Tribology International 99 (2016) 77–84

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

The effect of dimples geometry in the sliding surface on the tribological properties under starved lubrication conditions

L. Galda*, J. Sep, S. Prucnal

Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, Powstańców Warszawy 12, 35-959 Rzeszów, Poland

ARTICLE INFO

Article history:
Received 24 November 2015
Received in revised form
10 March 2016
Accepted 14 March 2016
Available online 19 March 2016

Keywords:
Starved lubrication
Surface topography
Burnishing technique

ABSTRACT

Surface topography should be constructed adequately according to the operating condition of the tribological system. Although there are many sophisticated lubrication systems that deliver the lubricant to the sliding elements, in exploitational conditions, co-acting elements operate in starved lubrication, as well. For example, while starting and stopping the machine, certain parts are exposed to wear or failure. In the article, the results of examinations of sliding pairs in material matching of steel–steel are presented. The tests were conducted with application of the tribology tester pin-on-disc with the modified sliding pair geometry. The ball surface was subjected to grinding to obtain uniform contact of approximately 10 mm^2 with a co-acting disc. The disc surface was subjected to burnishing technology to produce dimples in various dimensions. The values of the friction coefficient were measured and compared to all examined elements with pits and without depressions. It was established that the presence of dimples improved the tribological characteristics under starved lubrication conditions at low sliding speeds. The positive effect of the dimple presence was more significant at a lower load. The dimensions of the depressions in the surface had an influence on the tribological characteristics. The decrease of the friction coefficient values was substantial where dimples were shallow and where the area density of oil pockets was thus small.

1. Introduction

The surface geometry of the sliding elements plays a significant role in fine operating performance assurance. The surface should be smooth enough, because in this way, the hydrodynamic oil film is not interrupted, and the adequate load carrying capacity is easy to obtain, however, the irregularities retain oil in the case of the starved lubrication. In spite of the sophisticated lubrication systems construction and application, which could deliver the suitable amount of lubricating substance to the sliding assemblies, there are still exploitational conditions when the sliding pairs co-act under starved conditions. These conditions often occur during the starts and stops of the machine. Lubricating substance does not separate the co-acting surfaces, and part of the load is carried by the contact zones. In such situations, pits in the surfaces could improve the lubrication conditions via a permanent increase in oil capacity.

The lubricant feeding plays a highly important role in friction reduction and has been well-studied by the researchers. Brito et al. [1] analysed the bearing performance in a broad range of selected conditions and found that the construction and the number of grooves strongly influenced the performance parameters. In the experimental work conducted by Brito et al. [2], it was found that the twin groove configuration deteriorated the bearings performance in comparison to the single groove arrangement when the assembly was heavily loaded.

To predict the safe operation conditions during the start-up, Monmousseau and Fillon [3] examined the running time at differential operational conditions. These researchers emphasised that during the start-up period, the journal bearings were extremely sensitive to seizure. The authors noted the importance of not only the operating conditions but also the determination of bearing geometrical parameters to ensure the safe operation. Extensive experimental research on the friction during the start-up of hydrodynamic plain journal bearings was performed by Bouyer and Fillon [4]. The authors examined the journal bearings under varying feeding conditions, radial clearance, length, bearing materials and surface roughness. These researchers concluded that the friction coefficient increased with increasing surface roughness (Sa); however, when the surface topography was isotropic and when the dimples could retain the oil, the friction coefficient of the sliding pair with higher roughness was lower. The bearing behaviour strongly depends on material parameters that were used for the sliding pair. Great attention is paid to the special

* Corresponding author: Tel.: +48178651904, fax: +48178651184.
E-mail address: lgktmiop@prz.edu.pl (L. Galda).

http://dx.doi.org/10.1016/j.triboint.2016.03.015
0301-679X/

material application, such as polymers or ceramics, in case of severe operating conditions. These materials are characterised by a low coefficient of friction, anti-seizure properties and superior resistance to chemicals. Different materials or coatings for bearings were tested in diverse applications [5,6]. Fillon and Glavatskih [6] tested the thrust bearings with polytetrafluoroethylene (PTFE) faced pads and established that the influence of pad active surface geometry on the thrust bearing characteristics was a highly important parameter. Wasilczuk et al. [5] examined, under severe operating conditions, the tilting pad thrust bearing with a collar lined with a carbon-based coating. These researchers demonstrated that no visible wear was obtained on the carbon-based coating of the collar after the test, including under the mixed lubrication regime and for the start–stop tests. There are attempts to solve the problem with difficult operating conditions during start-up by texture creation on the sliding surfaces. Henry et al. [7] examined the influence of the surface texture on the thrust bearings behaviour during the start-up period. The greater texture area of 56% reduced the time to reach the hydrodynamic lubrication of thrust bearings. There are many examples of texture implementation that lead to tribological characteristics improvements. The specially created grooves on shafts lower the friction coefficient and wear of the air-bearings. Honing grooves decrease the wear of cylinder liner [8]. Ryk et al. [9] obtained a 25% decrease in the friction value between partially textured piston rings and cylinder liners compared to non-textured ones. Pits on the cylinder bore and flat oil control rings are able to produce the hydrodynamic support that may reduce friction and wear [10]. In the case of seals, an improvement was observed, especially in the leakage decrease due to shallow textures [11]. In the artificial dust condition, the lower value of co-acting elements wear was obtained in the case of the application of spherical pits on the shaft surface compared to plain shafts [12]. On the contrary, surfaces with spherical pits in bronze samples exhibited more damage than plain ones in artificially increased dustiness conditions [13]. Adequate shape, dimensions and area density of oil pockets of approximately 10% allowed for a lower friction coefficient and reduced wear of steel-spheroidal cast-iron sliding pairs [14]; however, at higher speeds, the depressions in sliding surfaces led to a greater tendency for seizure [15]. In the case of hydrodynamic lubrication, the depressions could break the hydrodynamic film continuity. Zouzoulas and Papadopoulos [16], in their computational investigation of thermohydrodynamic (THD) analysis, found that a large shallow pocket at the inflow region of the pad resulted in the friction decrease and increase in the minimum film thickness compared to plain pivoted-pad thrust bearings.

