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EXPERIMENTAL STUDY OF ARTIFICIAL FEATURES ATTENUATION IN ROLLING/SLIDING CONCENTRATED CONTACTS

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ABSTRACT

A surface roughness attenuation approach based on the Fourier decomposition of surface roughness into harmonic components may allow predictions of the behavior of real rough surfaces within concentrated contacts. Recently the simplified model for rolling/sliding conditions was suggested.

A high pressure ball on disk tribometer was complemented by hi-speed digital camera with the aim to observe a progress of roughness feature pass through the contact. The experiments with artificial features were carried out under rolling/sliding conditions, evaluated by thin film colorimetric interferometry and compared with theory. Detail understanding of real roughness behavior inside contact under rolling/sliding conditions can have extensive impact on practical design of machine components.

INTRODUCTION

The surface roughness represents an important issue from many tribological aspects. Roughness features significantly affect minimum film thickness, pressure distribution and friction in concentrated contacts. It can enhance the risk of wear, scuffing, pitting etc.

Fast numerical solution methods developed in recent years can be employed to study roughness effects in concentrated contacts, but dealing with real rough surfaces is time-consuming and not suitable for the practical design. Hence some researchers have considered harmonic features of various wavelengths to describe the behavior of the real roughness. It was shown that the amplitude reduction of an initial roughness in pure rolling contacts can be completely described by a single curve [1]. This approach along with the Fourier decomposition represents the possible way to obtain simple fast tool for prediction of real roughness behavior within highly loaded lubricated contacts.

The behavior of the roughness in the rolling-sliding elastohydrodynamic contacts is more complex compared with pure rolling case. The concept of a complementary wave and a particular integral was introduced [2].

When the one dimensional harmonic wave-shaped surface passes through the contact, the amplitude of the initial wave is reduced, and the phase is changed [3]. This can be described by amplitude ratio h_a/A_o given by

$$\frac{h_a}{A_0} = \frac{1 - \mathrm{i}CQ}{1 - \mathrm{i}Q - \mathrm{i}CQ}, \qquad (1)$$

where h_a is the complex number representing the modified amplitude and phase, $C = hE'\omega / 4B$ implies the fluid compressibility effect. The value of Q heavily depends on the shear behavior of the fluid. It can be written [3] for Eyring fluids as

$$Q = sign(\Delta u)\frac{6\tau_e \lambda^2}{\pi^2 E' h^2}. \qquad (2)$$

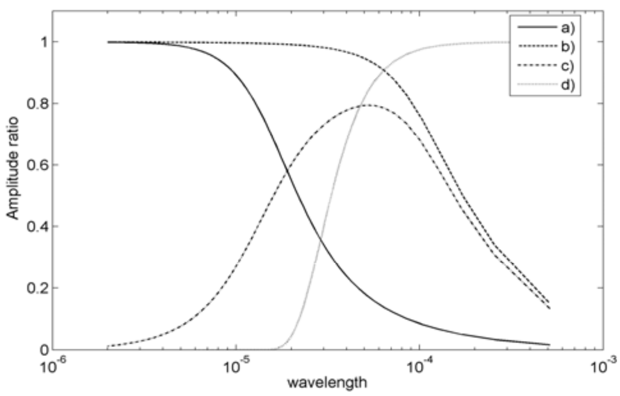

Figure 1 a) amplitude of the attenuation wave h_a, Rel. 1; b) total amplitude h_t, Rel. 8; c) amplitude of the CW h_c, Rel. 7; c) Decay of the CW on dist. b; calculated for parameters M = 766; L = 4.4; Σ = -1.

Also the complementary wave (CW) is generated in the inlet as the roughness enters the conjunction. The wave moves through the contact at the entrainment speed, whereas the amplitude decays, and the wavenumber changes, but this change is sufficiently low to be neglected. The one dimensional CW can be written as

$$\delta h_c = \mathrm{Re}\left[h_c \exp\left[(-\beta + \mathrm{i}\omega_c)x'\right]\exp(-\mathrm{i}\omega_c ut)\right], \tag{3}$$

where β is decay rate [3]; ω_c wavenumber of CW given by

$$\beta = \frac{F}{|Q|\,\lambda}; \quad F = 2\pi\left|1 - \frac{v}{u}\right|\left(\frac{v}{u}\right)^3; \quad \omega_c = \frac{2\pi}{\lambda}\frac{v}{u}, \tag{4-6}$$

