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ANALYSIS OF THE EFFECT OF LOADING PROCESS ON TRIBOLOGICAL SYSTEM PROPERTIES

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Abstract

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The effect of loading on the properties of selected sliding pair is monitored and analysed in the submitted contribution. The obtained results of dynamic loading were also compared with static loading. The experimental tests were performed using the testing machine Tribotestor M10. Steel 11 600 was selected as a material sample for the shaft as it belongs to commonly used materials in the manufacturing of agricultural components of shaft type or pin type. A full-bronze centrifugally moulded bearing shell from the material CuSn12 was selected as the second element of friction pair. Two oils were selected for lubrication of friction node – the mineral gear oil Madit PP80 and ecological oil Plantohyd 46 S. The selected friction pairs were tested in three loading regimes according to the methodology (two dynamic processes and one static process). 60 tribological tests were performed, i.e. 10 for each type of loading and lubrication. The weight losses of the friction pair elements were part of the tracked and analysed parameters. The polluted oil was examined using the ferrographic analysis to verify the weight losses. The abrasion particles of friction pair and their contribution to oil pollution were also analysed. Following the performed experiments different effects of loading regimes may be concluded, essentially in terms of wear size and the number and size of wear particles as well. The obtained results confirmed that the power spectral density of generated signal is probably an important criterion for assessment in terms of simulated random dynamic load in given experiment. In terms of technical application in loading processes – power spectral density is actually the amount of energy supplied to the process.

Keywords: Tribotestor, random process, dynamic processes, static process, lubrication, sliding node

INTRODUCTION

Working conditions of agricultural machinery are so heterogeneous and specific that they very adversely affect the life of individual components and nodes. The vast majority of agricultural machinery in operation is exposed to dynamic effect. The stress of structural parts caused by adverse operating load crucially determines their operational reliability. New approaches to designing structures require these characteristics of operating load to be respected and included in the calculation and construction procedures and taken into account when designing new machinery and equipment (Kučera *et al.*, 2008; Křupka *et al.*, 2008).

However, a reliable operation of agricultural machinery generally depends on the reliability of tribological node. It is a place where functional parts of the node interact while external and internal factors are in action (Kučera, 2004).

The consequence of adverse operating loads of tribological node in operation is their wear and thereby the clearance of the friction pair increases. The results of practice show that the most common cause of decommissioning of shafts is the loss of their functional capacity due to wear (Blaškovič, 1990).

An effort to simulate the tribological behaviour of the practical system or its part through model tests exists in simulated tribological tests (Křupka *et al.*, 2007). From this follows that this area of tribometry is extremely difficult due to the complexity of tribological processes and a large number of influencing factors. The use of the systems approach is extremely important here (Blaškovič, 1990).

To fulfil these conditions materials, lubricants and the atmospheric environment are usually selected first. Further, geometric and contact conditions of the test system are adapted to conditions of a practical system, taking into account the question of scale factor. Finally, operating variables are adjusted in order to obtain the same tribological interactions in both test and practical systems (Blaškovič, 1990; Bair *et al.*, 2013).

A sensitive area of every node is its lubrication. This is particularly important in terms of environmental protection. The replacement of mineral and synthetic lubricants with environmentally friendly lubricants that are biodegradable is one of the ways to fulfil this requirement (Tkáč *et al.*, 2014; Kosiba *et al.*, 2013; Bošanský *et al.*, 2005; Bošanský *et al.*, 2011).

In terms of a possible using of environmentally friendly oils for lubrication of tribological nodes, those results of tribological experiments are interesting in which these oils were used and in which they were compared with mineral oils or with another environmentally friendly oil at the same time. Following the results of the experiment the eco-friendly oil ARNICA 46 S was comparable with the oil MADIT PP 80 in the 'pin–shaft' tests (Kročko, 2012). It has been found by comparing the environmental oils of the producers Panolin, Fuchs and MOL with the Arnica oil that the results in conditions of the 'pin–shaft' experiment are even better (Gášpár, 2011). According to the results of experiments, in the 'pin–shaft' experiment with oils of the same viscosity class 46 – Mogul, Plantohyd, Hydros and Naturelle, the order of these oils was determined (Tóth *et al.*, 2014). The oil PP80 and the ecological oil Hydros UNI were studied in dynamic stress conditions. In experimental conditions the oil Hydros UNI had better results (Kostoláni, 2013). The results of the mentioned experiments pointed out the need to examine the properties of organic oils due to the possibility of their application as substitutes for mineral or synthetic oils.

