Tribology International 81 (2015) 179–189

Contents lists available at ScienceDirect

Tribology International

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

Observations on the effects of grooved surfaces on the interfacial torque in highly loaded rolling and sliding tests

Shravan Janakiraman [a], Peder Klit [a,*], Niels S. Jensen [a], Jens Gronbaek [b]

[a] Department of Mechanical Engineering, Technical University of Denmark, Lyngby 2800, Denmark
[b] Strecon A/S, Stodagervej 5, Sonderborg 6400, Denmark

ARTICLE INFO

Article history:
Received 14 June 2014
Received in revised form
18 August 2014
Accepted 21 August 2014
Available online 1 September 2014

Keywords:
Transverse grooves
Traction
Rolling-sliding
Multigrid method

ABSTRACT

Some efforts have been undertaken to study the effects of grooved surfaces on the interfacial film thickness and torque between two contacting non-conformal surfaces under heavy loads. Transverse grooves of micrometer scale depth were engraved on polished, flat ring surfaces using established industrial methods like laser engraving and wire cutting. The grooved surfaces were then run against a polished flat surface at loads corresponding to high normal Hertzian pressures. Experiments were conducted to study the effects of the following parameters on the interfacial torque-groove depth, groove wavelength, load, inlet speed and slide-roll ratio. Experimental results were then justified, in certain cases, based on a multigrid model predicting the interfacial pressure and film thickness.

1. Introduction

Surface texturing has been used to study their effect on the tribological behaviour of sliding surfaces and journal bearings [1–3]. Ronen et al. [1] modelled the effect of micro pores on the friction losses in a reciprocating system and concluded that a friction reduction of at least 30% is possible with textured surfaces. Ramesh et al. [4] investigated lubricated sliding features having micrometer scale surface textures and reported a friction reduction of 80% for textured surfaces compared to non-textured surfaces at certain operating conditions. Surface textures increase the film thickness and reduce friction at certain operating conditions. Nanbu et al. [5] studied the effects of sliding and rolling speeds on the lubrication in concentrated conformal contacts. It was concluded that a faster moving textured surface compared to the non-textured surface, improved film thickness. Křupka et al. [6] investigated the effects of an array of micro-dents within a relatively lightly loaded (max. Hertzian pressure of 0.505 GPa) EHL contact. The authors concluded that the depth of micro-features is an important parameter in determining the tribological properties of an EHL contact. Wedeven and Cusano [7] studied the effects of parallel and perpendicular micro-grooves on the film thickness at pure rolling and sliding. It was concluded that under pure rolling conditions, both sets of grooves reduced the nominal film thickness when compared to the film thickness for smooth surfaces. Thus micro-textures are known to improve the film thickness at hydrodynamic loads. However there is no significant research conducted to study the tribological effect of these micro-textures at elastohydrodynamic (EHL) loads. The purpose of this study is to engrave micro-sized grooves on a ring surface using two well-established industrial methods and then study their tribological effects under EHL loading conditions. It is thought that if these grooves are found to be beneficial at high loads, a similar engraving process can be employed to engrave the surface of a rolling element in a rolling element bearing to improve their tribological performance. The parameter used to judge the tribological performance in this study is the interfacial torque in the conjunction.

There are multiple methods to texture grooves or dimples on metal and ceramic surfaces [8–18]. Etching grooves of sub-micrometer depth on a hardened steel ring is an extremely expensive process. This paper does not deal with sub-micrometer grooves because of this aspect. So micrometer scale grooves are engraved on the surface of a 100Cr6 bearing steel ring by two methods, laser engraving and wire cutting.

A multigrid method, using a combination of methods described by [19,20], is used to predict the film thickness and pressures generated in the lubricant, for a transverse groove of varying dimensions. These numerical method results are used to explain the experimental observations of the tests which study the effect of varying wavelength on the interfacial torque.

2. Test rig

The test rig consists primarily of two drive shafts and a hydraulic cylinder Fig. 1. One test ring is mounted on each shaft respectively. The two ring surfaces are brought into contact against each other by applying a normal load, using a hydraulic cylinder. Each ring has a conical bore, fitting on to a corresponding conical shape on the shaft.

* Corresponding author. Tel.: +45 45256267.
E-mail address: klit@mek.dtu.dk (P. Klit).

http://dx.doi.org/10.1016/j.triboint.2014.08.015
0301-679X/

Nomenclature

Symbol	Description
A	dimensionless amplitude of the groove
H_i	dimensionless film thickness at node i
H_o	dimensionless initial minimum film thickness
N	node number at the outlet
P_i	dimensionless pressure at node i
P_i^n	updated value of dimensionless pressure at node i
P_i^o	previous value of dimensionless pressure at node i
$P^{(k)}$	dimensionless pressure at grid level k
U	dimensionless speed parameter
W'	dimensionless groove wavelength
w	dimensionless load parameter
X_i	dimensionless x-coordinate at node i
X_d	dimensionless x-coordinate of the groove center
ΔX	dimensionless nodal distance
ω_{gs}	Gauss–Seidel under-relaxation factor
ω_{ja}	Jacobian under-relaxation factor
μ	dimensionless viscosity

The contact pressure between the ring and the shaft is controlled by the axial positioning of the ring on the shaft. Each drive shaft is capable of rotating at frequencies between 0 and 50 Hz. There is a provision for relative slip between the two rings when the two shafts rotate at different frequencies respectively. Hence it is possible to create conditions of rolling and sliding. Drive shaft 2 is connected to the Master motor and Drive shaft 1 is connected to the slave motor.

