EFFECT OF LOAD CONDITIONS ON THE SIZE AND PRODUCTS OF WEAR

Marian KUČERA[1], Milan KADNÁR[1], František TÓTH[1], Jozef RÉDL[1], Jozef NOSIAN[1]

[1]*Department of Machine Design, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic*

Abstract
The submitted paper analyzes the effect of loading on the properties of selected sliding pair. Loading regimes were simulated based on two random signals after their statistical processing with a mean value equal to 1000 N. The aim of the study was to confirm the hypothesis of the effect of random loading method on the size and type of wear. It should also confirm the hypothesis of the effect of used lubricant in conditions of limiting friction in terms of its emergency properties. Steel E335 and bronze CC483K were used as material pair. Two oils were selected for lubrication of friction node – the mineral gear oil Madit PP80 and ecological oil Plantohyd 46 S. The result of this study is a ferrographic analysis of oil samples and the analysis of worn surfaces in relation to weight loss, which confirms the hypotheses.

Key words*: tribotestor; random process; sliding node; lubrication.*

INTRODUCTION
The design of construction nodes is required to fully respect the characteristics of operating loads (*Kučera & Rusnák 2008; Kučera 2014*). An effort to simulate the tribological behaviour of the practical system exists in simulated tribological tests. This area of tribometry is extremely difficult and the use of the system approach is extremely important here (*Blaškovič et al. 1990; Liček 2017; Kučera 2014*). The effect of factors (load cycle, lubricant) on the friction pair was statistically verified by the 2-factor Analysis of Variance (ANOVA). The respective differences between the mean values of each sample were defined by Duncan´s Multiple Range Test with a significance level (p-value) of 0.05 (*Kučera et al. 2016; Kopčanová et al. 2018*). The hypothesis of significant effect of random load was solved in several studies. Under the conditions of experiment, Hydros UNI had more favorable results (*Kostoláni, 2013*). Mogul, Plantohyd, Hydros and Naturelle oils with the same viscosity class of 46 loaded statically and dynamically showed better results compared to mineral oils in terms of friction coefficient (*Tóth et al. 2014; Kučera 2014*). In terms of environmental protection, the decisive factor is also the replacement of mineral and synthetic lubricants with ecological lubricants that are biodegradable (*Kosiba et al. 2013; Majdan et al. 2016; Tkáč et al. 2014; Bošanský et al. 2005*). The aim of this study was to confirm the effect of random loading process and ecological oil on the size and type of wear in terms of emergency properties of friction pair.

MATERIALS AND METHODS
We selected steel E335 as the material sample for the shaft. The sample was pressed on the auxiliary shaft even before grinding to final dimension. The shafts were then grinded to the final dimension of Ø 29.960 mm to achieve the H8/f7 fit, i.e. close clearance fit. We selected a bearing shell as the second friction element. The commercial marking of the bearing shell is B60 and its dimensions are Ø 35r7 × Ø 30F7 × 20 (Fig. 1).

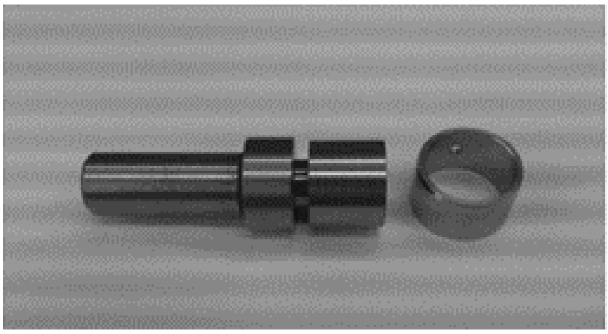


Fig. 1 View of real shaft and bearing shell

Tribological experiments were performed using the laboratory experimental test device Tribotestor M10 (SUA in Nitra, Slovakia).

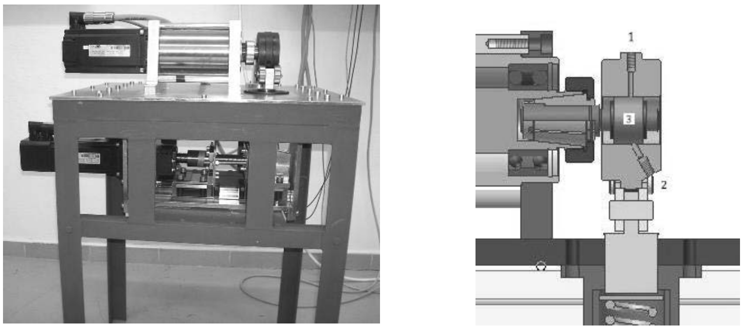


Fig. 2 View of the test device Tribotestor M10 (left) and the tribological node (right)

