Tribology International 102 (2016) 265–274

Contents lists available at ScienceDirect

Tribology International

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

Vibration studies of lubricated textured point contacts of bearing steels due to surface topographies: Simulations and experiments

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ARTICLE INFO

Article history:
Received 7 December 2015
Received in revised form
25 May 2016
Accepted 27 May 2016
Available online 28 May 2016

Keywords:
Lubricated point contact
Surface textures
Fractals
Vibrations
Numerical simulation
Experiment

ABSTRACT

Vibration studies at the lubricated textured point contacts formed between bearing steels have been reported under the unidirectional sliding motion.The flat textured surface has been simulated using the fractal geometries. For vibration studies generic lubricated point contact is modeled as single degree of freedom system keeping together a non-linear spring and viscous damper in parallel in place of lubricating film. The stiffness of point contacts is computed using finite element analysis software. The damping is obtained experimentally through the acceleration response. Good matching between the simulated and experimental vibration results have been observed at the contact resonance frequencies. In presence of certain textures, vibration reduces due to the enhanced value of damping in comparison to the contacts having smooth surfaces.

1. Introduction

Surface textures are being employed for improving the tribological behaviors of the lubricated contacts found in machine elements. It is widely reported in the literature that the surface textures provided at the lubricated contacts impart the effective lubrication which improves the tribological behaviors. The presence of innumerable micro dimples/grooves of a textured surface at the mating interface act as tiny fluid film bearings under certain operating conditions, which enhance the tribo dynamic behaviors of the contacts [1]. Moreover, the tiny features (dimples and grooves) of textures also retain the lubricant, which help in providing the lubrication through smearing of the lubricant at the interface under the mixed and boundary lubrication regimes [2]. The numerical [3–6] and experimental [7–9] studies performed for the understanding of the lubrication mechanisms at the textured concentrated contacts reveal that the shallow depth of the micro/nano features improves the lubrication [3–7] and reduces the friction [8,9]. The roles of textures' attributes and lubrication regimes on the fatigue life of the concentrated contacts are also being explored and established [10,11]. It has been reported that the textures' fabrication techniques also play vital role on the tribological behaviors of the contacts [12,13]. It happens due to the localized modification in materials' properties (mainly hardness) at the surface during the texturing processes (particularly with the use of lasers).

It is worth noting here that the surface topography of mating solids significantly influences the friction [14] contact deflection [15,16] contact stiffness and contact damping [17]. For the case of concentrated contacts, the effect of surface roughness is not negligible at lighter loads [17]. The surface topographies of mating solids significantly influence friction and vibration of the contacts under the mixed and boundary lubrication regimes [18–20]. The presence of lubricant is found to contribute towards enhanced contact damping for the case of concentrated contacts [21,22]. Few studies [23–26] have also explored the roles of surface textures in reducing contact vibration for the case of mating solids. Presence of textures on the interacting surfaces of contacts significantly reduce the friction [23,24] and also contribute in enhancing the damping behavior [26] due to the retention of lubricant in micro/nano reservoirs of textures. However, the presence of texture reduces the contact stiffness [26], which causes change in the dynamic behavior of the concentrated contacts.

Based on the literature survey, it has been noticed that till date mainly the tribological behaviors of textured surfaces have been explored by the researchers. For developing the hard working and

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http://dx.doi.org/10.1016/j.triboint.2016.05.040
0301-679X/

Nomenclature

a	half Hertzian contact diameter, m
c	damping coefficient, N s/m
E'	effective modulus of elasticity, N/m^2
G	dimensionless material parameter
H_{min}	minimum film thickness at the point contact, m
k	nonlinear contact stiffness
k_L	linearized stiffness, N/m
L, L_s	lowest and highest spatial frequencies
m	effective inertial mass, kg
M	ridge number
R_q	composite surface roughness, m
$S_{zz}(k)$	spatial frequency, Hz
$S_{zz}(\omega)$	temporal frequency, Hz
t	time, s
U_s	sliding speed m/s
W	load, N
z_1	surface roughness height, m
z	response of ball (m)
Z	relative displacement $(z_1 - z)$
u	$(Z-\overline{Z})/\sigma_Z - Z/\sigma_Z\lambda$
u_0	$-Z/\sigma_Z$
ν	density of profile frequency
ρ	density, kg/m^3
$\phi_{m,n}$	random phase
σ_Z	variance of surface roughness
ξ	damping factor

