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INFLUENCE OF SURFACE DENTS ON ELASTOHYDRODYNAMIC AND MIXED LUBRICATION

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Abstract: *Machine parts with non-conformal contact surfaces frequently operate in elastohydrodynamic or mixed regime of lubrication. In surroundings of asperities significant changes in lubricant film thickness and also contact pressure occur, which can lead to failure. The article deals with the influence of surface dents on film thickness, contact pressure and rolling contact fatigue. These quantities are important for machine design in terms of failure (pitting and scuffing). Lubricant film thickness is measured by thin film colorimetric interferometry (TCFI) and contact pressure is calculated using inverse elasticity theory enhanced by convolution algorithms. Rolling contact fatigue tests show that it is possible to design surface textures of suitable layout of microdents which can have positive effect on lubrication and rolling contact fatigue life.*

Keywords: ***Elastohydrodynamic lubrication, EHL, surfaces, roughness, contact pressure, asperities, dents, contact fatigue.***

1. Introduction

Many machine parts with non-conformal friction surfaces operate in elastohydrodynamic or mixed lubrication regime. Asperities on real friction surfaces cause changes of lubricant film thickness and contact pressure distribution in the vicinity (Kaneta et. al., 1980; Luo et al., 2001; Choo et al., 2003; Cann et al., 2005). These changes can lead to failure like lubrication film rapture, pitting or scuffing. Surface asperities can be created unwillingly from technological process or from particles of wear, from foreign particles in oil etc. On the other hand, asperities can be created purposely by mechanical way (shot peening, indentation) or by laser surface texturing (LST) in order to improve tribological performances. Dents within surface texture can act like reservoir of lubricant (Hartl et al., 2004) in starvation phase of lubrication. These dents can also modify friction between surfaces and it is believed that they can have positive effect on rolling contact fatigue. The behavior of surface asperities in lubricated contact, their positive or negative influences and suitable arrangement of dents in surface texture is still discussed (Guangteng et al., 2000; Vrbka et. al, 2010). The change of real aperities in contact is based on roughness attenuation (Venner et al., 2005; Šperka et al., 2009).

2. Objective

The aim is to study the influence of dents on lubrication film, contact pressure distribution, and rolling contact fatigue (RCF). The knowledge of the influence of dents on tribological quantities will be important for design of suitable surface texture which can prolong contact fatigue life.

3. Methods

The experimental study of real rough surface attenuation requires the evaluation of both the undeformed surface roughness and lubrication film thickness. Lubrication film thickness that carries the information about in-contact deformation is measured using an optical test rig. Thin film colorimetric interferometry (TFCI) was used for film thickness measurement. This technique (Hartl, 2004) is based upon colorimetric analysis of chromatic interferograms (Fig. 1) using appropriate

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colour matching algorithm and colour-film thickness calibration. Based on previously obtained results it is believed that the film thickness resolution is approximately 1 nm. Operating conditons are described in Tab. 1. The contact is realized between steel ball and glass disc.

Contact pressure is in relation with deformation of friction surfaces, which can be derived from experimentally evaluated film thickness. Determination of contact pressure from surface deformations is an inverse problem based on the elasticity theory (Vaverka et al., 2008). The force balance condition must be included into the system of equations.

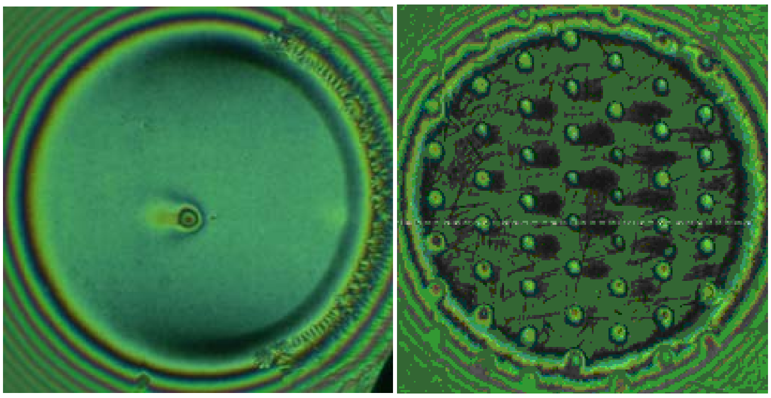

Fig. 1: Interferogram of surface with single dent (on the left), surface texture (on the right).