Test parameters:

- ***Loading force 1:*** 500–1500 N (dynamic regime D1), according to generated and statistically processed random signal 1, mean value 1000 N (Fig.3);
- ***Loading force 2:*** 500–1500 N (dynamic regime D2), according to generated and statistically processed random signal 2, mean value 1000 N (Fig.4);
- ***Loading force 3:*** 1000 N (static regime) – marked as ST (Fig.5);
- ***Loading regimes:*** according to the processed course of performance of two random processes and comparative (reference) static regime of the test;
- ***Operating speed of shaft:*** 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 E335; according to standard EN 10025-2 : 2004;
- ***Material of counterpart:*** a full-bronze bearing shell of material CC483K; according to standard STN 423123.

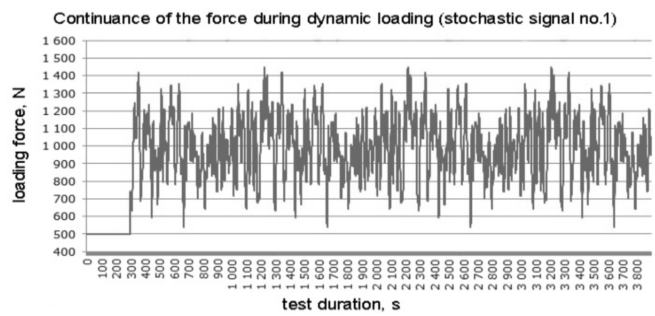


Fig. 3 Course of the loading force during dynamic loading, signal no. 1

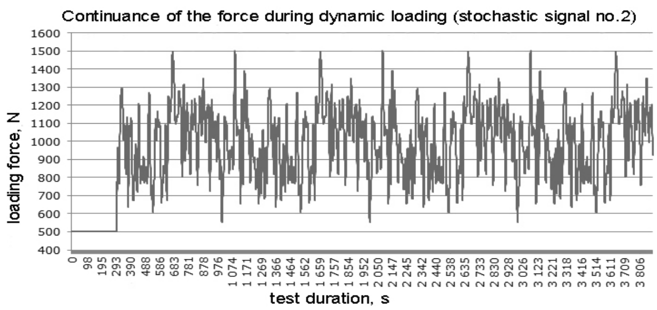


Fig. 4 Course of the loading force during dynamic loading, signal no. 2

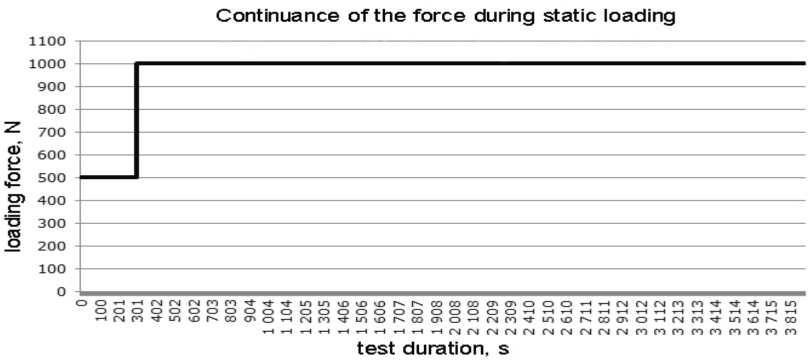


Fig. 5 Course of the loading force during static loading

Oil samples were standardly prepared before implementing the ferrography. Ferrogram was assessed by visual diagnostics and documented with a digital camera and with microscope of Kapa 6000 type (Novel, Xiamen,China), in cooperation with digital camera Moticam 1000 1.3 MP (Motic, Xiamen, China) (magnification was set to 200x). Ferrogram was examined in the area about 5 mm from the start of the flow of oil sample up to the length of 20 mm, i.e. the length of about 15 mm.

RESULTS AND DISCUSSION

We performed 60 tribological tests, i.e. 10 for each type of loading and lubrication. Each of the tests started with a 5 minutes run-up period.

Results of weight loss analysis

Determination of the weight loss of the material pair was performed using laboratory scales Voyager® (Ohaus Corporation, Pine Brook, USA) with an accuracy of 0.001g. Both pre-test and post-test weighing was performed under steady-state conditions to minimize measurement errors. The results (average values) are presented in Tables 1 and 2. Their interpretation in terms of the effect of loading method on the size of wear in experimental conditions is quite clear.

