operation, which results from the fact that working surfaces are not suitable for the conditions of use. Therefore, testing was initiated in order to establish whether the roughness of working surfaces of crankshaft journals obtained as a result of the repairs may have a considerable influence upon the limitation of durability of the journal-bushing sliding joint. Wear tests were performed in the model arrangement constituting material representation and, in the case of crankshaft journals, also the geometrical representation of real parts. The wear tests were performed for established sliding and load values with the assumption

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of variable roughness of roller modelling the crankshaft journals. On the basis of the statistical evaluation of the test results, it was shown that there is a significant relationship between the initial condition of microgeometry of the rollers as described by values of average arithmetic deviation of the profile from the medium line (parameter Ra) and the measure of linear use of the bush material of the sample.

Introduction

Slide bearings of the crankshaft of Diesel engines in agricultural machines constitute examples of sliding joints subject to complicated operating effects. Due to such conditions as the variability of loads and relative speeds as well as various conditions of use and operation, it is difficult to forecast the durability and reliability of the slide bearings. This also means that indicated service intervals and repair activities as well as the expected time of normative and inter-repair courses may be burdened with a considerable degree of uncertainty. In considering the above and the observed practice of users' failure to comply with due dates for technical inspections as well as errors relating to interpretation of the operation manual [Bujak 2003], it may be concluded that discrepancies between manufacturers' forecasts and the needs conditioned upon technical condition of the machines are even greater. A significant problem is connected with agricultural machines subject to post-guarantee repairs. As results from the tests performed indicate, as many as 50% of farmers decide to make repairs on their own [Płocki 2005]. In the event of the absence of appropriate knowledge and technical support in most cases, it is justified to suspect that the quality of such repairs is rather poor [Tomczyk 2009].

Results of the author's tests indicated that the use of regenerative grinding and smoothing of crankshaft journals during repairs does not fulfil the condition for adjustment of the part for the acceptance of the full range of operating loads from the start of the process of use [Stawicki 2006]. It was established that microgeometry of the technologically obtained roughness of the journals does not correspond to the surfaces obtained in the process of operating run-in. The condition of the surface of the journals following finishing machining during repairs mostly corresponded to the roughness of Class 8 according to PN 87/M04251, i.e. Ra within the range of 0.33-0.63 μm (frequently $Ra > 0.63$ μm), where the tested run-in parts were characterised by average the arithmetic deviation of the profile from the average line below 0.20 μm. This may be opposed to the proposal of the optimisation of use of the normative durability of sliding joints, which provides that shaping of technological roughness, which is possibly close to the microgeometry typical of the operating top layer, and should result in shortening of the time of the adjustment of working surfaces to the conditions of use, the limitation of intensity of use during running in and, as a consequence, larger reserves of the part material for normal wear and tear [Burakowski; Marczak 2000; Legutko, Nosal 2004].

A possible favourable variant of repair should result in the susceptibility of working surfaces to the shaping of balanced roughness during the short period of operating running-in. It is thought that the balanced condition of the surface ensures minimum values of potential energy and the least dissipation of energy in given conditions of friction cooperation [Kombałow 1974], which, in turn, is identified with thermodynamic stability and the resistance of the top layer to tribological wear [Sadowski 2009]. From the current testing experience, it appears that the presently applied technological solutions (structural, materials, and machining) do not comply with the above-mentioned proposal of the preparation of the working surfaces. This is confirmed by the results of tests of the microgeometry of surfaces of the crankshaft journals that, after the recommended periods of operating running-in, were characterised by greater roughness than after machining during the process of repair [Śliwiński 1990, Wanke 1997].

As it has already been shown, it is difficult to obtain recurrent and optimum machining effects with respect to shaping of microgeometry of working surfaces of crankshaft journals in the repair practice. The question is, whether the initial condition of surfaces of journals may have significant effects upon the durability of the entire sliding joint. If the answer to the question is yes, the current methods of the repair of sliding joints should be verified and the adopted criterion of their evaluation should involve the possibility of the standardisation of the initial condition and the standard may also involve the balanced condition of friction surfaces.

