# Abstract

Gears are the critical components for motion and power transmission in the desired ratio and high efficiency. These factors can be satisfactorily achieved if the gears have no faults. Whenever a fault or defect occurs in a gear system (e.g., wear, scuffing, plastic deformation, Hertzian fatigue, crack, fracture, and bending fatigue), the performance of the gears deteriorates. The demanded motion and power cannot be transferred under deteriorated conditions—the early detection of these defects results in saving of catastrophic failure and substantial economic losses. The condition-based maintenance (CBM) helps in the early detection of machinery faults so that the appropriate action can be taken before failure and the system's reliability can be improved. In the literature, various reasons were reported for the gearbox failure, like misalignment, lubricant deterioration, bearing failure, foreign particles contamination, etc. Out of these reasons, misalignment and lubricant deterioration play an important role in gear failure. Misalignment may result from installation errors, manufacturing errors in gears, distortion of the gearbox housing, excessive radial spacing in bearings, excessive stresses and thermal effects, design failure, etc. The lubricant degradation may result from contamination from foreign particles, water ingress, oxidation, etc.

In the present work, a mathematical expression is developed for the effect of different types of misalignments (angular, radial, and axial) on the surface wear of gears. Misalignment leads to a change in contact pattern and load distribution, which results in increased surface wear that further leads to the change in contact pattern. The resulting mathematical model results were validated with the existing literature and experimentally obtained wear results. Additionally, the effect of different parameters (module, pressure angle, number of teeth on the pinion, and gear ratio) on wear

resistance is studied. It was found that the load share ratio in the double teeth pair region increases with an increase in the module, gear ratio, and number of teeth on pinion and decreases with an increase in pressure angle. The wear depth decreases at the transition from double teeth pair region to single pair region with an increase in module, gear ratio. The wear depth decreases at the initiation of the contact point and overall mesh cycle with increased pressure angle and the number of teeth on the pinion, respectively.

Further, run-to-failure experiments were conducted on a single-stage spur gear test rig developed in-house. The real-time vibration, wear debris, and oil quality have been obtained. The classical time synchronous averaging was used to denoise the vibration data, and statistical features were obtained from the denoised signal. These vibration features were then compared with the online wear progression. It was observed that the wear debris progression provides early detection of the fault progression compared to the vibration signature. The oil samples were collected periodically for offline analysis. Scanning electron microscopy (SEM) imaging of the wear debris harvested from the oil samples was done to study the wear debris morphologies. It was observed that the morphology of the wear debris changes from a fiber-like structure to a more spherical one as the wear progresses.

Further, the study extends to see the effect of nano-lubricants on degraded lubricant and the wear of the spur gears. An artificial lubricant ageing by chemical degradation (mixing the aqueous HCl (36.46% HCl + 63.54% aqueous) is proposed to simulate the ageing process of gear lubricants. The pH value of the oil is used to estimate the ageing time of the lubricant. The oil samples were analyzed using ATR-FTIR spectroscopy by monitoring the degradation of additives, level of moisture, and sludge formation. The aged gear lubricant was tested on the developed gear test setup. Initially, three nano-additives were selected: graphite, graphene and “graphene oxide functionalized with silicon oxide ($GO@SiO_2$)". A preliminary study on the chosen nano-additives (two levels of each nano-additives) was conducted using L8 orthogonal array to estimate the performance and interaction of nano-additives. Based on the analysis of variance (ANOVA), graphene was eliminated due to its least (0.31%) contribution. The L16 (four levels of graphite and $GO@SiO_2$) orthogonal array was used to optimize the percentage of nanoparticles. Finally, the optimum percentage of nano-additives (Graphite:0.125% w/w, $GO@SiO_2$: 0.15% w/w) was applied for the experimental study on the gearbox test rig. ATR-FTIR studies have been performed to understand nano-additives' effect on the fresh and degraded gear lubricant.

Overall current work analyses the significance of misalignment in gear and oil degradation on the wear behavior of spur gear in lubricated conditions. Further, the study identified the effect of variation in pH value as a critical aspect of oil deterioration which leads to accelerated wear. Also, this thesis portrays the effect of different parameters on spur gear surface wear for effective detection and quantification. Furthermore, the different mode of wear detected by this study clarifies the understanding of gear designing for the reliability of the transmission systems.