ISSN 1068-3666, Journal of Friction and Wear, 2016, Vol. 37, No. 2, pp. 187–190. © Allerton Press, Inc., 2016.
Original Russian Text © M. Kandeva, D. Karastoyanov, E. Assenova, K. Jakimovska, S. Simeonov, A. Vencl, 2016, published in Trenie i Iznos, 2016, Vol. 37, No. 2, pp. 238–243.

The Influence of the Valena Metal-Plating Additive on Tribotechnical Characteristics of the Steel–Bronze Tribological System

M. Kandeva[a], D. Karastoyanov[b], E. Assenova[c], K. Jakimovska[b, d], S. Simeonov[e], and A. Vencl[b,f,*]

[a]*Faculty of Industrial Technology, Technical University of Sofia, Kliment Ohridski Blvd, 8, Sofia, 1000 Bulgaria*
[b]*Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Acad. G. Bonchev str., Block 2, Sofia, 1113 Bulgaria*
[c]*Society of Bulgarian Tribologists, Tribology Centre, Technical University of Sofia, Kliment Ohridski Blvd, 8, Sofia 1000 Bulgaria*
[d]*Ss. Cyril and Methodius University, Faculty of Mechanical Engineering in Skopje, P.O. Box 464, Karposh II bb, Skopje, 1000 Republic of Macedonia*
[e]*Faculty of Mechanical Engineering, Brno University of Technology, Technická, 2896/2, Brno 616 69 Czech Republic*
[f]*University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade 35, 11120 Serbia*
**e-mail: avencl@mas.bg.ac.rs*

Received November 15, 2015

Abstract—The paper considers a change in the coefficient of friction and the temperature distribution in the contact zone of the steel–bronze tribosystem. Investigations were carried out by the shaft–bushing system for three values of the load in the mixed-to-boundary lubrication regime with SAE 80W transmission oil without and with Valena additive. It is found that the additive presence in oil decreases the coefficient of friction by 11–21%, depending on the applied load. At the same time, the maximum decrease in the coefficient of friction is observed at a maximum applied load of 1500 N.

Keywords: coefficient of friction, contact temperature, lubricant, Valena additive

DOI: 10.3103/S1068366616020082

INTRODUCTION

The development of new lubricants and additives is very promising for reducing friction and wear in boundary lubrication conditions. Repair-restoration additives play a significant role in this process and, in certain lubrication regimes, partially restore worn surfaces and reduce the coefficient of friction in the tribosystem. These additives include metal-containing additives that are soluble in oils [1–4]. Their influence is connected with self-organization and selective transfer of material [1, 7–10]. The Valena metal-plating additive is the metal-containing oil-soluble material patented by Kornik et al. [2]. This additive is capable of enhancing the tribotechnical, wear, and seizure properties due to the formation of a thin film (1–4 μm) on surfaces in the contact zone.

The aim of the study is to investigate the influence of the Valena metal-plating additive on changes in the coefficient of friction and temperature in the contact zone for a steel–bronze tribosystem operating in the mixed-to-boundary lubrication regime by the shaft–bushing system.

MATERIALS AND METHODS

The coefficient of friction was measured by a shaft–bushing system (plain bearing unit) using a DM 29M installation represented in Fig. 1. The dimensions and materials of the bearing unit investigated are given in Table 1. A lubricating mixture with the Valena additive was prepared by a special procedure.

Measurements of the coefficient of friction were carried out on the DM 29M installation (Fig. 1) using the following procedure:

—the necessary constant rotational speed $n = 1350$ min^{-1} was set using the control of a three-step wedge-shaped belt transmission *13*;

—starting the lubrication system by regulating valve *17*, which provides the drip feed of the lubricant by 30–40 droplets per minute for SAE 80W transmission oil with and without the Valena additive;

—setting normal load $P = 500$ N using loading screw *9* and registering the data on dynamometer *10* (Fig. 1); then, the experiment is repeated with loads of 1250 N and 1500 N with the system operating nonstop;

—resetting two tensometers, i.e., *4* and *7*, to zero;