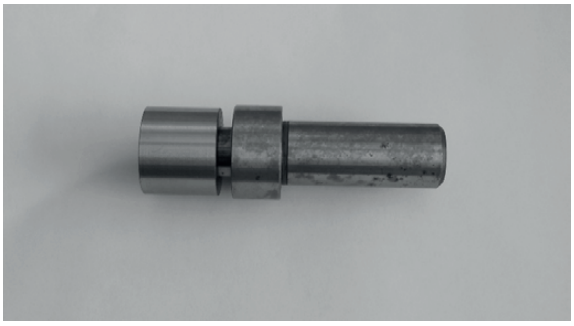
MATERIAL AND METHODS

Great attention was paid to the selection of suitable material. Steel 11 600 (EU – E355) was selected as the material sample for the shaft as it belongs to commonly used materials in the manufacturing of agricultural components of shaft type or pin type in various agricultural machines without heat treatment (tractors, harvesters, cutters, etc.), which had worn functional surfaces of cylindrical shape (Kadnár *et al.*, 2008). Steel E355 is an unalloyed structural steel suitable for machine components loaded statically and dynamically.

The sample was pressed on the auxiliary shaft even before grinding to final dimension. The shafts were then grinded to the final dimension of ϕ29.960 mm to achieve the H8/f7 fit, i.e. close clearance fit (Shigley *et al.*, 2010; Bhushan, 2001). The sample of the shaft prepared like this (as the first friction element) underwent the experiment and subsequent assessment.

A bearing shell was selected as the second friction element. The commercial marking of the bearing shell is B60 and its dimensions are ϕ35r7 × ϕ30F7 × 20 (shown in Fig. 2). It is a full-bronze, centrifugally moulded bearing shell from the material CuSn12. The material CuSn12 is a tin bronze and is used for manufacturing of slide bearings. The material is suitable for working conditions with hydrodynamic and limited lubrication as well as for transmission of rotating and sliding motion.

Tribological experiments were performed using the laboratory experimental test device Tribotestor M10, which is designed for fast detection of parameters and properties of slide bearings in general (both at static as well as random dynamic loading). The experimental device is located in laboratories of the Department of Machine Design of the Slovak University of Agriculture in Nitra. The device enables performing basic tribological experiments. The control system of the device enables changing the load and its process (as one of the main parameters of the experiment). The picture of the experimental test device is shown in Fig. 3.



1: *View of the test sample of shaft type*

2: *View of real bearing shell*

3: *View of the experimental test device Tribotestor M10*

Test parameters:

- Loading force 1: 500–1500 N (dynamic regime D1), according to generated and statistically processed random signal 1, mean value 1000 N;
- Loading force 2: 500–1500 N (dynamic regime D2), according to generated and statistically processed random signal 2, mean value 1000 N;
- Loading force 3: 1000 N (static regime) – marked as ST;
- Loading regime: according to the processed course of performance of two random processes and comparative (reference) static regime of the test;
- Shaft operating speed: 180 min^{-1};
- Time of test: 60 min;
- Running-up period: 5 min, loading 500 N;
- Lubrication method: gravity feed of lubrication (cup in a height of 500 mm);
- Oils used: Madit PP80, producer Slovnaft Bratislava, Plantohyd 46 S – producer Fuchs;
- Material of shaft: steel 11 600 (E355);
- Material of counterpart: a full-bronze bearing shell of the material CuSn12.

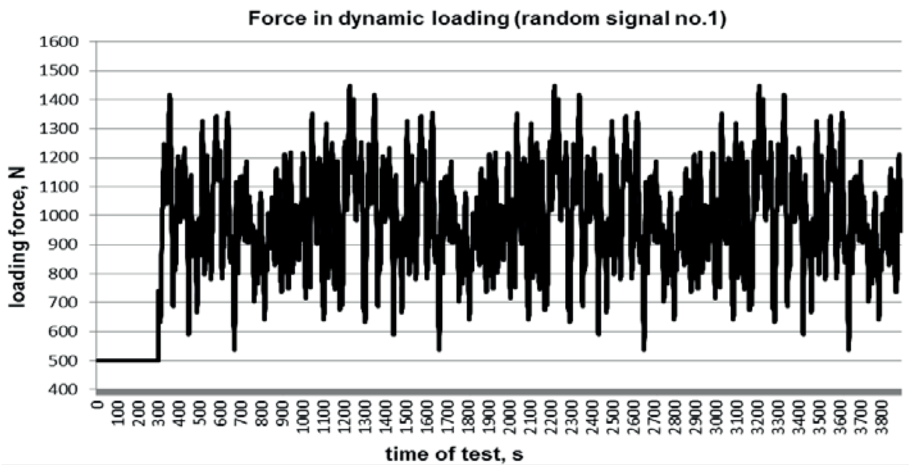
Simulation of Random Loading Processes for Experimental Needs

