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Optimization of texture shape based on Genetic Algorithm under unidirectional sliding

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ABSTRACT

A numerical approach was proposed for the optimization of shape contour of recessed surface texture under unidirectional sliding. The approach was developed based on a Genetic Algorithm to improve the tribological performance. Results indicated either bullet or fish shape to be the preferable texture shape contours. Analyses on the hydrodynamic pressure distribution suggested that the increase in hydrodynamic upthrust of the obtained textures being the major reason for their superior tribological behaviors. Experimental tests confirmed that textures of the bullet and fish shapes have lower friction coefficient than those of circular shape, which may verify the simulation results.

1. Introduction

Current emergence and development of advanced fabrication technologies facilitate the possible production of many intricate surface textures on mechanical component. Hence, the tribological performance of these textures is understood and their practical application becomes realizable. Numerous experimental and theoretical studies have demonstrated the relatively superior performance, especially in wet lubrication [1], with tribo-surfaces having a certain level of roughness than their counterparts with smooth surface. Such finding seems to be contradicted to the traditional view that smooth surface was generally the best. The adaptation of animals and botanies to their habitational environments usually evolves some special functional biological surfaces: typically, the special micro-structures on shark skin can dramatically reduce water drag [2]. Further correlative analyses of the tribological effect of different biological surfaces stimulates researches on texturing tribological surfaces of mechanical components [3]. Although studies of most biological surfaces with efficient tribological performance suggest that they are mainly protrusion/bulge textures in nature, the available manufacturing technologies to produce these micro- or nano-scale textures (especially for large quantity production) are normally costly. Furthermore, the fabrication is often inconsistent, and the replicated geometry and size are hard to control accurately [4]. As a result, recessed textures, such as pit and/or groove textures, were essentially focused upon in the field of studies [5,6] instead. These studies have revealed that the merit of recessed surface textures for improving tribological performance of friction pairs can mainly be observed on: (i) the implementing of recessed-dot arrays to improve service-life of artificial joints [7]; (ii) the fabricating micro-grooves on automobile cylinders to minimize wear and energy loss [8]; (iii) the introducing of micro pits on slider bearing to enhance bearing load and to lower down friction resistance [9]; and (iv) so on.

Recent development of advanced manufacturing technologies/processes, such as laser processing, electrical erosion, embossing, LIGA, and so on [10–12], makes possible to fabricate precisely recessed textures of different shapes. The shape of recessed texture is an important geometrical character influencing the hydrodynamic behavior over a textured surface. Many research groups have deliberated theoretically and experimentally the effect of different shape contours of textures on their tribological performance. Due to the advantage of easy fabrication, circular dimples have generally been selected as a typical surface texture shape in many investigations [6,13]. These studies confirmed that the recessed dimples effectively increase bearing load, reduce friction resistance and reduce wear under wet lubrication. Besides circular dimples, other texture shapes, like square and triangular, were also applied to the interfacial surfaces of mechanical friction units. Their corresponding tribological performance was suitably evaluated and compared. For example, Brajdic-Mitidieri et al. [14] fabricated the surface of a wedge-

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Nomenclature

C	boundary perimeter
d	diameter
F	friction
h	film thickness
h_0	minimum film thickness
h_p	dimple depth
l	side length of square computational domain
n	half endpoint number of the inpolygon
n_r	rotational speed
P	contact pressure
p	hydrodynamic pressure
p_a	atmosphere pressure
p_c	cavitation pressure
r	coverage ratio of textures
u	velocity
W	bearing load
η	dynamic viscosity
λ	film thickness parameter
μ	friction coefficient
ρ	density of lubricant
σ_1, σ_2	roughness of upper and lower surfaces
σ	combined roughness
φ_c	contact factor
φ_s	shear flow factor
φ_x, φ_y	pressure flow factor in x- and y-directions

shaped slider bearing with closed squared textures, and then applied a CFD method to simulate the performance of liquid flow over the wedge slider. The studies have indicated that the fabricated square textures on wedge surface are able to reduce friction coefficient significantly. Wang et al. [15] studied the influence of triangular surface textures on tribological behavior under the mode of point-contacts. Results illustrated triangular textures with proper coverage ratio and depth substantially lowers friction coefficient when compared to that of their counterparts with plane surface.

