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Tribological performance of differential gear end-face sliding on washer with a radial groove

Wei Yuan[a,*], Guangneng Dong[b], Qianjian Guo[a], Wentao Sui[a], Leian Zhang[a], Weiyun Yuan[c]

[a] School of Mechanical Engineering, Shandong University of Technology, Zibo 255000, China
[b] Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System, Xi'an Jiaotong University, Xi'an 710049, China
[c] Tuha Drilling Company of CNPC Xibu Drilling Engineering Company Limited, Shanshan 838200, China

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ABSTRACT

Effects of a radial groove perpendicular to relative sliding direction on the tribological properties of the differential gear end-face on the corresponding thrust washer, were experimentally investigated under both sufficient and insufficient lubrication. A radial groove was artificially introduced into the thrust washer. The monitored friction force signals were analyzed by discrete wavelet transform. The wear scar of thrust washers were scanned with scanning electron microscope. The wear particles were collected and identified in the tests under insufficient lubrication. Results indicated that (i) the radial groove tended to decrease the friction force at the running-in period and to cause several fluctuation of approximate 5 (A5) of the friction force at the test beginning time, and the amplitudes of detail 5 signals reflected the performance deterioration of the thrust washer after a specific operating period under sufficient lubrication; (ii) the amplitude of the friction force was reduced and the values of the pulsation of A5 gradually increased before the friction failure time under insufficient lubrication; (iii) with the effect of the radial groove, non-contact area and smooth surface area were found in the groove regions of the washer under sufficient lubrication, and shallow and narrow plowing grooves on the washer's wear scar were the dominant wear morphologies and the percentages of irregular and elongated particles were significantly high under insufficient lubrication.

1. Introduction

Key components of machines or equipment with surface-contacting friction pairs, sometimes have discontinuous contact working surfaces, which may be artificially designed for convenient fixing or may be undesirably caused by the performance degradation of the components. Taking the crankshaft bearings and the curved-surface thrust washers (Fig. 1) as example, the streak discontinuous positions are perpendicular to the relative sliding direction. The decreased contact area can be practically negligible with such radial grooves, however, the radial grooves are able to release the machining residual stress and to detach the wear particles from the mating surfaces which is beneficial to avoid the abrasive wear and then to improve the anti-wear performance. The tribological performance of these key components with grooves in the contact surfaces is thus drawing much attention of manufacturers or users.

Surface contact with relative sliding motion is extensively applied in industry, and the tribological properties of the mating surfaces, thereby, have been comprehensively analyzed in previous literature. Under various lubrication mechanism, the surface

* Corresponding author.
E-mail address: wyuan16@sdut.edu.cn (W. Yuan).

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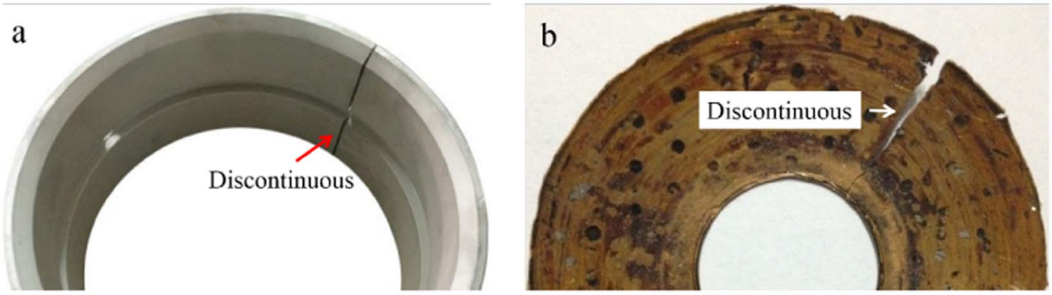

Fig. 1. Discontinuous working surfaces of (a) crankshaft bearing and (b) thrust washer.

asperity and textures [1–3] play very important role on the interface lubrication during the contact sliding processes. Influence of surface topography on torsional fretting under surface contact was investigated by Lu et al. [4]. The results can provide guidance for the initial surface design of surface roughness and texture directions to reduce fretting wear. The torsional fretting wear mechanism under surface contact was a combination of deformation, cracks, delamination abrasive wear and oxidation wear [5], and the effects of debris on stress-redistribution resulted to the wear scar uneven under mixed slip. However, the influence of the macro discontinuous contact surfaces on the tribological performance of the components has rarely been investigated.