Superscripts

$\cdot$	first derivative with respect to time
$\cdot\cdot$	second derivative with respect to time

energy efficient concentrated contacts, it is needed to explore together the tribological and dynamic behaviors of the lubricated textured contacts for overall improvements in the contacts' performance. Thus, it is an important task to develop the understanding on the dynamic behaviors of the lubricated textured point contacts in terms of various attributes of textures (dimple depth, dimple diameter, dimple area density etc.). Comprehensive numerical models to predict the dynamic behaviors of textured concentrated contacts have the advantage of cost and time reductions in optimizing the attributes of textures in comparison with experimental investigations. Therefore, the objective of this paper is to numerically explore the dynamic behaviors of lubricated textured point contacts by simulating the textured surfaces having different attributes of tiny features of textures. The numerical models (used in simulating the surface textures and computing the vibrations) have been validated by performing few experiments for developing the confidence in the numerical results presented herein.

2. Geometric description of point contacts

The vibrations at the lubricated lapped/textured point contacts have been studied numerically for the physical configuration as illustrated in Fig. 1(a). Few experiments have also been performed using the physical configuration for validating the proposed numerical model. In the studies (both numerical and experimental) presented herein, the stationary smooth (lapped) steel balls (AISI 52100) were allowed to form the concentrated point contacts with rotating lapped/ textured steel disks (AISI 52100). Moreover for establishing the governing equation to study the vibration behaviors, the lubricated point contact is replaced using

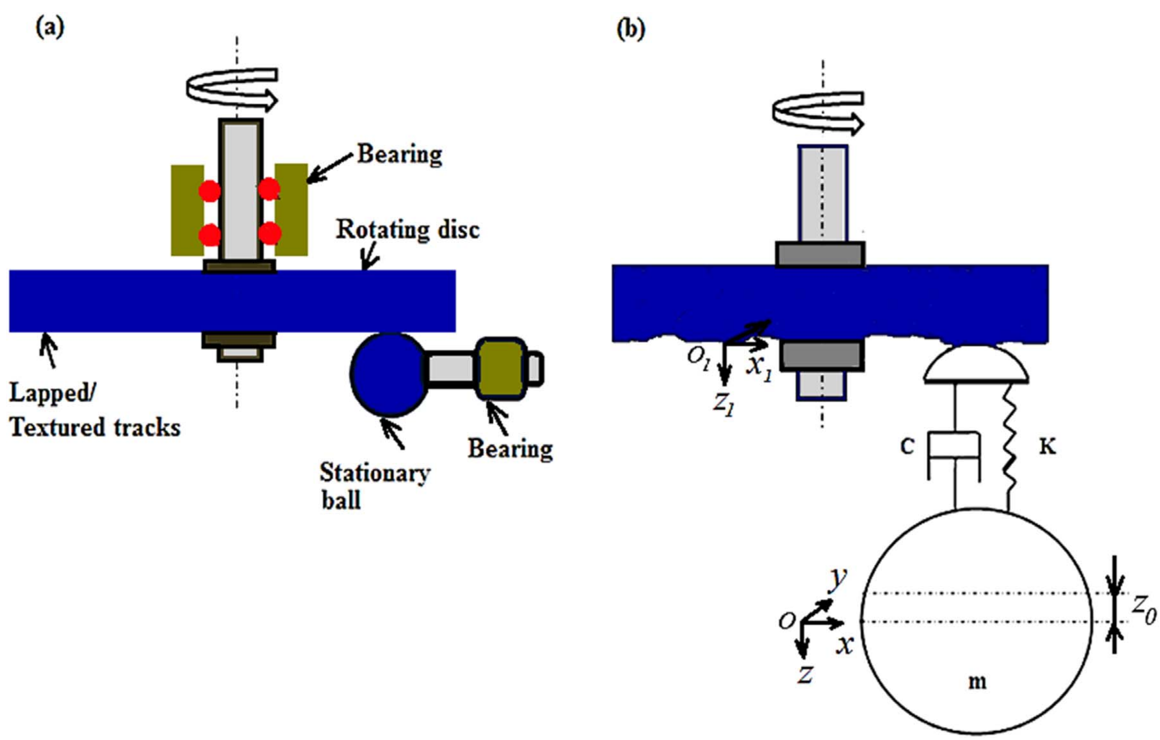

Fig. 1. Description of the point contact (a) schematic view of point contact formed between the ball and disc (b) contact representation for developing the dynamic model.