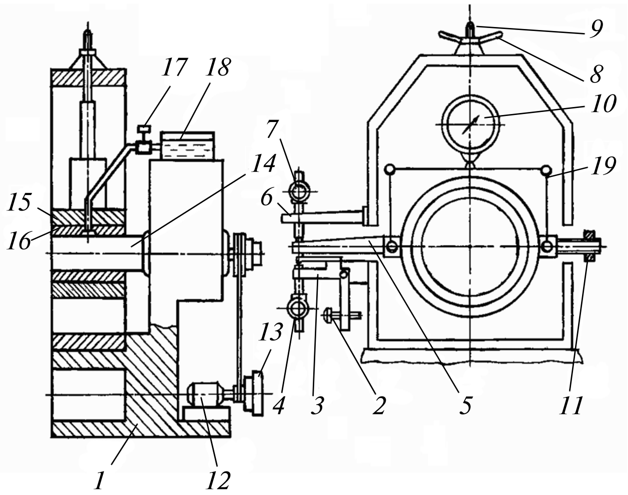
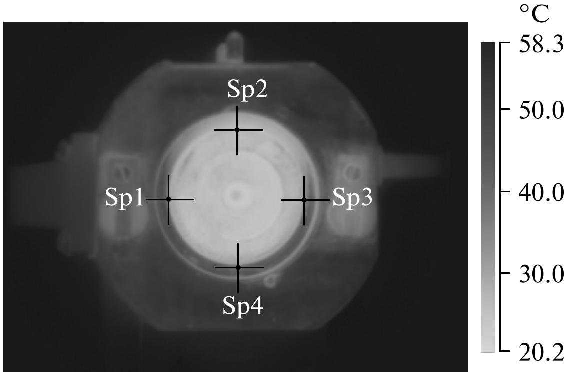


Fig. 1. Schematic of the used DM 29M test installation: (*1*) body; (*2*) regulating screw; (*3*) mobile beam; (*4*) and (*7*) tensometers; (*5*) tensometric beam; (*6*) fixed beam; (*8*) hand-grip; (*9*) loading screw; (*10*) dynamometer; (*11*) counterbalance; (12) direct current motor; (*13*) three-step wedge-shaped belt transmission; (*14*) shaft (journal); (*15*) duraluminium housing; (*16*) plain bearing (bushing); (*17*) regulating valve; (*18*) oil reservoir; and (*19*) loading frame.



Environment temperature	21.8°C
Environment relative humidity	43.0%
Sp1 temperature	58.4°C
Sp2 temperature	60.4°C
Sp3 temperature	59.5°C
Sp4 temperature	67.4°C
Average contact temperature	61.4°C

Fig. 2. Thermographic picture, environmental conditions, and contact temperature for transmission oil without the Valena additive at $P = 500$ N.

—switching on a direct current motor; recording values δ from lower tensometer *4* in every 20 s, i.e., after 20, 40, 60, 80, 100, and 120 s; the value on the upper tensometer must be zero;

—calculating the coefficient of friction μ at every time interval for given load *P* using the formula

$$\mu = k\frac{\delta}{P}, \tag{1}$$

where $k = 0.23$ is the constant value for the given installation, δ is the value of the friction force measured on lower tensometer *4* (Fig. 1), and *P* is the given normal load.

For every test, after 120 s of operation, thermograms were recorded using a FLIR P640 thermal infrared camera at four points (Sp1, Sp2, Sp3, and Sp4) arranged in the contact zone of the shaft–bushing system at an angle of 90° to one another according to the schematic in Fig. 2. The environmental temperature and the relative humidity were also measured at these points. The FLIR P640 infrared imager specification was as follows: the IR resolution was 640 × 480 pixels, the thermal sensitivity was 30 mK at 30°C, the temperature range was –40 to 500°C, the field of view was 12 × 9°, the minimum focus distance was 1.2 m, and the spatial resolution was 0.33 mrad. Measurements were carried out at a distance of 1 m from the installation; and emissivity coefficient $\varepsilon = 0.55$.

RESULTS AND DISCUSSION

Table 2 lists the experimental data of the coefficient of friction at normal loads of 500, 1250, and 1500 N. The values were calculated for every 20-s interval during a total test time of 120 s. Figure 2 demonstrates the thermogram of the contact zone for transmission oil SAE 80W without the Valena additive at $P = 500$ N.

It is clear from Table 2 that the presence of the Valena additive in SAE 80W oil decreased the coefficient of friction for all applied loads. In addition, its presence affects the character of change in the coefficient of friction over time, i.e., the steady-state is

Table 1. Characteristics of plain bearing unit

Shaft diameter	$d = 60$ mm
Bushing length	$l = 60$ mm
Diametral clearance	$C = 0.06$ mm
Shaft material	Structural carbon steel 45 (GOST 8731–87); $HRC = 35$
Bushing material	Tin foundry bronze BrO5Ts5C5 (GOST 613–79); 60 *HB*
Lubricant	SAE 80W transmission oil with Valena additive (8 vol %) and without it

Table 2. Coefficient of friction at different loads

t, s	20			40			60			80			100			120		
P, N	500	1250	1500	500	1250	1500	500	1250	1500	500	1250	1500	500	1250	1500	500	1250	1500
Transmission oil																		
μ	0.100	0.036	0.026	0.090	0.027	0.020	0.070	0.025	0.020	0.070	0.024	0.019	0.060	0.023	0.019	0.055	0.022	0.019
Transmission oil with the Valena additive																		
μ	0.059	0.023	0.015	0.057	0.023	0.015	0.056	0.022	0.015	0.052	0.022	0.015	0.050	0.021	0.015	0.049	0.019	0.015

attained at almost the very beginning of the test, which is not observed in the absence of the Valena additive in the transmission oil. Nevertheless, the final value of the coefficient of friction (after 120 s) was used for comparison (Fig. 3) because the contact temperature was also measured at the end of the test (after 120 s).