and h_c is amplitude of the CW. Hooke et al.[3] proposed a semi-analytic way to determine the amplitude of the CW, however, it disturbs simplicity of the attenuation approach as was originally intended. Recently, Morales-Espejel et al. [4] suggested the approximation in a simple form, which can be solved rapidly. It requires subtraction of the attenuated wave amplitude h_a (Rel.1) from a total amplitude h_t defined by

$$h_c = h_t - h_a; \quad \frac{h_t}{A_0} = \frac{1}{1 + 0.15\nabla_{nn} + 0.015\nabla_{nn}^2}, \tag{7-8}$$

$$\nabla_{nn} = 0.8\nabla\left(\frac{1+\Sigma}{2}\right)^{0.1+0.5K}; \quad K = 1 - \tanh\left(0.25\frac{|Q|}{\nabla}\right) \tag{9-10}$$

NOMENCLATURE

A_0	complex amplitude of the initial wave
B	bulk modulus of the fluid
E'	equivalent elastic modulus
M, L	Moes parameters
b	radius of the Hertz contact circle
h	mean film thickness
h_a	complex amplitude of the attenuated wave
h_c	complex amplitude of the complementary wave
h_t	total amplitude of both waves
u	entrainment speed, $(v + w)/2$
v	speed of rough surface (ball)
w	speed of smooth surface (disk)
x'	x coordinate from contact inlet
τ_e	Eyring stress of the fluid
λ	wavelength in entrainment direction
Σ	slide to roll ratio, $\Sigma = 2(v-u)/u$
∇	dimensionless parameter $(\lambda/b)(M/L)^{0.5}$

EXPERIMENTAL APPARATUS AND CONDITIONS

The experimental apparatus, ball-on-disk tribometer, consists of a microscope and an optical test rig, where an elastohydrodynamic film is formed between a steel ball and a flat glass disk coated by a chromium layer. Interferograms are recorded by hi-speed digital camera with the aim to observe a progress of roughness feature pass through the contact. Thin film colorimetric interferometry was used for the film thickness evaluation. Experimental parameters M = 766; L = 4.4; Σ +1 and-1; entrainment speed u = 0.02 m/s; maximum Hertz pressure P_h = 0.64 GPa.

RESULTS

Figures 2, 3 show centerline profiles of transverse ridges during their passage through the contact. It can be seen as the

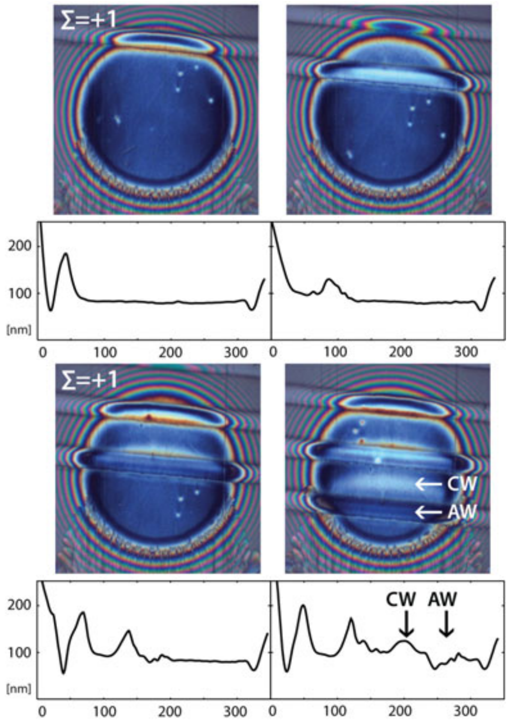

Figure 2 Interferograms and centerline profiles of transverse ridge passage through the contact; Σ >0 (disk is slower than ball).

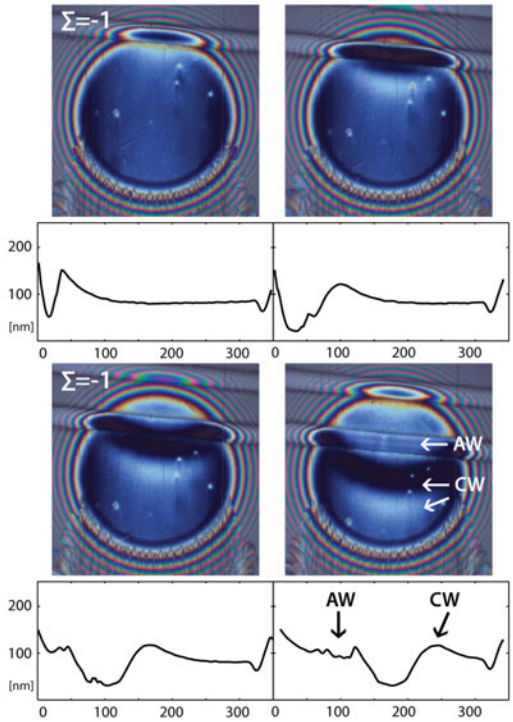

Figure 3 Interferograms and centerline profiles of transverse ridge passage through the contact; Σ <0 (disk is faster than ball).