Two random processes were simulated using own software at the department. This was followed by statistical analysis and the calculation of main characteristics in the correlation theory of random processes. Periodogram, power spectral density and correlation functions were determined subsequently. The statistical significance of the highest frequency and other frequencies was determined after the application of Fisher's exact test. The most important frequency of the process No. 1 is 3.5296 Hz and the most important frequency of the process No. 2 is 0.1008 Hz. The tests of stationarity showed that both processes are stationary (in mean value as well as in dispersion). Courses of smoothed signals were used in loading – as two dynamic regimes of loading with the mean value equal to the value of static loading (1000 N). The progress of loading is shown in Figs. 4–6.

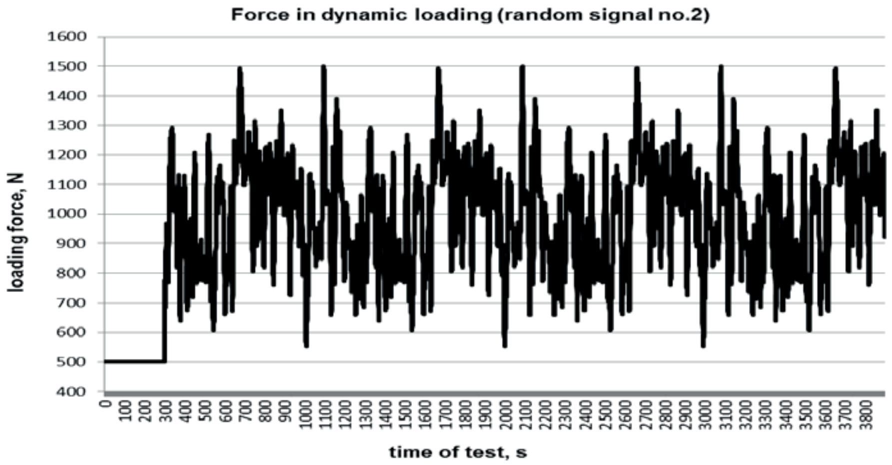
RESULTS AND DISCUSSION

Evaluation of Results of Experiments

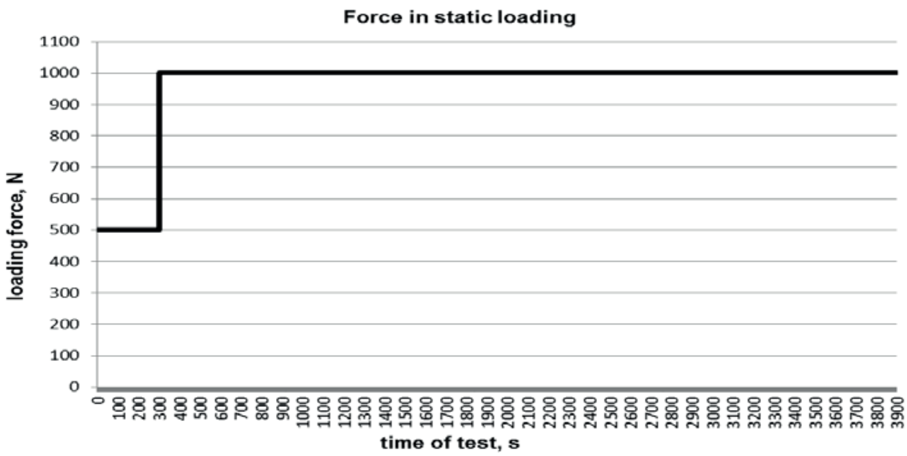
The selected friction pairs were tested according to the methodology in three loading cycles and in the environment of two different lubricating oils. 60 tribological tests were performed in total, i.e. 10 for each loading regime and each lubrication method. Each test started with the running-up period of 5 minutes. Equal conditions were set in this run-up period (in constant load) to achieve the stable state of friction of the given pair. The measurement started automatically after the run-up period and it was indicated by the control system.