The most popular technique used worldwide for texturing the mechanical components is laser surface texturing (LST) because the LST enables a short processing time and it is quite easy to control the dimensions of the dimples and the arrangement of the pits. The texture application on surfaces of parallel thrust bearings was experimentally and theoretically examined by several researchers [7,17–19], especially during the last two decades. The friction coefficient of the partially textured thrust bearings was reduced over 50% compared to the untextured bearings [17]. According to [20] the friction coefficient is very sensitive to the asperities area fraction, but the influence of the asperity shape is less important. Mourier et al. [21] demonstrated that deep microcavities induced a decrease in the oil film, while shallow micropits could generate a large increase in the film thickness during the elasto-hydrodynamically lubricated (EHL) point contact. Due to the texture on one of the non-conformal mating surfaces, the friction reduction of 9% was obtained in starved lubrication by Ali et al. [22]. The dimple size affects its load-carrying capacity, and the high dimples area density of 58% is beneficial in lowering the friction coefficient of laser textured stainless steel rings [23].

The range in dimensions of pits created on sliding surfaces is wide, and the scope of dimples area density is broad as well. The depth of the pits primarily ranges from 1 to 100 μm, the length is between 5 μm and 1000 μm and the area density is from about 2% to over 50%. The effects of the geometrical parameters of the pits on the exploitational properties depend on the operating conditions of the friction pair. In full lubrication conditions, the dimples could act as micro-hydrodynamic bearings, and in starved lubrication, the dimples could act as micro-sources of lubricant. The area of full lubricated textured mechanical components was widely examined theoretically and experimentally [10,18,19,24]. In several publications, from the area of biomaterials application, the role of the surface topography of implants on the reduction of wear is emphasised. The valleys in the surface left after the production process of implants influenced the reduction of wear. According to [25], the valleys were filled with Ringer's lubricating liquid in the friction tests, and the amount of wear of the polymeric pin was lower in comparison to the other surface type of implants.

A few publications [7,22,26] considered textured friction pairs operating under starved lubrication. The aim of this study was the evaluation of the possibility of improving the tribological characteristics under starved lubrication via determined texture creation on the sliding surface.

2. Experimental details

2.1. Specimens

The samples were 42CrMo4 steel discs measuring 25.4 mm in diameter. The burnishing technique was employed to obtain pits of a determined layout on steel samples. The hardness of samples of approximately 30 HRC was achieved after heat treatment. The distance between the pits (centres) was identical in each series and equal to 0.8 mm. The burnishing process was realised with the percussive head application with a spherical ending of radius equal to 0.125 mm. The bulges around the pits were removed by grinding. Fig. 1 shows images and surface profiles of the prepared samples after burnishing and grinding. The surface roughness between the pits characterised by Ra (arithmetical mean deviation of the roughness profile) was on average 0.12 μm.

As a result of the burnishing process, surfaces with the specified area density of pits (Sp) were obtained, and the dimples were in a deterministic arrangement and of specific dimensions. In Table 1, selected geometrical parameters characterising dimples in the analysed surfaces are presented. Differences in dimensions of depth (h) and diameter (d) were approximately three- or two-times; however, it resulted in a greater than twelvefold increase in single pit volume (v_i) with less than twice the growth of diameter from 160 to 300 μm. The area density of dimples is related to the total area of the disc surface.

Counter-specimens were made of 100Cr6 steel of approximately 62 HRC hardness. Co-acting balls were subjected to grinding to obtain a flat surface with an area of approximately 10 mm^2. In this way, the conformal contact during the tests was realised on a pin-on-disc tribomachine. The roughness of the counter-specimens mating surface after lapping described by Ra was approximately 0.08 μm.

2.2. Test set

The tribological tests were conducted using a pin-on-disc tester. A photo of the sample and the counter-sample placed in the