Materials and methods

The author's own tests aimed at the verification of the influence of the roughness of working surfaces of journals in regenerated crankshafts upon the durability of the journal-bushing sliding joint. Therefore, laboratory wear tests were performed in the model arrangement, which constituted the material representation and, in the case of the journal, a geometrical representation of the real system of the sliding joint. The tested sliding joint is presented in Fig. 1. The rollers (1) were made of 40 HM steel in accordance with the technology of the shaping of utility properties of crankshaft journals: tempered on 51÷53 HRC and then subject to the grinding process with the parameters corresponding to machining finishing of such parts as the roller. The grinding parameters used made it possible to select two groups of rollers with roughness parameters corresponding approximately to limits of Classes 8 and 9 (selection on the basis of the value of *Ra* parameter). The other ground rollers were subject to smoothing or roughing with the use of sandpaper with appropriate grit size. This made it possible to select another two groups of rollers that were characterised by roughness corresponding to limits of Classes 10 and 9 (Table 1 shows the results of measurements of *Ra* parameter of surfaces of the rollers used in the tests). Samples (2) in the form of plates with measurements of 7.5x20 mm were made of bimetal tape before shaping them in the form of semi-bushings of bearing slides of the crankshaft in engines of agricultural tractors.

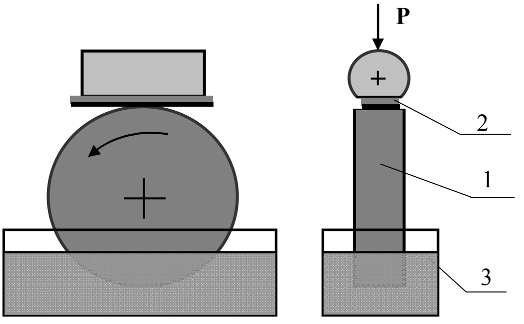

Fig. 1. Accepted configuration of the tested joint: 1 – sample of steel 40HM, 2 – sample of bearing alloy, 3 – engine oil
Rys. 1. Przyjęty układ węzła testowego: 1 – rolka ze stali 40 HM, 2 – próbka ze stopu łożyskowego, 3 – olej silnikowy SUPEROL CC 30

Table 1. Roughness of rollers used in the wear tests
Tabela 1. Chropowatości rolek zastosowanych w badaniach zużyciowych

Roller No.	Average roughness according to Ra [μm]	Standard deviation s [μm]	Limits of roughness classes according to PN 87/M04251 [μm]	Rollers qualified for roughness classes
1 2 3 4 5	0.17 0.14 0.17 0.15 0.18	0.04 0.02 0.03 0.03 0.03	0.16	10
6 7 8 9 10	0.32 0.27 0.27 0.31 0.32	0.11 0.04 0.05 0.09 0.06	0.32	9
11 12 13 14 15	0.61 0.59 0.57 0.61 0.69	0.08 0.07 0.06 0.04 0.08	0.63	8
16 17 18 19 20	1.15 1.12 1.28 1.21 1.13	0.09 0.10 0.15 0.07 0.11	1.25	7

The friction tests were made with the use of the following determined forced values:

- Load P = 368 N,
- Sliding speed v = 1 m/s,
- Wear test time t = 1800 s.

SUPEROL CC 30 engine oil was used as a lubricant used in agricultural industry.

During the friction tests, linear wear of the bushing material (measurements of the depth of wear trace in the sample), the temperature of the lubricant, and the resistance of roller movements were recorded. After each testing run, measurements of the surface of rollers were made with the use of a profiler in order to determine the influence of operating parameters of the tested joint upon qualitative and quantitative changes of the initial roughness of the counter-samples.

Presentation and evaluation of the test results

Table 2 includes the results of tests on linear wear of Z_i samples as compared to the values of the parameter *Ra* roughness of rollers used in subsequent friction tests. The results of measurements with the use of a profiler are also presented. The results are related to the evaluation of the condition of the surface of counter-samples and were obtained following the wear tests.