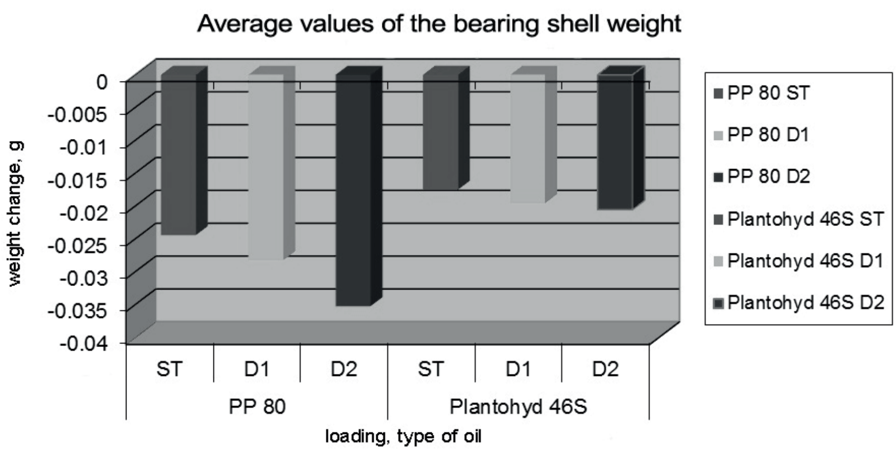
4: *Course of force in dynamic loading, signal No. 1*



5: *Course of force in dynamic loading, signal No. 2*



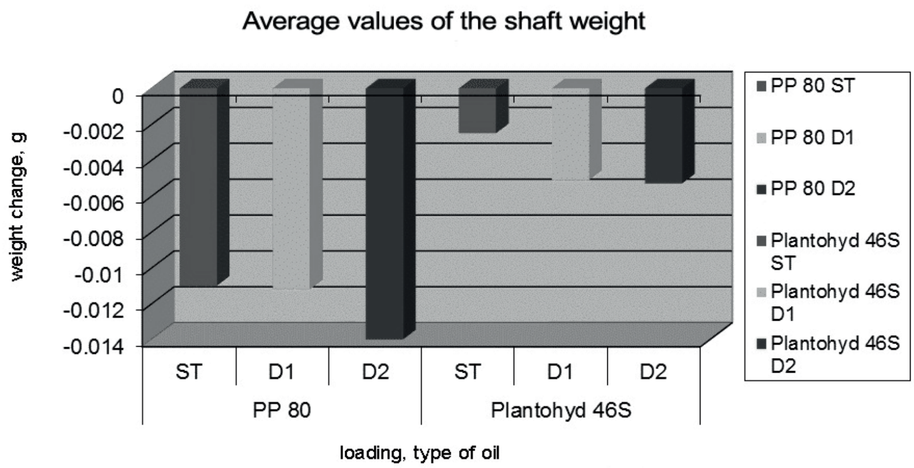
6: *Course of force in static loading*



7: *Weight losses of bearing shell*

Each experiment was completed automatically after reaching the set time of the test.

Wear (given by weight loss) is one of the most important characteristics of the behaviour of friction pair materials in experimental conditions. The weight losses of materials were detected using the laboratory scales Voyager® Pro with an accuracy of 0.001 g. Weighting before and after the test was performed in stable conditions in order to minimize the measurement errors. The average values of weight loss of each material were calculated from measured data in experimental conditions. The results are graphically presented in Fig. 7 for bearing shells and in Fig. 8 for shafts. The interpretation



8: *Weight losses of shaft*

of results is quite clear in terms of the effect of loading regime on the size of wear in experimental conditions.

We decided to explore what kind of wear particles arose in particular friction pair loading and how these particles contributed to oil pollution to confirm the results of experiment.

Based on the recorded and processed results of the experiment the following can be stated:

- The smallest wear in the whole set of bearing shell samples was observed in the static loading regime lubricated with the oil Plantohyd 46 S, and it was 0.0175 g. On the other hand, the largest size of wear was observed in the bearing shell samples loaded with the dynamic regime D2 and lubricated with the oil PP 80, and it was 0.0352 g. Dynamic loading regimes cause higher weight losses in comparison with static loading, regadless of the lubrication method. In terms of the oil used, it can be stated that the wear size of bearing shells is smaller in samples lubricated with the ecological oil Plantohyd 46 S in comparison with the oil PP 80.
- The smallest wear in the whole set of shaft samples was again observed in the static loading regime lubricated with the oil Plantohyd 46 S, and it was 0.0025 g. The largest size of wear was observed in the shaft samples loaded with the dynamic regime D2 and lubricated with the oil PP 80, and it was 0.014 g. In terms of the oil used, it can be stated (the same as for bearing shells) that the wear size of the shafts is smaller in samples lubricated with the ecological oil Plantohyd 46 S in comparison with the oil PP 80. In terms of loading regime, it can be stated that dynamic regimes cause higher weight losses in comparison with static loading, regardless of the lubrication method.