Tab 1. Average values of the bearing shell weight loss

Type of oil	PP 80			Plantohyd 46S		
Loading	ST	D1	D2	ST	D1	D2
Weight loss, g	0.024 4	0.028 2	0.035 2	0.017 5	0.019 5	0.020 5

Tab 2. Average values of the shaft weight loss

Type of oil	PP 80			Plantohyd 46S		
Loading	ST	D1	D2	ST	D1	D2
Weight loss, g	0.011	0.011 2	0.014	0.002 5	0.005 1	0.005 3

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

The smallest wear in the whole set of the bearing shell samples was observed at static loading regime lubricated with oil Plantohyd 46 S and it was 0.017 5 g. On the other hand, the highest wear was observed in the bearing shell samples loaded with dynamic regime D2 lubricated with oil PP 80 and it was 0.035 2 g.

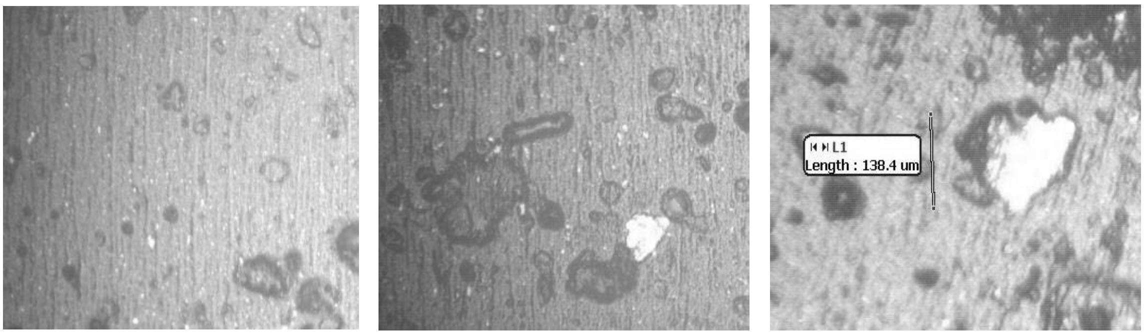
The smallest wear in whole set of the shaft samples was again observed at static loading regime lubricated with oil Plantohyd 46 S and it was 0.002 5 g. The highest wear was observed in the shaft samples loaded with dynamic regime D2 lubricated with oil PP 80 and it was 0.014 g.

Results of the ferrographic analysis

We prepared 3 samples of oil Madit PP 80 for the ferrographic analysis. The samples were randomly taken during the experiment for each loading regime:
-Sample no. 1 – loaded with constant force – marked as static – ST (reference),
-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.

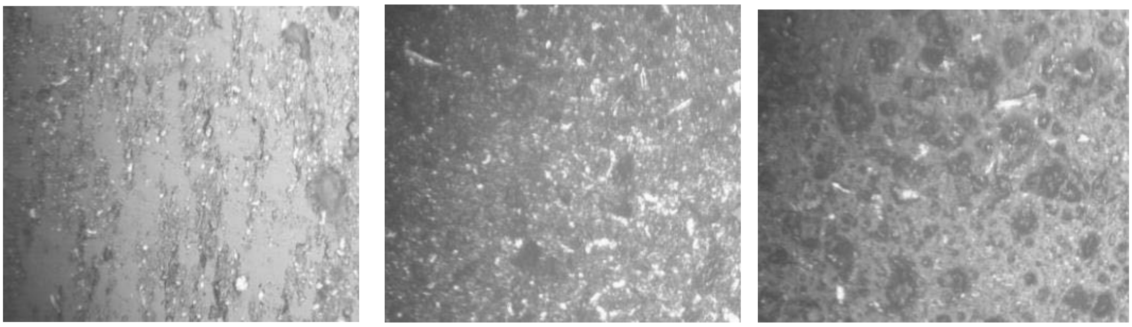
At the same time we also prepared 3 samples of oil Fuchs Plantohyd 46 S. The samples were randomly taken during the experiment for each type of loading regime:
-Sample no. 4 – loaded with constant force – marked as static – ST (reference),
-Sample no. 5 – loaded according to generated signal 1 – marked as dynamic – D1,
-Sample no. 6 – loaded according to generated signal 2 – marked as dynamic – D2.