Table 2. The comparison of results of measurements of the rollers with the use of a profiler and linear wear of the samples
Tabela 2. Zestawienie wyników badań profilografometrycznych rolek oraz zużycia liniowego próbek

Friction pair No.	Data relating to roughness of counter-samples (rollers)		Data relating to wear of the samples	
	Before the test *Ra* [µm]	After the test *Ra* [µm]	Z_i [mm]	$Z_{i\,śr}$ [mm]
1	0.17	0.38	0.021	0.047
2	0.14	0.33	0.042	
3	0.17	1.04	0.122	
4	0.15	0.36	0.022	
5	0.18	0.33	0.028	
6	0.32	0.30	0.029	0.071
7	0.27	0.36	0.104	
8	0.27	0.38	0.020	
9	0.31	0.29	0.101	
10	0.32	0.49	0.103	
11	0.61	0.52	0.200	0.233
12	0.59	0.76	0.143	
13	0.57	0.56	0.299	
14	0.61	0.57	0.153	
15	0.69	0.65	0.370	
16	1.15	1.08	0.495	0.600
17	1.12	1.03	0.583	
18	1.28	1.24	0.638	
19	1.21	1.22	0.658	
20	1.13	1.22	0.600	

On the basis of the statistic evaluation of the *Ra* value, it was found that operating conditions of the tested joint in the case of friction pairs numbered from 1 to 5 resulted in a significant increase of the roughness of counter-samples. The greatest degree of roller roughness and, at the same time, the greatest degree of sample wear, applied to the Friction Pair 3. The tests confirmed that the value of *Ra* increased six times (from 0.17 to 1.04 µm), and the measure of wear of the sample bushing material increased approximately three times as compared to wear of the remaining samples cooperating with rollers of the same roughness class. The observed relationships are reflected in the course of changes of the friction moment in the function of time of the testing run (Fig. 2) – the third pair is characterised by greatest resistance of movements.

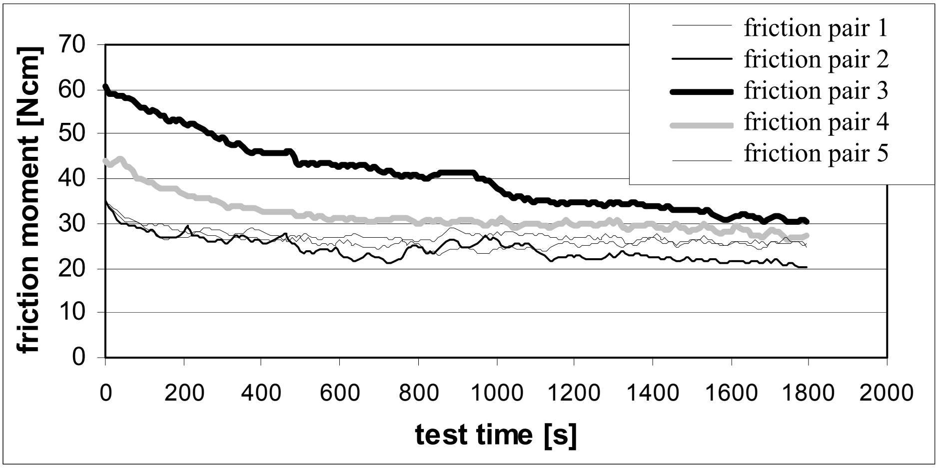

Fig. 2. The course of changes of the friction moment $M_t = f(t)$ for applied rollers of Class 10
Rys. 2. Przebieg zmian momentu tarcia $M_t = f(t)$ dla zastosowanych rolek klasy 10

In the event of rollers qualified as roughness Classes 7, 8 and 9, no significant changes in microgeometry as described by *Ra* values were observed after the wear tests. However, the quantitative evaluation of the roughness of the rollers does not explain the differences in the measure of the wear of the rollers and, in particular, in the case of tests, for which rollers qualified as roughness Class 9 were used. In order to identify the cause of the above, qualitative evaluation of the microgeometry of the surface of rollers was performed following the wear tests. Roughness profiles as well as corresponding courses of the curve of the material ratios were evaluated. It was established that the qualitative differences in the topography of particular rollers might have affected the degree of sample wear. In order to confirm that this observation is justified, the comparison of Roller 6 roughness profiles (Z_i = 0.29 mm) and Roller 7 roughness profiles (Z_i = 0.104 mm) as well as corresponding material ratios are presented in Fig. 2. Roller 7 is characterised by a steeper course of the curve of material ratio as compared to counter-sample 6, which proves lesser bearing of its surface. As for the determined values of external forces, lesser bearing share means greater unit pressures, and this could result in the observed intensification of destructive effects in the area of the friction contact.

