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Assessment of surface contact fatigue failure in a spur geared system based on the tribological and vibration parameter analysis

M. Amarnath [a], Sang-Kwon Lee [b,*]

[a] Department of Mechanical Engineering, PDPM-Indian Institute of Information Technology Design and Manufacturing, Jabalpur, Jabalpur 482001, India
[b] Acoustics & Vibration Signal Processing Laboratory, Department of Mechanical Engineering, Inha University, 253 Yonghyun-Dong, Nam-Gu, Incheon 402-751, Republic of Korea

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ABSTRACT

Gears are one of the most common mechanisms for transmitting power and motion and their usage can be found in numerous applications. Studies on gear teeth contacts have been considered as one of the most complicated applications in tribology. The changes in operating conditions such as increase in temperature, load, reduction in viscosity result decrease in lubricant film thickness and degradation of lubricating oil thereby triggering several types of failures on tooth surfaces viz. pitting, scuffing, micro pitting, scoring, and spalling, these faults influence changes in vibration signals. This paper presents the results of experimental investigations carried out to assess wear in spur gears of single stage spur gear box under fatigue test conditions. The studies considered the lubricant film thickness analysis, wear mechanism studies on gear tooth surfaces, oil degradation analysis using Fourier transform infrared radiation (FTIR) method along with vibration signal analysis. The results provide a good understanding of tribological and vibration parameters as measures for effective assessment of wear in spur gears.

1. Introduction

Gears are known to be the essential and most efficient mechanical components in many machinery applications for power and motion transmission. Lubricating oil is used in a geared system to reduce friction and wear by interposing a film of oil between gear teeth, it plays a significant role in minimizing propagation of wear damage on gear tooth surfaces. In order to maintain a proper lubrication, it is important not only to use lubricant with suitable properties but also to monitor and analyze operating conditions viz. lubricant film thickness, specific film thickness, and degradation of lubricants in a periodic manner [1–3]. Oil film between working surfaces of gear teeth surface influences strongly the operating performance of a geared system. Gear failures such as wear, scuffing, micro pitting, spalling, and scoring are influenced by the lubricant parameters such as film thickness, viscosity, and temperature. High temperature leads to low viscosities which causes reduction in lubricant film, if the lubricant film on gear teeth fails, the aforementioned failures take place thereby altering noise and vibration levels [4–6].

Karacay and Akturk [7] conducted fault detection experiments on ball bearings using conventional vibration signal analysis. Statistical parameters of vibration signals such as peak-to-peak, crest factor and kurtosis values were considered to investigate formation and development of localized defects in a ball bearing. Spectrum analysis of vibration signals revealed defect locations on inner race

* Corresponding author. Tel.: +82 032 860 7305.
E-mail address: sangkwon@inha.ac.kr (S.-K. Lee).

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Nomenclature

a	contact half width
E	Young modulus
E'	dimensionless elasticity modulus, $E' = \left[\frac{1}{2}\left(\frac{1-\upsilon_1^2}{E_1} - \frac{1-\upsilon_2^2}{E_2}\right)\right]^{-1}$
G^*	dimensionless parameters of material
h_m	oil film thickness
H_m	dimensionless oil film thickness
HRB	Brinell hardness
L	face width of the gear
P_0	Hertzian pressure
U_*	velocity dimensionless parameter
W	load normal to tooth
W_*	dimension less load parameter
α	pressure viscosity coefficient
μ_0	dynamic viscosity
υ	Poisson's coefficient
R_a	average surface roughness
R_z	peak-to-valley surface roughness

and outer race and balls. Microscopic analysis of rolling contact surfaces showed the details of wear mechanisms occurred during the test period. Itagaki et al. [8] presented a study on the influence of grease degradation on the vibration levels in a ball bearing operated at allowable load condition. The vibration signal analysis was carried out on the ball bearings lubricated with three types of greases viz. Li soap/silicon grease, Na soap/mineral oil grease and Li soap/mineral oil grease. Results obtained from the experiments showed that the abnormal vibrations occurred in the ball bearings lubricated with all types of greases. Li soap/silicon oil grease and Na soap/mineral oil grease resulted in abnormal vibrations when the grease acts on the vibratory system as a negative damping moment during the normal vibration. However in ball bearing lubricated with Li soap/mineral oil grease, the abnormal vibration occurs due to a positive damping moment of the grease which gradually decreases over a time period and it acts on the vibratory system.

Peng and Kessissoglou [9] have considered wear particle and vibration spectrum analysis techniques to detect faults in a worm geared system. Experimental investigations carried out in this work include three operating conditions viz. lack of proper lubrication, normal operating condition and contaminant particles added into the lubricating oil. Integration of wear particle and vibration spectrum analysis in gear fault detection resulted in more reliable assessment of wear on gear tooth surfaces. Wear debris analysis revealed wear rate and wear mechanism on the gear wheel, whereas vibration signal analysis provided quick and reliable diagnostic information on bearing faults in the worm gearbox.

Tan et al. [10] carried out experiments to diagnose faults in a back-to-back power recirculation type spur gearbox. Pitting fault was intentionally simulated on a spur gear tooth, this fault was detected using fast Fourier transform (FFT) of acoustic emission signals. Authors have considered operating conditions such as temperature, viscosity and lubricant film thickness to assess fault propagation on gear teeth. Results obtained from acoustic signal analysis in conjunction with lubricant film thickness analysis appeared to be promising diagnostic tools to detect developing faults in spur gears. Elforjani and Mba [11] described results of fault detection investigations in a spur geared system in which natural pitting was allowed to occur. Throughout the test period, acoustic emission, vibration and metal contents in oil samples were monitored continuously to correlate and compare these techniques with the natural degradation of gears. The authors observed that the rate of change of three parameters i.e. Fe concentration, acoustic emission and vibration root mean square (RMS) values with respect to gearbox operating time increased with increasing the applied torque. Serrato et al. [12] conducted experimental studies to characterize the vibration behavior of roller bearing and lubricant film thickness. The bearings were operated under oil lubrication with radial load condition, the load considered in this experiment was about 10% of the allowable load of the bearing. Results obtained from the experiments highlighted the relationship between RMS values of vibration signals and specific film thickness, the trend plot of RMS versus specific film thickness showed a good correlation with Stribeck curve.

Amarnath and Praveen Krishna [13] carried out experiments to analyze the effects of reduction in film thickness on the vibration signals in a spur gearbox. Vibration signals were acquired under full film (FL), elastohydrodynamic lubrication (EHL) and boundary lubrication (BL) conditions were processed using conventional signal processing techniques, kurtosis parameters were extracted from vibration signals to detect surface fatigue wear on gear tooth surfaces. Further, fault diagnostic information obtained by these results was enhanced by using ensemble empirical mode decomposition (EEMD) method. Akagaki et al. [14] carried out fault diagnosis experiments on deep groove ball bearing using wear debris and vibration signal analysis methods. Wear debris morphology viz. thread like debris, cutting chip debris and plate like particles reveals wear mechanism developed on the rolling contact surfaces. Authors have highlighted the advantages of vibration and wear particle analysis methods to detect surface fatigue wear damage in deep groove ball bearings.

Hamzah and Mba [15] conducted experiments to assess wear damage in a helical geared system by considering the influence of different speeds and loads using acoustic emission (AE) signals. Specific lubricant film thickness analysis was also considered in conjunction with AE signal analysis. The RMS values of AE signals increase in nine- and fourfold changes which provide the exact lubrication condition in the operating geared system. Zakharich et al. [16] carried out experimental investigations to determine service deterioration of transformer oil using Fourier