A mechanical Rockwell C type indenter has been used for indentation of specimen surface. Indentation process is fully controlled by PC, so it allows us to create accurately desired surface textures. The design of selected surface textures is in Tab. 2. Two types of arrangements of dents are depicted in Fig. 2. The aim was to find suitable surface texture, which prolong RCF life of a test specimen. Rolling contact fatigue tests was conducted on R-mat device. Cylindrical specimen is in contact with steel disc. Rolling-sliding conditions were applied during experiments (rolling-sliding ratio is 0.05). These vibrations had been monitored during experiments. When failure was observed, measurement was automatically stopped.

Tab. 1: Basic data decribing operating conditions.

Load F	29 N
Pressure viscosity coefficient a	23 GPa^{-1}
Dynamic viscosity η	0.421 Pa·s
Radius of the ball R	12.7 mm
Reduced modulus of elasticity E_r	313.7 GPa

Tab. 2: Layout of dents in surface textures.

Texture designation	Arrangement of dents	Distance in the direction of rolling	Distance perpendicular to the direction of rolling	Depth of dents
T0	Smooth surface without dents (RMS =0.04 after polishing)			
T1	Triangular	150 μm	75 μm	0.6 mm
T2	Triangular	150 μm	75 μm	1.45 mm
T3	Triangular	75 μm	75 μm	0.6 mm
T4	Square	75 μm	75 μm	0.6 mm

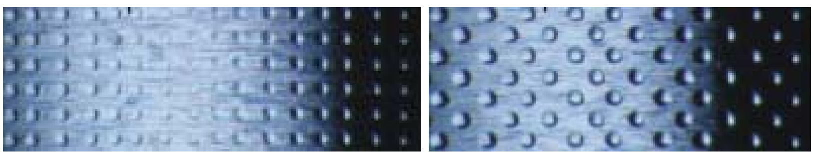

Fig. 2: Layout of surface textures with square (on the left) and triangular arrangement (on the right).

4. Results

Chromatic interferograms (Fig. 1) were obtained from experiment using optical test rig. Contact pressure was calculated using the inverse elasticity theory. This calculation is very time consuming, hence it is enhanced by convolution algorithm. Fig. 3 shows changes in lubricant film thickness and contact pressure distribution on the area with single dent (depth of dent is 360 nm, slide to roll ratio is 0.45). It is evident that lubricant deforms the surface in the vicinity of dent.