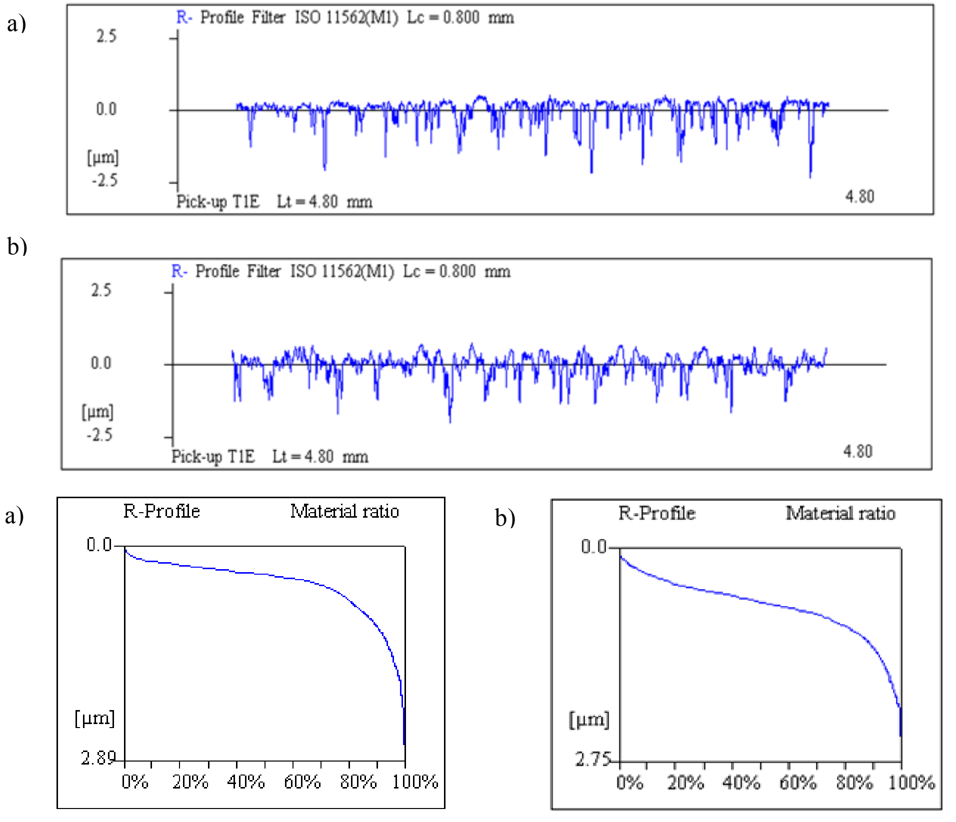

Fig. 3. Comparison of roughness profiles and material ratios of surfaces of selected rollers: a – Roller 6, b – Roller 7
Rys. 3. Porównanie profili chropowatości i udziałów materiałowych powierzchni wybranych rolek: a – rolka 6, b – rolka 7

Despite the discrepancies shown with respect to the wear of particular samples cooperating with counter-samples of a given roughness class, it may be concluded that wear depends on roughness classes of the rollers. This relationship was interpreted in the form of characteristics of $Z_I = f(Ra)$, presenting average values of linear wear of samples depending on roughness of the rollers (Fig. 4). The model of linear regression was chosen for the description of the measure of the wear of samples as a function of condition of roller surfaces, because this model ensures best adjustment to empirical data. On the basis of the statistical evaluation of the adopted regression model, a significant relationship between the linear wear of samples and the value of the roughness of the rollers was shown (Student and Fischer-Snedecor tests were used – relevance level $\alpha = 0.01$). The obtained adjustment of the trend line to the experimental data (determination coefficient $R^2 = 0.98$) also indicates the possibility to forecast the value of linear wear of samples depending on a given value of the *Ra* parameter of the roller surface. This proves the practical suitability of the *Ra* parameter as a criterion of the evaluation of the quality of repair of real part working surfaces.

