PhD thesis title: **Tribo-performance studies of textured concentrated contacts at heavy loads using nano-lubricants**

Student: **Rameshwar Chaudhary** (2015MEZ8166)

Supervisors: **Prof. R. K. Pandey** and **Dr. S. K. Mazumdar** (formerly ED, R & D, IOCL Faridabad)

Abstract

There is a growing demand for energy-efficient and high-power density concentrated contacts for hard-working machines and mechanical systems. Therefore, the concentrated contacts found in the machine elements, such as rolling bearings, gears, cam-followers, tractive drives etc., are expected to work efficiently in elevated/severe operating conditions. Since the last couple of decades, several techniques, i.e., surface heat treatments, hard coatings, use of additives in lubricant, nano-lubricants, surface polishing, new materials etc., are being employed by researchers/engineers time-to-time to enhance the tribo-performance behaviours of lubricated concentrated line/point contacts. Recently, surface texture has emerged as a viable technology employing which investigators are exploring to improve the tribo-dynamic performance behaviours of the concentrated contacts. Moreover, it is worth noting here that since the researchers are also making recent past attempts to use nano-lubricants to explore and address the concerns related to starved lubrication. Nano-additives involving CuO, carbon nanotubes, graphene oxides, boron nitrides, metal oxides, PTFE and metal sulfide particles etc., have been widely employed in the explorations for improving the tribo-performance behaviours. It is mainly observed that the roles of surface textures have been experimentally studied for the performance behaviours of lubricated line/point contacts at low to medium loads (characterized by Hertzian pressure varying in the range of 0.2-1.5 GPa) and rolling/sliding speeds (0.02 to 1 m/s) under the reciprocating and unidirectional motions. Therefore, the objectives of this research work have been set to explore to reduce the friction and wear and to increase the lubricating film formation behaviours at the textured line and points contacts operating at a wide range of loads (P_H = 0.20 to 3.5 GPa) under reciprocating (0.2-0.4 m/s) and unidirectional speeds (up to 3 m/s) using nano oils and greases.

The tribo-performance behaviours of lubricated textured point contacts have been explored at relatively high contact loads (up to 3 GPa) under reciprocating motion (0.2 and 0.4 m/s) employing low ($\nu_{@40^0C}$ =100 cSt) and high ($\nu_{@40^0C}$ = 422 cSt) viscous oils as well as MoS_2 and PTFE nano oils. In this experimental study, two contacts (flat conventional surface vs. polished ball and textured flat surface vs. polished ball surface) have been created to investigate friction, wear, and contact potential (the ability for film formation). In the presence of texture at the concentrated contacts, the coefficient of friction and wear has reduced considerably with high viscous oil, irrespective of operating parameters. However, low viscous oil has increased wear under identical operating parameters. The contact potential (an indirect indication of film formation during the running-in period) in the texture's presence develops rapidly compared to the conventional surface with both oils. It has demonstrated a reduction in the running-in period in the presence of textures at the contacts. Moreover, better tribological performances have been achieved with PTFE nano oil compared to MoS_2 nano oil. Tribo-performance evaluations of reciprocating lubricated concentrated line contacts have also been presented herein, employing the synergistic presence of surface texture and MoS_2 and PTFE nano oils. Substantial reductions in friction coefficient (up to 48%) and specific wear rate (of worn rollers) have been found in the combined texture and nano oils at the concentrated line contacts. Moreover, a significant increase in the contact potential (an indication of film formation ability) has also been noticed in the presence of texture and base oils.

Tribo-behaviours of grease lubricated textured point contacts were experimentally explored at heavy loads (characterized in terms of Hertzian pressure, P_H=1.5-3.0 GPa) and relatively low sliding speeds (0.2 and 0.4 m/s) under the linear reciprocating motion employing lithium based low and high consistency greases as well as MoS_2 and PTFE nano greases. Using a controlled stress rheometer, the effects of grease consistency on the greases' rheological behaviours have also been found at two temperatures, 25°C and 80°C. Overall, textured concentrated contacts yielded a low coefficient of friction (reduction of up to 24.6%), reduced specific wear rate of the ball (decrease of up to 89.5%) and better development of contact potential compared to conventional contacts. The transmission electron microscopy (TEM) of used greases collected from textured contacts revealed less degradation in soap fibres. Moreover, the X-ray photoelectron spectroscopy (XPS) revealed the formation of ferric oxide (Fe_2O_3) and ferrous-ferric oxide (Fe_3O_4) protective chemical films on the worn surfaces of balls of the conventional and textured contacts. However, it is also found that friction coefficient and specific wear rate of worn balls reduced considerably in the presence of texture and nanoparticle (MoS_2 and PTFE) blended greases at the concentrated contacts irrespective of operating parameters. The coefficient of friction reduced up to 31% at concentrated textured contact lubricated with MoS_2 nano grease. Moreover, it reduces up to 30% when lubricated with PTFE nano grease. The specific wear rate of worn balls of concentrated textured contact was reduced to 94% with MoS_2 nano grease and 96% with PTFE nano grease.

The effect of MoS_2 and PTFE nano oil (MoS_2 and PTFE nanoparticle blended in oil) on the tribo-behaviours of textured point contacts have been explored at moderate loads (P_H=0.5 and 0.8 GPa) in different lubrication regimes. Two contact configurations (grounded disc vs ball and textured disc vs ball) have been employed to experimentally investigate the friction and wear under boundary, mixed and elastohydrodynamic lubrication regimes. A femtosecond pulsed laser has been used to create the surface texture (dimples) of two sizes and dimple area densities. It is found that friction coefficient and wears tracks' width are reduced due to the combined effect of texture and nano lubricating oil at the concentrated point contact irrespective of operating parameters. The textured concentrated point contact lubricated with MoS_2 and PTFE nano oil yielded a lower friction coefficient than conventional contact in both boundary and mixed boundary regimes. Moreover, the reduction in friction coefficient was observed more in the boundary regime than in the mixed regime due to the acting of dimples as lubricant reservoirs. The optical images of worn balls and discs, EDS of the worn textured surface and AFM images have been presented to describe the associated mechanism.

****