An inlet resting above the contact between the two rings allows for the lubricant to flow into the contact. The lubricant used is Mobil Delvac synthetic gear oil 75W-140, which is a fully synthetic, heavy duty drivetrain lubricant. This lubricant has a viscosity 182 cSt at 40 °C and 25 cSt at 100 °C [22]. The lubrication is not pressurised and the lubricant is allowed to fall freely, from a distance of approximately 2 cm, into the conjunction between the two rings. The inlet oil temperature is always maintained between 35 and 36 °C. A torque transducer is attached to drive shaft 2, so the interfacial torque generated between the two surfaces during slip can be measured.

Fig. 2 shows the schematic of the two rings in contact with each other. Each ring has an outer diameter of 70 mm. One ring has a chamfered surface with an axial width of 4 mm. The angle of chamfer is 10°. The opposing ring is unchamfered and has an axial width of 10 mm. The chamfered ring is then engraved by either laser engraving or wire cutting.

3. Experimental method

Two sets of tests are conducted. Test A studies the effect of varying groove depth on the interfacial torque. Test B studies the effect of varying wavelength on the interfacial torque.

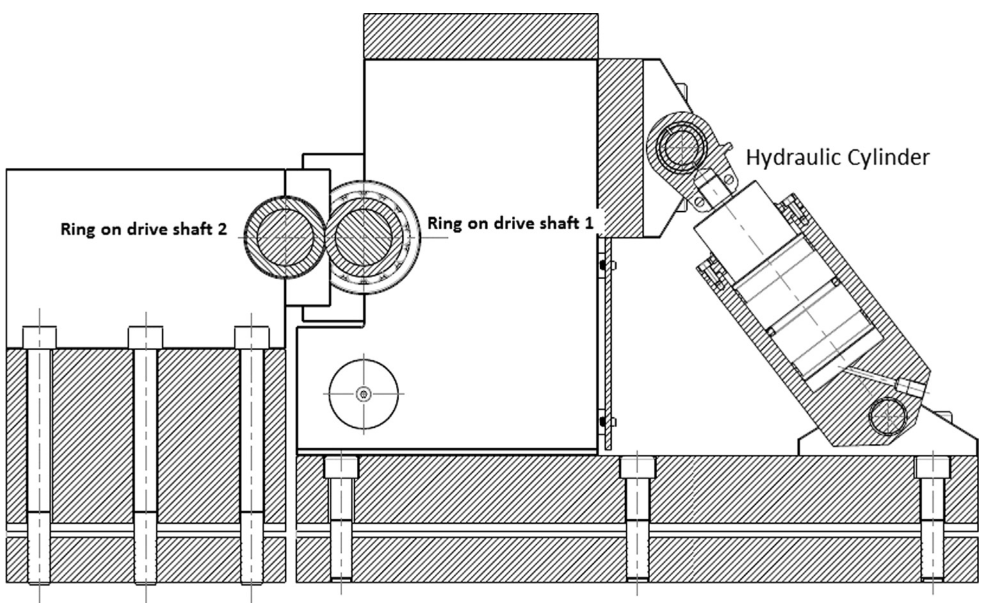

Fig. 1. Schematic of the rolling contact test rig.

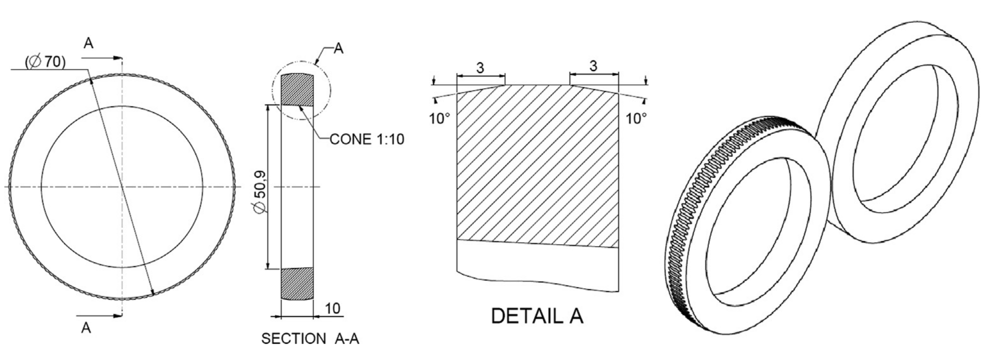

Fig. 2. Schematic of contact between grooved and smooth ring.