Results of Ferrographic Analysis

Friction and wear tests using the device Tribotestor are characterized by the formation of large number of particles in a relatively small volume of lubricant, particularly in case of test samples with higher intensity of load. The oil samples were standardly prepared before implementing the ferrography. Subsequently, the coverage of ferrogram with wear particles was evaluated. The ferrogram was assessed by visual diagnosis and documented by a digital camera and also using the microscope (Kapa 6000 type), in conjunction with the digital camera Moticam 1000.

The microscope was set to a 50 times magnification. The ferrogram was examined in the area of about 5 mm from the start of flow of oil sample to the length of 20 mm, i.e. in the length of about 15 mm. This area was chosen because of comparing the wear particles amount according to the intensity of ferrography slip coverage. The amount of wear particles was therefore evaluated according to the density of chains of small particles and also by visually assessing the saturation of hue of the layer of particles on the ferrogram.

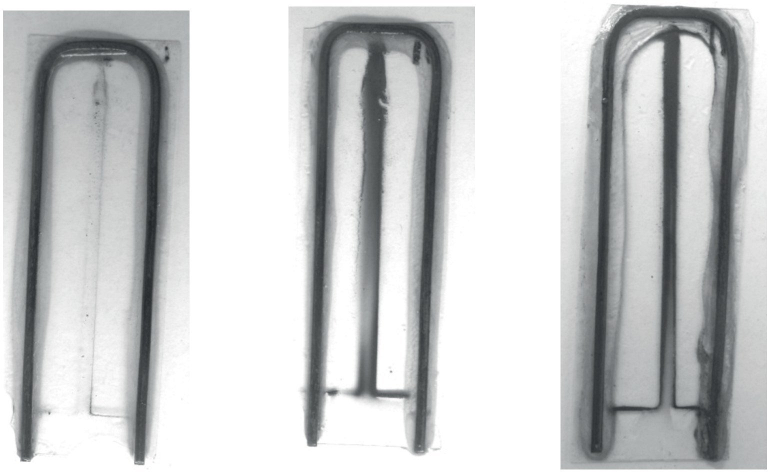
Results of Ferrographic Analysis of Oil Samples – Madit PP 80

Three samples of the oil Madit PP 80 were prepared for the ferrographic analysis. The samples were taken randomly during the experiment for each type of loading:

- Sample No. 1 – loaded with constant force – marked as static (ST).
- Sample No. 2 – loaded according to generated signal 1 – marked as dynamic (D1).
- Sample No. 3 – loaded according to generated signal 2 – marked as dynamic (D2).

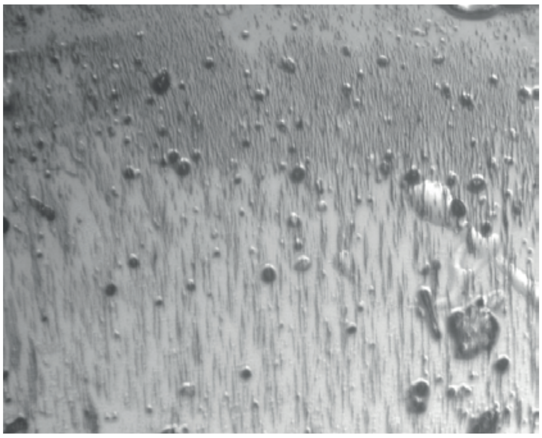
The view of prepared samples is shown in Fig. 9.

It can be stated that the sample No. 1 (Fig. 10) had the lowest number of present particles in comparison with the samples No. 2 and No. 3 (Fig. 11 and Fig. 12) according to visual assessment of the ferrogram. The particles in the samples No. 2 and No. 3 covered the ferrography mark with a thicker layer. The microscopic observation at the 50 times magnification confirms that the lowest number of wear particles was present in the sample No. 1. Thicker layer of the ferrography mark can

