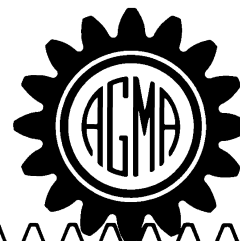


Roughness and Lubricant Chemistry Effects in Micropitting

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American Gear Manufacturers Association



TECHNICAL PAPER

Roughness and Lubricant Chemistry Effects in Micropitting

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Micropitting has been studied using a disc machine in which a central carburised steel test roller contacts three, harder, counter-rollers ("rings") with closely controlled roughness. We varied the roughness using different finishing techniques and investigated the effects of different oil base-stocks and additives, whilst keeping the viscosity approximately constant. We also developed a predictive model for the approximate analysis of rough-surface elastohydrodynamic lubrication based on the FFT approach of Hooke.

Damage on the test rollers included dense micropitting and "micropitting erosion" in which tens of microns of the test surface were completely removed. This phenomenon is particularly damaging in gear teeth where it has the potential to destroy profile accuracy. It was found that anti-wear additives led to a high rate of micropitting erosion and that the effect correlated more or less inversely with simple sliding wear results. There were also appreciable effects from base-stock chemistry.

The key parameter affecting the severity of damage seemed to be the near-surface shear stress amplitude arising from the evolved roughness; different chemistries led to the evolution of different roughness during initial running and thence to different contact stresses and different levels of damage.

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American Gear Manufacturers Association
500 Montgomery Street, Suite 350
Alexandria, Virginia, 22314

October, 2007

ISBN: 978-1-55589-918-9

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INTRODUCTION

In gear teeth, the phenomenon of micropitting is now widely recognized, either as a damage mechanism with a particular visual appearance (“grey staining”), or alternatively by its characteristic features of fine surface cracks with a particular geometry and orientation. [1–3]. However, micropitting is a phenomenon which extends beyond gearing affecting a wide range of mechanical components in which rolling–sliding contact takes place, notably including rolling bearings and cams. The key diagnostic feature appears to be surface cracking on a scale appreciably smaller than the dimensions of the nominal area of contact (usually Hertzian). In turn this is associated with the stresses caused by surface roughness. It is rolling contact fatigue caused by roughness [3].

Roughness of surfaces which are brought into contact creates local high pressures and stresses. In rolling contacts these high stresses will always be cyclic in nature since the rolling motion causes the contact pressures at a particular position to pulsate as the contact sweeps across the surface. If the opposite surface, the “*counterface*”, is rough and there is sliding present, each passage of the contact gives rise to *many* cycles of stress as the crests of the roughness slide past each point on the original surface, causing a rapidly pulsating pressure.

In turn, it is hardly surprising that the high cyclic stresses cause metal fatigue and thereby lead to cracking in the near–surface. However, this form of fatigue is evidently rather peculiar in nature and shows some features not shared, for example, by tooth root fatigue in gears. Among these are the following:

The stress field is mostly compressive but with a high shear stress range, so crack *opening* cannot easily be caused by the external loads; there is friction between the crack faces and, nearly always, there is crack face damage – making fractography particularly difficult.

The stresses are also *non-proportional* (stress components do not rise and fall in proportion to one another) and *randomly* distributed in time, so stress cycles are difficult to count even if the instantaneous pressure field can be analyzed.

The resultant cracking is often very dense and accompanied by extensive plasticity. This makes formal fracture mechanics treatment complex and difficult. It also predisposes the affected surface to severe wear (“micropitting erosion”) a feature particularly damaging to gear teeth where serious profile loss may result, leading to noise, vibration, dynamic loads and sometimes, consequential damage to the transmission system.

As a result for these difficulties, the development of calculation methods to ensure protection from micropitting has often resulted in procedures which are complex, conjectural in nature and difficult to validate. The subject has occupied a large amount of effort in the gearing industry world–wide, not least from AGMA [4].

However, recent years have seen substantial advances in the theory of lubrication. Until recently, although designers could calculate the “EHL film thickness” (using smooth body assumptions) and compare it to the measured roughness of gear teeth, it was not possible to describe how the stresses in the affected surface would be affected. For many practical gear engineers or would–be fatigue analysts, this rather made the whole exercise pointless! Stokes [5] is particularly scathing about the contribution of elastohydrodynamic lubrication (EHL) to gear design.

In the present paper we examine how a simplified micro–EHL analysis can be used to make predictions of near surface stresses and we compare these to some experiments to show how the stresses are related to the development of micropitting erosion.

In a previous FTM paper [6] it was shown that certain oil additives promote micropitting by maintaining the roughness (and the consequent stresses) at