Experiments showed that the contact temperature was nonuniformly distributed over four points (Sp1, Sp2, Sp3, and Sp4) for all applied loads. The highest value is obtained for every load at point Sp4 because this point is the most loaded. In most cases, the presence of the Valena additive in the transmission oil decreases the temperature in the contact zone.

Figures 3 and 4 show comparative diagrams of coefficients of friction and the average contact temperature in the end of each experiment (different applied load) in the case of the presence and absence of the Valena additive. The average contact temperature is used for comparison, since the coefficient of friction also has the average value for the whole shaft–bushing system.

The steady-state coefficient of friction is 0.015–0.055, which suggests that sliding occurs in mixed-to-boundary lubrication regime with coefficient of friction value of 0.05–0.15 [11]. In mixed lubrication regime, tribological characteristics depend on the hydrodynamic effect, the properties of surface layers of contacting bodies, and the lubricant composition. This complicates the description of the mixed lubrication. The prediction of the contact performance in the mixed lubrication mode is usually obtained via numerical modelling [12].

As already mentioned, the presence of the Valena additive in transmission oil decreases the coefficient of friction for all applied loads (Fig. 3). On average, decreases was approximately 11, 14, and 21% for normal loads of 500, 1250, and 1500 N, respectively. The greatest decrease of the coefficient of friction was obtained for the highest load of 1500 N and the highest contact temperature of 70.8°C (Fig. 4). This may be connected with the activation of tribochemical processes of copper-containing additive and contacting surfaces, which result in the formation of a copper layer at surfaces of the shaft and the bushing after selective transfer of the material. This also results in an increase of the real contact area and a decrease of the tangential component of the contact interaction. A decrease of the coefficient of friction occurs with an increase in the applied load in both cases, i.e., independently of the presence of the Valena additive (Fig. 3). This means that, according to the Stribeck curve, the hydrodynamic effect is more pronounced at high loads, i.e., hydrodynamic lubrication is observed to a greater degree [12].

Thus, in the tribological contact, most of energy lost due to the friction is released as heat. Because of this, contact pairs with lower coefficients of friction (Fig. 3) should have lower contact temperatures at the end of the test (Fig. 4) and vice versa. This does not occur because, after a load of 500 N, the experiment is repeated for loads of 1250 and 1500 N without inter-

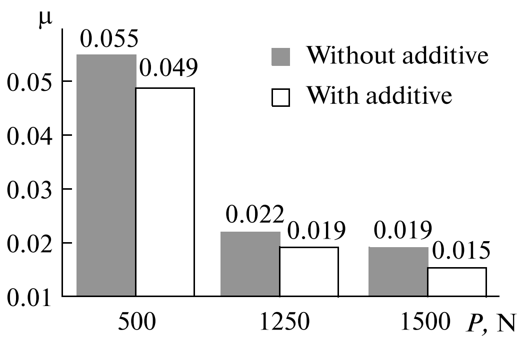


Fig. 3. Steady-state coefficient of friction (after 120 s) for transmission oil without and with Valena additive at applied loads.

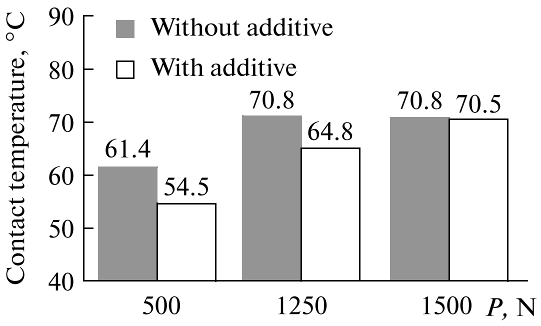


Fig. 4. Average contact temperature (after 120 s) for transmission oil without and with Valena additive at applied loads.

ruption of the operation of the system, as a result of which it is not cooled to the environmental temperature.

The average contact temperature rises with an increase in the applied load and stabilizes at a temperature of about 70°C (Fig. 4). The increase in temperature occurred more slowly in the presence of the Valena additive in the transmission oil. In addition, the average contact temperature was lower at an additive presence for all applied loads; thus, the smaller coefficient of friction yields a lower contact temperature. Only the contact temperature measured at point Sp4 (most loaded point of all points) was higher with the Valena additive (Fig. 2), and this only occurs in the case of mixed lubrication regime (loads 1250 and 1500 N). In case of boundary lubrication regime (load of 500 N), the Valena additive is effective and decreases the contact temperature at point Sp4.