Slender artificial defects were used to accelerate test in analyzing the performance of material or components [6]. Macro cracks artificially manufactured on specimens by electric discharge machining were often utilized in experimental study of contact sliding surfaces [7,8]. Available literatures [9–11] have indicated that macro defects generally result from manufacturing processes and may significantly affect the tribological properties of sliding pairs.

The streak defect on the embedded thrust washers in the differential case [12], for instance, is hardly diagnosable without disassembly although it may still protect critical parts from excessive wear before complete failure. For safety concerns, the working performance of components with a radial groove working surfaces has drawn considerable attention from both automobile manufacturers and users. Hence, the friction or wear properties of sliding pairs with discontinuous contact surfaces have also been widely investigated in the past in the relevant fields.

The tribological performance of the sliding pairs were frequently assessed based on the acquired friction and wear data information during pin/ball on ball tests [13–16]. Coefficient of friction (COF) was often calculated on the basis of the data of friction force and normal load. Wear is one of the critical factors, which influences the reliability and service life in mechanical components. To reduce the cost and time consumption, Finite element analysis has been frequently used as a tool to predict wear at the development stage [17]. To obtain the characteristics of COF curves, discrete wavelet transform (DWT) can be used to decompose the monitored friction signals into low-frequent bands and high-frequent bands [18], which can provide the momentary friction state and its tendency, respectively. Metal debris is the inevitable results of the wear process during machine operating, which can reflect the wear mechanism and wear conditions [19–21]. The on-line wear monitoring techniques, such as On-line Visual Ferrograph [22,23], are based on the wear particle collection and are frequently used as available tools to obtain the wear information of the motion contact pairs.

This study conducted a series of investigative experiments under sufficient and insufficient lubrication conditions with a differential gear end-face on thrust washer test rig, so as to explore the tribological properties of friction pairs slide with discontinuous contact surfaces by setting an artificial radial groove perpendicular to the sliding direction. The friction curves were acquired by force sensor and was subsequently decomposed by DWT method. An already existed classification method [24] of wear particles was used to identify the particle types after tests. In addition, a scanning electron microscope (SEM) was used to analyze the wear scar morphologies of the wear tracks.

2. Experimental details

2.1. Friction pair

The mating surfaces of the differential gear end-face and the thrust washer were shown in Fig. 2. The spherical surfaces of the washers, which were made of 20# steel GB/T711-88, were stamped with a curvature radius of 78 mm. The roughness R_a was about 0.45 μm. The textures on the washers were produced before stamping the washers, which is beneficial to improve the surface's anti-wear performance, as studied by Zhang et al. [2,25]. The dimple's depth on the textured regions of the thrust washer was 0.15 mm, while their radius was about 0.5 mm (Fig. 2a). The texture was reserved in the tests to approximately exhibit the real morphology, even though their tribological influence is not our research content. The width of the radial groove of 0.2 mm was artificially machined on the washers by electric discharge machining on the non-textured regions (Fig. 2a). The depth of radial groove was equal to the width of the thrust washer to eliminate the residual stress caused by machining process. The differential gears were made by 20CrMnTi GB/T3077-1999 with a roughness of 0.15 μm. The washer hardness was about 165 HV, which was significantly lower than the differential gear surface hardness of about 520 HV. Hence, wear of the sliding pairs will mainly occur on the thrust washers during the siding process. The worn morphologies of the thrust washers was analyzed by scanning electron microscope (SEM)