Many research groups compared the influence of various shapes on tribological performances of textures with intention to search for suitable texture shape design for some specific operating conditions. A series of tribological experiments on the SiC ring surface with triangular and circular textures were carried out in water lubrication by Xie et al. [16]. Their friction value of triangular textures, in comparison with other texture arrangements, was the lowest when the textures slid in clockwise direction. Theoretical studies of the influence of several texturing shapes typically like circle, rectangle, and triangle, on friction coefficient using mixed lubrication model were conducted by Zhang et al. [17]. Their studies suggested minimum friction coefficient with the triangular textured shape taking place when the textures were slid along a certain relative orientation. Numerical evaluation of the influence of various shapes of deterministic micro asperities was performed by Siripuram and Stephens [18]. Results of the study confirmed that the influence of geometry of the raised/recessed textures on friction coefficient was insignificant and negligible. In the exploration of the effect of several texture shapes (such as circle, ellipse, triangle, and chevron) on the tribological performance of gas lubricated parallel pad bearing by Qiu et al. [19,20], it indicated the superiority of tribological performance of ellipsoidal shaped surface texturing to that of the other texturing shape arrangements. By texturing different shapes on surface and studying their effect on Stribeck curve in wet lubrication, Galda et al. [21] identified the exhibition of best tribolobical performance with teardrop textures. In a comparative study of the tribological behaviors of textures with different geometries orientating to various directions to sliding by Yu et al. [22], it suggested that both geometrical shape and orientation significantly influence the bearing load of a friction interface. Uddin [23] derived a design to optimize a novel 'star-like' texture shape that enable to increase pressure and decrease friction. The surface texture shape design seems to have great potential to be practically applied to industrial slider bearings.

Although the aforementioned literature have investigated the tribological performances of a number of various texture shape contours (typically like: circular, square, elliptical, rectangular, triangular, and etc.), there is still little work to be done on optimizing complex texture shapes. This is mainly because: (i) complex shapes are generally described by a number of geometrical parameters, which are usually hard to be characterized and/or expensive to fabricate; (ii) the functional relationship between their features of shape contour and tribological behaviors, such as bearing load and friction, is likely or commonly nonlinear and rather complex; and (iii) the contact stress around the edge of complex texture shapes is generally complicated in nature [1].

Since the development of a sequential quadratic programming (SQP) algorithm to optimize the concave texture shape for achievement of highest load bearing capacity by Shen [24] in 2015, it facilitates accomplishing textures in chevron-type and trapezoid-like shapes which are considered as the favorable geometries for unidirectional and bidirectional sliding motions, respectively. The present study differs from the optimization performed in Ref. [24] mainly on: (i) the present model addressing the interaction between neighbor textures in y-direction, which was completely neglected in Ref. [24]; (ii) a constant coverage area ratio of textures being assumed whilst there was not any constraint to be imposed in the study of Shen; (iii) optimization taking the detrimental effect of dimple edges into consideration whilst the effect was completely ignored in the study of [24].

As Genetic Algorithm (GA) is an efficient optimization method in solving complex problems of high-multimodal, multi-dimensionality, nonlinear, discrete and discontinuous characters [25], it has been popularly used in engineering fields like designing control system and turbine engine, and selecting production parameter, etc [25]. It is thus also selected in the optimization process in the present study.

Generally, at the verge of initiating/terminating the relative sliding of mechanical friction pairs, or the sliding pairs are under a condition of being overloaded, the tribological systems are usually in mixed lubrication regime with the occurrence of direct metal-to-metal contact. The friction and wear in these tribological systems tend to be increased. Hence, study on tribological behaviors of surface texturing in mixed lubrication regime is particularly meaningful for enhancing the utilization and the service life of friction units. In this case, the hydrodynamic behavior is regarded as the dominant factor determining the tribological performance [1]. Thus, the average flow Reynolds equation, allowed for the influence of asperities, is employed to simulate the effect of surface textures on hydrodynamic pressure.

The study incorporates recursively (i) an average flow Reynolds equation for determining friction coefficient of texture shape with (ii) a GA for determining a better texture geometry to furnish with lower friction coefficient. The numerical model in this study describes the complex texture shapes as sets of points and lines in a polar coordinates system. Such approach in recursive determination of friction coefficient and generating of texture geometry with lower friction coefficient subsequently provides means to tackle the design problem of complex textures.

Although the approach mentioned in this study has been used to optimize complex texture contour curve under reciprocal sliding [26], the investigation of optimizing complex textures which are involved with unidirectional sliding is still absent. Since there are a large number of mechanical components associated with unidirectional sliding between