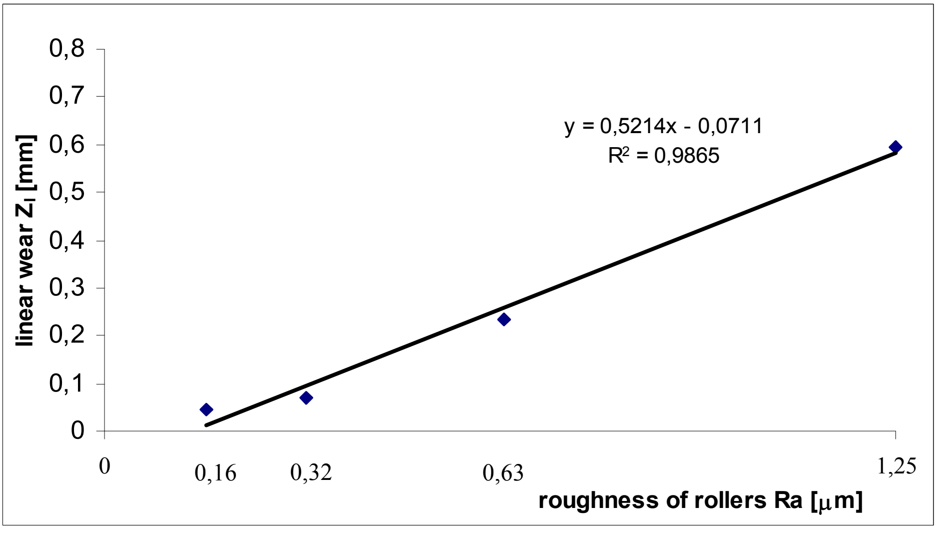

Fig. 4. The relationship between the measure of wear of the samples and average values of roller roughness surface – *Ra*

Rys. 4. Zależność miary zużycia próbek od średnich wartości *Ra* chropowatości powierzchni rolek

On the basis of the analysis of the course of wear tests, it was found that changes of the parameters of various intensity describing the cooperation of the tested joint element, i.e. temperature of the lubricant (T), friction moment (M_t) and wear (Z_i) in the function of time of the testing course corresponded to particular tribological tests. On the basis of the comparative analysis, it was found that there is a correlation between the condition of the microgeometry of the rollers and the recorded characteristi cs $Z_i = f(t)$, $T = f(t)$ and $M_t = f(t)$, and we may talk about a typical variability of the tribological parameter values for a given class of roughness of the rollers. In order to confirm this observation, Fig. 5 shows the comparison of test results for selected and representative friction pairs.