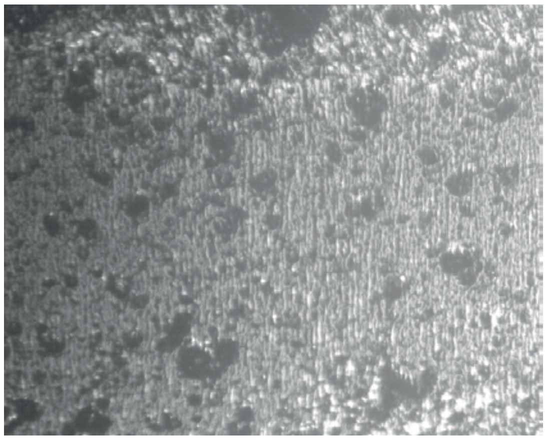


No. 1 No. 2 No. 3

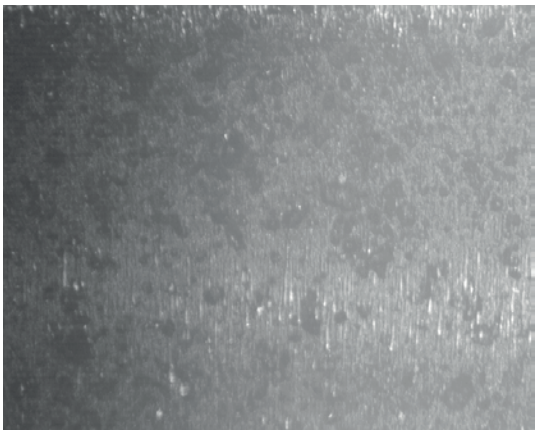
9: *View of oil samples – Madit PP 80*



10: *Sample No. 1 (50 times)*



11: *Sample No. 2 (50 times)*



12: *Sample No. 3 (50 times)*

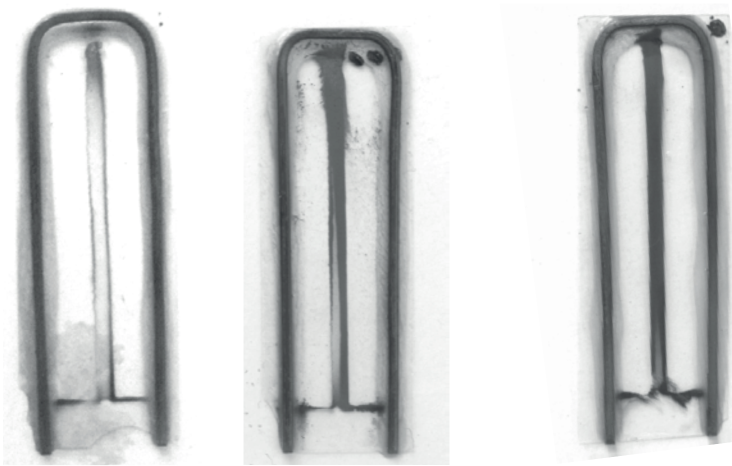
be observed in the sample No. 3 in comparison with the sample No. 2, which indicates a greater number of particles. The amount of particles on the ferrography mark was determined following the visual comparison of light areas not covered with particles and dark areas formed by chains of small particles. These dark areas merged into a continuous layer in the sample No. 3.

Results of Ferrographic Analysis of Oil Samples – Fuchs Plantohyd 46 S

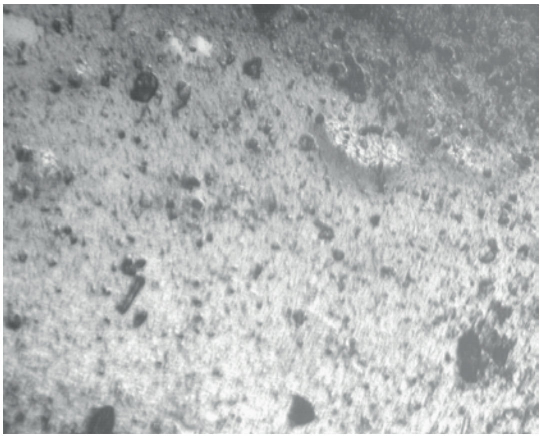
Three samples of oil were prepared for the ferrographic analysis. The samples were taken randomly during the experiment for each type of loading, while the sample No. 4 was the reference one. The view of individual samples is shown in Fig. 13.

- Sample No. 4 – loaded with constant force – marked as static (ST).
- Sample No. 5 – loaded according to generated signal 1 – marked as dynamic (D1).
- Sample No. 6 – loaded according to generated signal 2 – marked as dynamic (D2).

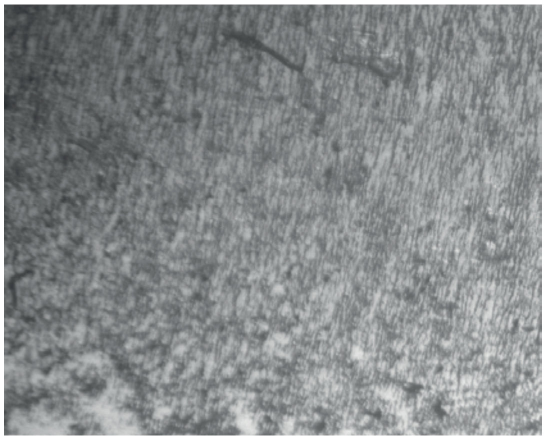
A very strong coverage of ferrogram can be observed in the sample No. 6 at the 50 times magnification (Fig. 16). The wear particles are completely covering the surface of the glass slide. This is reflected in a dark grey coloration of the whole area of ferrogram. An intensive coverage