ridge enters to the contact the attenuated wave (AW) and complementary wave (CW) are together. After, they start to separate because both components travel through the contact by different speed. Finally after some time they are detached almost entirely.

Figures 4, 5 present centerline profiles of measured film thickness distribution and prediction according the present model for the moment when the two waves are nearly totally detached. In Figure 4 speed of the disk is greater than speed of the ball and in Figure 5 it is opposite.

In the first case the prediction agree well with measurements, the AW is slightly less deformed then the observation shows. It must be noted, the region near to the contact enter can be influenced by next ridge coming to the contact inlet.

In the second case the agreement is much worse. The amplitude of AW is close; however the amplitude of CW is predicted lower than measurement shows. Similarly, also here the region close to the contact end can be influenced, to a certain extent, by previous ridges.

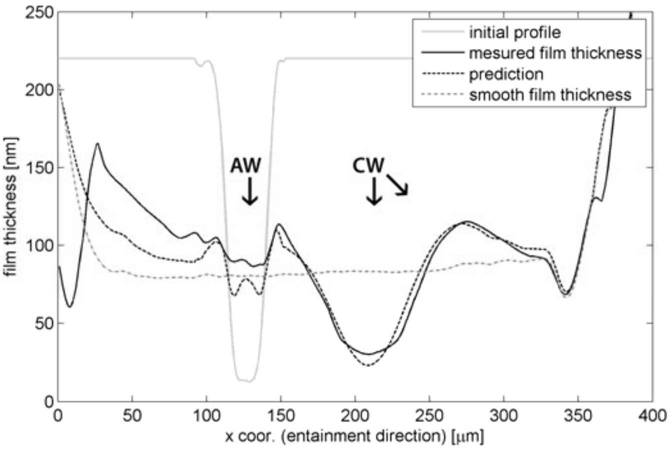

Figure 4 Profile of initial roughness, measured film thickness (rough and smooth) and prediction according present model added to the measured smooth profile for Σ = -1.

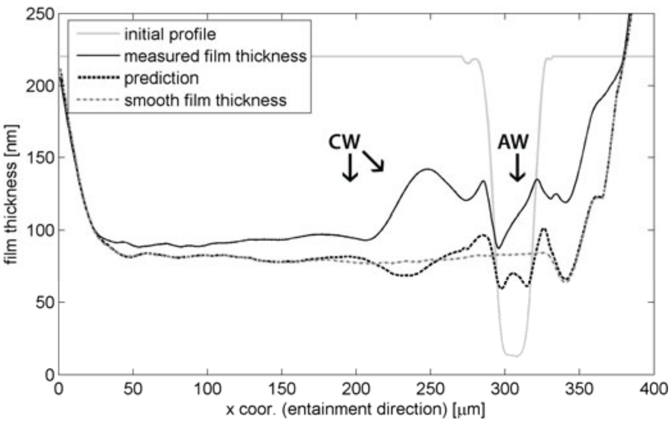

Figure 5 Profile of initial roughness, measured film thickness (rough and smooth) and prediction according present model added to the measured smooth profile for Σ = 1.

CONCLUSIONS

In this study, a recently suggested simplified attenuation approach for prediction of roughness behavior under rolling/sliding conditions was experimentally examined. The model is based on the presumption that the modification of the original roughness alone cannot explain all of the major effects that significantly affect film thickness under rolling/sliding conditions. The passage of artificial transverse ridge through the concentrated contact was observed by employing hi-speed digital camera and thin film colorimetric interferometry. The cases opposite slide to roll ratios (SRR) were studied. Good agreement was observed for the case when the disk is faster than the ball. However, the prediction for the contrary case gave significantly different results compared with measurements. Actually it can be suggested that the amplitude of the CW should have the opposite amplitude to the initial roughness in the second case.

Generally the current model cannot sufficiently describe the amplitude of CW for positive SRR. In other cases the agreement is sufficiently well to be able provide a rapid and simple tool for predictions of real roughness behavior within concentrated contacts.

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