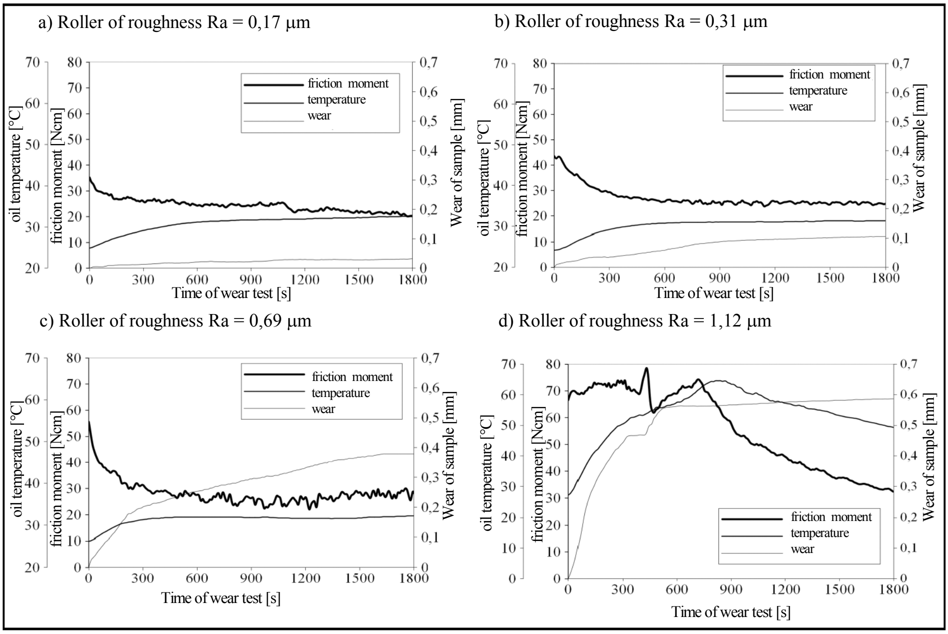

Fig. 5. The comparison of research test results for selected friction pairs, for which rollers of various roughness classes were used

Rys. 5. Porównanie wyników testów badawczych wybranych par tarcia, w których stosowano rolki różnych klas chropowatości

The presented results prove the significance of microgeometry of the rollers for the intensity of mechanical and power engineering effects occurring within the friction area. The greater degree of roughness corresponds to the increase of sample wear and to the less stable conditions of friction cooperation.

Summary and conclusions

Referring the obtained test results to the journal-bushing friction joint, one has to consider the different character of the friction contact of cooperating elements and different range of external force values in real conditions (relative speeds and loads) as compared to the prescribed test conditions. However, this does not mean that the indicated real relationship between the wear of the bushing material and condition of roughness of the roll modelling the crankshaft journal is not applicable to operating practice. There are two main arguments in favour of this as follows:

- Technologically shaped roughness of working surfaces of the journals does not correspond to the microgeometry of the part running-in during a long period of time.

- In undetermined (start up, stop, operating overload) conditions typical of agricultural machines, we may deal with the contact of friction counter-surface and, in the case of failure to adjust to acceptance of external forces, with accelerated wear of part materials.

Having considered the above and the results of the statistical evaluation of the wear tests performed, it may be concluded that there is a significant dependency of durability of the journal-bushing sliding joint on the initial condition of the top layer of crankshaft journals in agricultural engines. This means that the shaping of the technological roughness of the journal, which is different from the optimum condition obtained during the operating running-in process, proves that the sliding joint is not adjusted to conditions of cooperation and, consequently, has effects upon the limitation of its operation time until reaching admissible wear.

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Badanie wpływu chropowatości czopa na trwałość łożyskowań mechanizmu korbowego silników maszyn rolniczych

Streszczenie

W procesie eksploatacji ciągników rolniczych i kombajnów zbożowych zachodzi potrzeba okresowego wykonania obsługi technicznej w zakresie naprawy łożyskowań mechanizmu korbowego silników spalinowych. Stosowane rozwiązania techniczne w zakresie obróbki wykańczającej, regenerowanych szlifowaniem czopów wałów korbowych wymuszają jednak potrzebę ich docierania eksploatacyjnego, co jest efektem nieprzystosowania powierzchni roboczych do warunków użytkowania. W związku z tym podjęto badania zmierzające do ustalenia, czy uzyskiwany w naprawach stan chropowatości powierzchni roboczych czopów wałów korbowych może istotnie wpływać na ograniczenie trwałości węzła ślizgowego czop–panewka. Wykonano badania zużyciowe w układzie modelowym stanowiącym odwzorowanie materiałowe, a w przypadku czopów również geometryczne części rzeczywistych. Testy zużyciowe realizowano przy ustalonych wartościach prędkości ślizgania i obciążenia, przyjmując za zmienną chropowatość powierzchni rolek modelujących czopy wały korbowego. Na podstawie oceny statystycznej wyników badań wykazano, że istnieje istotna zależność między stanem początkowym mikrogeometrii rolek, opisanym wartościami średniego arytmetycznego odchylenia profilu od linii średniej (parametr Ra), a miarą liniowego zużycia materiału panewkowego próbki.