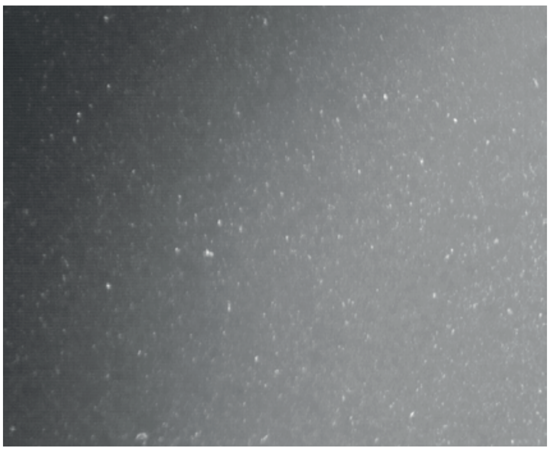
13: *View of oil samples – Fuchs Plantohyd 46 S*



14: *Sample No. 4 (50 times)*



15: *Sample No. 5 (50 times)*



16: *Sample No. 6 (50 times)*

of small bright particles is also visible in the sample No. 6. The sample No. 4 (Fig. 14) covered the ferrogram surface with the lowest number of particles (we may observe only short chains of very small particles). The sample No. 5 (Fig. 15) represents a sort of intermediate step between the samples No. 4 and No. 6. There are present densely spread long chains of small particles in this case, which are covering the surface more intensively than in the sample No. 4. The light areas in the samples No. 5 and No. 4 represent the areas of glass surface that are not covered with particles.

Comparison of Ferrograms – Oil Fuchs Plantohyd 46 S and Oil Madit PP 80

It can be stated that statically loaded samples covered the ferrogram with the lowest number of particles according to the results of experiments and ferrographic analysis. Also the size of wear particles is the smallest in case of static load. The largest wear particles were observed in samples dynamically loaded with the process D2; their size was around 100 µm. The particles of size ranging from 20 µm to 50 µm were mostly observed in samples loaded dynamically according to the process D1.

CONCLUSION

Tribological experiments were carried out to verify the dynamic ways of loading in experimental conditions. Loading based on randomly generated signals adjusted and processed by the statistical dynamics apparatus was considered to be the dynamic loading method. For experimental needs two random processes with different spectral power density but with the same mean value of the process (equal to the value of signal for static loading) were generated and statistically analysed. Precisely defined material pair was subjected to the processed loading regime in the same working conditions. All experiments began under the ambient temperature of 21 °C and they were terminated after reaching the set time of the test, i.e. 60 minutes.

The results of the experiments yielded valuable information about the behaviour of friction material pairs in given conditions, according to which we can state the following:

The size of wear of the friction pair elements is one of the key factors affecting the durability and reliability of the friction node. The lowest wear of bearing shells in experimental conditions was recorded in static load in the environment lubricated with the oil Plantohyd 46 S, and it was 0.0175 g. The highest wear was recorded in bearing shell samples loaded with the dynamic regime D2 in the environment lubricated with the oil PP 80, and it was 0.0352 g. Higher weight losses were observed in dynamic loading regimes compared to static load as found out in all experiments. It may be stated that in cases of lubrication with the organic oil Plantohyd 46 S the wear of bearing shells is lower in comparison with the oil PP 80. The same can be stated in case of shaft wear. The value of the lowest wear is, however, in case of using the organic oil substantially lower (0.0025 g), and it was recorded again in static load. On the contrary, the highest wear was indicated in shaft samples loaded with the dynamic regime D2 and lubricated with the oil PP 80, and it was 0.014 g. In terms of the lubricating oil used it can be concluded that when lubricating with the organic oil Plantohyd 46 S, shaft wear is lower in comparison with the oil PP 80. Moreover, higher loss of weight was observed in dynamic loading regimes compared to static load, the method of lubrication being irrelevant.

The results of ferrographic analysis confirm the results of measured weight losses for individual methods of loading, meaning that probably in case of static loading, adhesive wear was the predominant mechanism. In cases of dynamic loading gradual transition to abrasive wear was recorded. Following the ferrographic analysis it can be concluded that lower values of wear using the organic oil Fuchs Plantohyd 46 S were likely caused by the lower concentration of particles present in the oil. The visual inspection of the ferrograms in Figs. 10–12 and their comparison with Figs. 14–16 proves this claim.