The effect of loading methods on wear type and wear size of the friction pair materials was demonstrated by observing the ferrograms at 50x magnification (*Kučera et al 2016; Kopčanová et al 2018)*. The aim of observing the ferrograms at 200x magnification (as well as worn surfaces) was to confirm the hypothesis of wear type and transfer of abrasion particles from surface to surface. Based on the observations of the ferrograms (Madit oil) it can be stated that the thickest layer of the ferrographic film is at the sample no. 3 (Fig. 6c). Large particles above 100 μm have been recorded (measured in photo). By observing the surfaces of the shafts lubricated with Madit oil we found small amounts of transferred material with degradation signs regardless of the loading method. The pictures are therefore not mentioned. By observing the samples no. 4 and no. 6 lubricated with oil Plantohyd, their intense coverage has been recorded (Fig. 7). The highest coverage was at the sample no. 6 with signs of tiny shiny particles. The least intensive coverage of this sample set is at sample no. 4 where large numbers of medium-sized particles up to 30 μm have been observed. Several particles of about 100 μm were recorded at sample no. 6. By observing the surfaces of shafts lubricated with oil Plantohyd, substantially larger quantities of transferred material are visible, especially in dynamic loading methods (Fig. 8b, c). Fig. 8b (shaft sample no. 21) shows the areas of continuous surface of transferred material in the form of thin scales after multiple plastic deformation, indicating the presence of adhesive wear. Fig. 8c (shaft sample no. 22) shows, that in addition to the continuous surfaces of the transferred material, there are signs of abrasive wear in the loading cycle D2.
The performed experiments can be characterized as wear tests under the conditions of limiting friction. The effect of dynamic loading is visible in Fig. 8b, c. There are visible continuous layers of transferred material without degradation signs, which resulted in "lower" shaft wear. Finally, the transferred material behaved as a triboactive element, what in the end affected the better friction coefficient *(Kopčanová et al 2018).*



a b c

Fig. 6 View of wear particles (200x)



a b c

Fig. 7 View of wear particles (200x)

This also confirms the hypothesis of the effect of dynamic loading method on the wear size as a result of the transfer of material from the softer element of the pair.

a b c

Fig. 8 Surface of the shaft after a - ST, b – D1, c – D2 loading, lubricated by oil Plantohyd 46S (sample no. 20, 21, 22) (20x)

CONCLUSIONS

The selected material pair (steel E335 and tin bronze CC483K) were tested in two-oil-lubricated environment. On a representative sample, dynamic loading has been shown to cause higher wear of the material pair compared to static. Under the conditions of given experiment (limiting friction state), the difference is 0.01 g for shells and 0.003 g for shafts. Friction node degradation occurred in the environment lubricated with Madit PP80. In ecological lubrication with Plantohyd 46S, the transferred material along with the oil acted as a triboactive element. This has also been confirmed for dynamic loading methods. Plantohyd 46S has better properties in terms of emergency properties. This is also evidenced by lower shaft wear (0.005 3 g) compared to Madit PP80 (0.014 g).

REFERENCES

1. Bhushan, B. (2001). *Modern Handbook of Tribology*. Boca Raton: CRC Press.
2. Blaškovič, P., Balla, J., & Dzimko, M. (1990). *Tribology*. (Tribológia). Bratislava: ALFA.
3. 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*.
4. Kopčanová, S., Kučera, M., Kučera, M., Kučera, M., & V. Kučerová, V, (2018). The Effect of Friction Behaviour and Wear Protection Ability of Selected Base Lubricants on Tribo-pairs Parameters of Machine Components. *Tribology in Industry, 40*(4), 681-691.
5. Kostoláni, P. (2013). *Study of the influence of the stochastic loading process on the properties of the tribological system* [PhD thesis], (in Slovak). SUA in Nitra.
6. Kučera, M., & Rusnák, J. (2008). *Study of tribological properties of materials deposited on the surface by selected surfacing technologies* (in Slovak). SUA in Nitra.
7. Kučera M., Majdan R., Abraham R., Kučera M., & Haas P. (2016). Analysis of the

Effect of Loading Process on Tribological System Properties. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 64*(3), 825–833.
8. Kučera, M. (2014). *Verifikácia postupov simulácie náhodných procesov zaťažovania v podmienkach experimentu* [PhD thesis]. SUA in Nitra.
9. Licek, R, (2017). Evaluation of Tribological Properties by Using Different Process Fluid by Test Ball on Disc. *Manufacturing Technology, 17*(2), 217-223. ISSN: 1213-2489.
10. Majdan, R., Tkáč, Z., Abrahám, R., Szabó, M., Halenár, M., Rášo, M., & Ševčík, P. (2016). Proposal for filtration system for biodegradable lubricants in agricultural tractors. *Agronomy Research, 14*(4), 1395-1405. ISSN 1406-894X.
11. Tkáč, Z., Majdan, R., & Kosiba, J. (2014). *Research of properties of ecological liquids and new test methods of lubricating oils* (in Slovak). SUA in Nitra.
12. Tóth, F., Rusnák, J., & Kadnár, M. (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.

Corresponding author:
doc. Ing. Marian Kučera,PhD., Department Of Machine Design, Faculty Of Engineering, Slovak University Of Agriculture In Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic,
phone: +421 641 4106, e-mail: marian.kucera@uniag.sk