CONCLUSIONS

The paper represents a comparative investigation of changes in the coefficient of friction and the temperature distribution in the contact zone of the tribological shaft–bushing system under the mixed-to-boundary lubrication by SAE 80W transmission oil with and without the Valena additive. Experiment data showed the following:

—Steady-state values of the coefficient of friction provide a basis to believe that sliding occurs mainly in mixed lubrication regime. The boundary lubrication only occurs at the lowest applied loads. The decrease in the coefficient of friction with an increase the applied load occurs in both cases, i.e., independently of the presence of Valena additive. The lowest coefficient of friction was achieved at the highest normal load.

—The presence of Valena additive in the transmission oil reduces the coefficient of friction at applied loads and affects the character of the time change in the coefficient of friction, i.e., the steady-state is achieved almost from the beginning of the test. The coefficient of friction decreases by 11–21% depending on the normally applied loads, and the highest decrease is observed at the highest applied loads.

—The contact temperature is different at different points of the contact zone of the shaft–bushing system for all applied loads. For every load, the maximum value was measured at the most loaded point. The average contact temperature rises with an increase in the applied load and shows a tendency to stabilize in both cases independently of the presence of Valena additive. The presence of additive in the transmission oil decreases the average contact temperature for all loads.

ACKNOLEDGMENTS

The work was supported by the following projects: (a) Program for Scientific-Technological Collaboration in the Tribology Study of the Metal-Plating Additive Valena of the Tribology Center at TU Sofia and the Rudservice company from Gezkazgan, Kazakhstan; (b) International Faculty Agreement of Cooperation between the Faculty of Mechanical Engineering at the University of Belgrade and the Faculty of Industrial Technology at the Technical University of Sofia; (c) FP7-REGPOT project no. 316087: AComIn (Advanced Computing for Innovation), funded by the FP7 Capacity Programme (Research Potential of Convergence Regions); (d) CEEPUS III Network CIII-BG-0703; (e) project TR 34028 and TR 35021, supported by the Republic of Serbia, Ministry of Education, Science and Technological Development; and (f) DUNK-01/3 funded by the Bulgarian Ministry of Education and Science.

REFERENCES

1. Garkunov, D.N., *Tribotekhnika (iznos i bezyznosnost'): Uchebnik* (Tribotechnics (Wear and Nonweariness), A Textbook), Moscow: MSKhA, 2001, 4th ed.
2. Babel', V.G., Garkunov, D.N., Mamykin, S.M., and Kornik, P.I., RF Patent 2277579, *Byull. Izobret.,* 2006, no. 16.
3. Kandeva, M., Vencl, A., and Assenova, E., Influence of "Valena" metal-plating additive on the friction properties of ball bearings, *Tribol. J. BULTRIB,* 2014, vol. 4, pp. 18–24.
4. Mamykin, S.M., Lapteva, V.G., and Kuksenova, L.I., Investigation into the tribotechnical efficiency of the Valena metal-plating additive to lubricating materials, *J. Mach. Manuf. Reliab.,* 2007, vol. 36, no. 2, pp. 153–159.
5. Nicolis, G. and Prigogine, I., *Self-Organization in Nonequilibrium Systems,* New York: Wiley, 1977.
6. Haken, H., *Synergetics. An Introduction. Nonequilibrium Phase Transitions and Self–Organization in Physics, Chemistry, and Biology,* New York: Springer-Verlag, 1983.
7. Litvinov, V.N., Mikhin, N.M., and Myshkin, N.K., *Fiziko-khimicheskaya mekhanika izbiratel'nogo perenosa pri trenii* (Physico–Chemical Mechanics of Selective Transfer at Friction), Moscow: Nauka, 1979.
8. Shpenkov, G.P., *Friction Surface Phenomena,* Amsterdam: Elsevier, 1995.
9. Kandeva, M., Ivanova, B., Assenova, E., and Vencl, A., Influence of additives and selective transfer on wear reduction in the lubricated contact, *Proc. Int. Conf. on Mater., Tribol., Recycling–MATRIB–2014, Vela Luka, Croatia,* 2014, pp. 197–206.
10. Padgurskas, J., Snitka, V., Jankauskas, V., and Andriusis, A., Selective transfer phenomenon in lubricated sliding surfaces with copper and its alloy coatings made by electro-pulse spraying, *Wear,* 2006, no. 6, pp. 652–661.
11. Hamrock, B.J., Schmid, S.R., and Jacobson, B.O., *Fundamentals of Fluid Film Lubrication,* New York: Dekker, 2004.
12. Dobrica, M.B. and Fillon, M., Mixed lubrication, in: *Encyclopedia of Tribology*, Wang, Q.J. and Chung, Y.-W., Eds., New York: Springer-Verlag, 2013, pp. 2284–2291.

Translated by S. Ordzhonikidze