Conducted experiments and their assessments allow conclusions on the effect of dynamic loading method on properties of the tribological system in given conditions. A different influence of loading method can be stated especially in terms of the size of wear, which was created by a pair of materials – steel 11 600 and tin bronze CuSn12. The influence of loading method was verified in conditions of lubrication with two oils, namely the gear oil PP 80 verified by technical practice and the ecological oil Plantohyd 46 S. The results confirmed that in experimental conditions in case of simulated random dynamic loading methods, the important criterion for their evaluation is likely the spectral power density. In terms of its technical application in the loading process, spectral power density is actually the rate of energy supplied to the process.

Acknowledgement

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REFERENCES

BAIR, S., ŠPERKA, P., KŘUPKA, I. et al. 2013. Quantitative elastohydrodynamic film thickness of mechanically degraded oil. *Tribology International*, 65(8): 33–38.

BHUSHAN, B. 2001. *Modern Handbook of Tribology, Boca Raton*. CRC Press.

BLAŠKOVIČ, P., BALLA, J., DZIMKO, M. 1990. *Tribológia*. Bratislava: ALFA.

BOŠANSKÝ, M. TÖKÖLY, P. VANYA, A. et al. 2011. Vozmožnosť ispoľzovanija neevoľventnogo zaceplenia v korobkach peredač seľskochozjastvennych mašin. In: Visnik Nacionaľnogo Techničnogo Universitetu 29. Sevastopol. 26. 8.–1. 9. 2011. Nacionaľnij Techničeskij Universitet, 21–29.

BOŠANSKÝ, M. VEREŠ, M. GADUŠ, J. 2005. Possibilities of the use of C-C gearings in agricultural and building machines working in environments with increased environmental hazard. Acta Technologica Agriculturae 8(3): 78–81.

GÁSPÁR, T. 2011. *Štúdium vlastností ekologických olejov pri mazaní klzných dvojíc*. Ph.D. Thesis. Nitra: Slovenská poľnohospodárska univerzita v Nitre.

KADNÁR, M. RUSNÁK, J. 2008. *Ekologické oleje aplikované do oblasti klzných uložení – metódy, prístroje a interpretácia*. Nitra: Slovenská poľnohospodárska univerzita v Nitre.

KOSIBA, J., TKÁČ, Z., HUJO, Ľ. et al. 2013. Effect of ecological energy carriers on flow characteristics of tractor hydraulic pump. *Journal of Central European Agriculture,* 14(4): 1415–1425.
KOSTOLÁNI, P. 2013. *Štúdium vplyvu stochastického procesu zaťažovania na vlastnosti tribologického systému*. Ph.D. Thesis. Nitra: Slovenská poľnohospodárska univerzita v Nitre.
KROČKO, M. 2012. *Štúdium degradability tribologického systému vplyvom pôsobenia ekologických mazív*. Ph.D. Thesis. Nitra: Slovenská poľnohospodárska univerzita v Nitre.
KŘUPKA, I., HARTL, M. 2007. The effect of surface texturing on thin EHD lubrication films. *Tribology International*, 40(7): 1100–1110.
KŘUPKA, I., HARTL, M., BAIR, S. et al. 2008. An experimental validation of the recently discovered scale effect in generalized newtonian EHL. *Tribology Letters*, 33(X): 1–9.
KUČERA, M. 2004. Analysis of the information from the test of tribological characteristics of selected materials. In: *Nové trendy v konštruovaní a v tvorbe technickej dokumentácie*. Nitra. 27. 5. 2004. Slovenská poľnohospodárska univerzita v Nitre, 75–80.
KUČERA, M., RUSNÁK, J. 2008. *Štúdium tribologických vlastností materiálov nanesených na povrch vybranými technológiami navárania*. Nitra: Slovenská poľnohospodárska univerzita v Nitre.
SHIGLEY, E., MISCHKE, C., BUDYNAS, R. 2010. *Konstruování strojních součastí*. Translation of university textbook. Brno: VUT v Brně.
TKÁČ, Z. MAJDAN, R. KOSIBA, J. 2014. *Výskum vlastností ekologických kvapalín a nových testovacích metód mazacích olejov*. Nitra: Slovenská poľnohospodárska univerzita v Nitre.
TÓTH, F., RUSNÁK, J., KADNÁR, M. et al. 2014. Study of tribological properties of chosen types of environmentally friendly oils in combined friction conditions. *Journal of Central European Agriculture,* 15(1): 185–192.

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