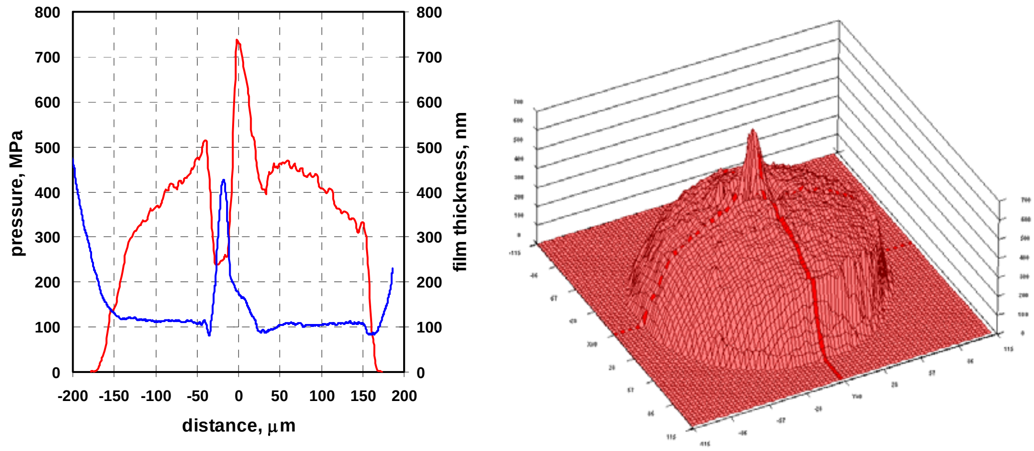

Fig. 3: Influence of dent on lubricant film thickness (blue) and contact pressure (red).

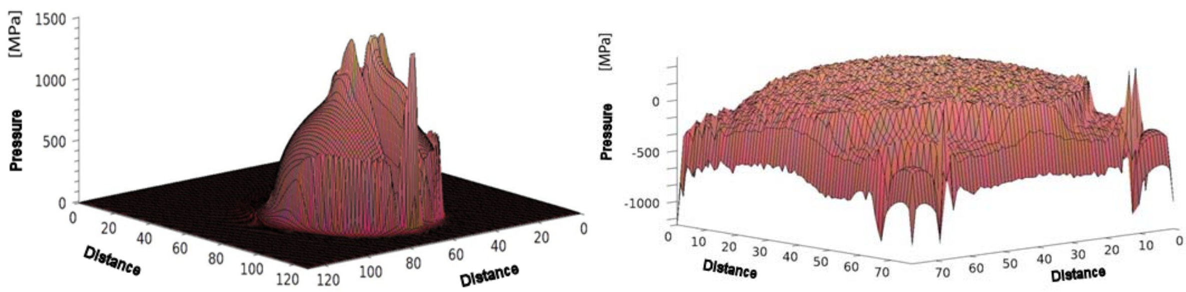

Fig. 4: Contact pressure distribution with single dent (on the left) and with real asperities including cavitation (on the right).

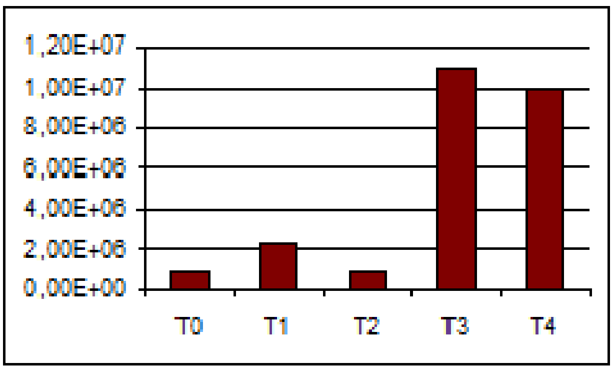

Fig. 5: Interferogram of surface texture (on the left), fatigue life of individual surface textures in cycles to failure (on the right).

The contact pressure distribution on the domain with single dent (depth is 700 nm) is in Fig. 4 on the left. The algorithm for calculation of contact pressure is very sensitive on the purity of input data, cavitation in the outlet cause contamination of input values of lubricant film thickness (Fig. 4 on the right). Fig. 5 shows the contact fatigue life in cycles obtained from RCF test of individual surface textures T1, T2, T3, and T4 in comparison with specimen having smooth surface (T0). The influence of dents arrangement on RCF was not observed. Depth and density of dents can have positive influence on fatigue life (textures T3 and T4). Example of failure is in Fig. 6.

Fig. 6: Example of failure.

5. Conclusions

The results show that shallow dents can have positive effect on lubrication and rolling contact fatigue, nevertheless it is suitable to make further experiments and calculations with big amount of samples under variety of operating conditions. It is assumed that local increases of mixed lubrication film thickness have positive influence on contact fatigue life. Presence of a texture on a friction surface can also lead to local hardening of the surface. In the future we would like to use method of pressure attenuation (Hooke, 2006) to study contact pressure distribution in more detail.

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