Synopsis

Surface texturing to achieve reduced sliding friction has been a widely studied topic, as seen in contemporary literature. Laser surface texturing, grinding and ion beam milling are popular techniques accepted by researchers today for creating specific surface textures. Among these, grinding is a popular process adopted today in mass manufacturing around the world. In this study, we look at grinding as a method of surface texturing and studying the effect of various grinding parameters on the friction when sliding a relatively softer material against the generated surface. The system chosen was aluminum pins sliding against a stainless steel surface on which specific textures were generated.

The specific system was chosen as an aluminum-steel pair is increasingly used in automobiles as weight reduction is a priority for automobile engine manufacturers today. Automobile engine manufacturers are increasingly shifting to aluminum cylinder blocks to make their power-trains lighter. The tribo-system was lubricated with the mineral base oil used in a SAE 30 grade engine oil blends. The tribo-system was in reciprocating sliding motion, driven by a scotch yoke mechanism similar to that used in a reciprocating internal combustion engine. Though aluminum-silicon alloys and steel are widely used in engines, pure aluminum and stainless steel was chosen in this study for a fundamental understanding of the different parameters involved in an aluminum-steel tribo-system. Aluminum being softer than Al alloys will deform at the asperity level and in oxidation will be much lower in stainless-steel, thus avoiding tribo-oxidation mechanisms operating. Different topographies were created on stainless steel using the conventional grinding methods and differentiated for their effect on sliding friction using a reciprocating tribometer.

Different surface topographies were created on a lab scale table grinder using coated abrasive sheets. Sliding friction between an aluminum pin and these stainless steel flats under contact pressures not exceeding 7.5 MPa (similar contact pressures existing in an IC engine – This has to be checked) were tested in a sparsely lubricated sliding environment. Certain surface topographies showed an extraordinary reduction in the average coefficient of sliding friction. The average surface roughness of the topographies that showed lower

friction was not different from topography of others that showed higher friction. Separate topographies were created on the stainless steel mirror finished countersurface corresponding to P1200, P320 abrasive disc. Group 1 virgin mineral base oils viz. SN500, SN150 and SN60 with viscosities 100, 30 and 12 cSt at 40 deg C were used. The topographies when tested for cycle average coefficient of friction revealed that P1200 finished surface showed an exceptionally low value under 0.02.

In a scotch yoke mechanism, the velocity varies according to a sine curve with maximum velocity occurring at the center and with zero velocities at the ends. This would mean that the lubrication regimes, as given by the Stribeck curve would change from boundary lubrication at the ends to a possible hydrodynamic lubrication when the velocity reaches a maximum. Therefore, it was decided to understand the evolution of the frictional force response of these topographies for each reciprocating cycle. When the individual cycle friction force response was examined in greater detail along with other components in the tribo-system, it was found that the behavior of these plots was significantly different from those predicted by classical Stribeck principles.

For the mirror finished stainless-steel flat surface while sliding with the aluminum pin at 1Hz or 40 mm/s average sliding velocity showed a frictional force plot as shown in figure I below. The alternating “M” and “W” patterns corresponded to the frictional force variations when the velocity of sliding varied in a sinusoidal manner corresponding to the velocity profile of the scotch yoke follower mechanism. This variation could be explained well using the classical Stribeck curve where coefficient of friction is expected to reduce as the velocity is increased from zero at the extremes of the track to a maximum at the center of the track, which is defined by the amplitude and frequency of reciprocation.

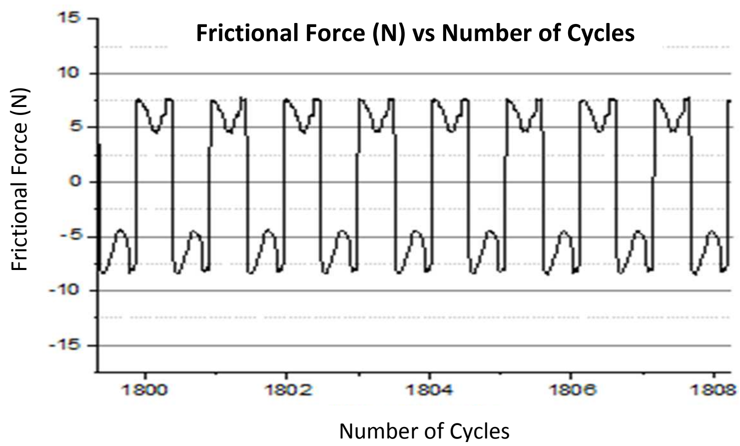

figure I: mirror Finished flat with SN 500 oil at 1800 cycles

When a P1200-finished surface was tested for 1800 cycles at the same average velocity, the frictional force was as shown below in figure II. The plots showed extremely low frictional force. Frictional force corresponding to the accelerating region was the only response visible and the rest of the cycle approached near zero frictional force. Different average velocities of sliding, viz. 12 mm/s, 40 mm/s, 80 mm/s and 200 mm/s corresponding to 0.3Hz to 1Hz, 2Hz and 5Hz reciprocating frequencies respectively were tested. The tests were carried out for the same number of cycles for a P1200 finished surface.

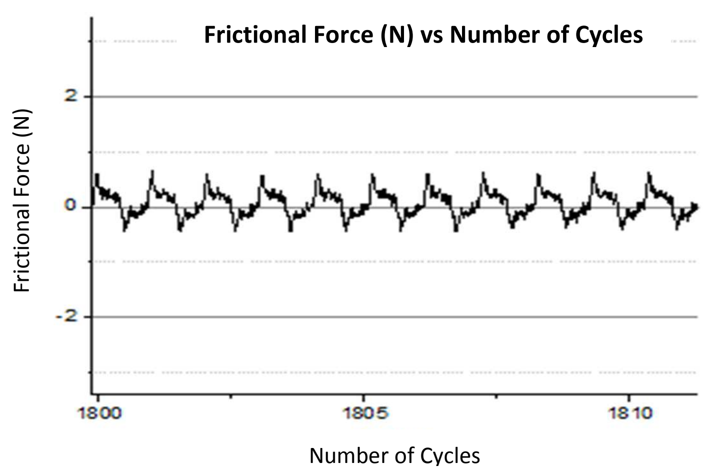

figure II: P1200 Finish with SN 500 oil at 1800 cycles

As the sliding velocities were increased from 1 Hz to 5Hz, faster transitions to a steady state was observed. At 1Hz, the system reaches a steady state at about 1000 cycles. At 2Hz, the steady state was reached after around 500 cycles and at 5Hz, the system seemed to reach the steady state from the initial few cycles. It was felt that there were some modifications happening on the aluminum pin surface and/or stainless steel flat countersurface as the test progressed. This change happens at a faster rate and the system reached a steady state faster when the relative velocities of sliding were higher. Thus, for the test conducted at the lowest frequency of 0.3Hz there was no change in the shape of the frictional force plots till the end of the test and friction remained high. The above tests were also done for other topographies viz. mirror and P320 finished surfaces. At velocity corresponding to 5Hz, even the mirror finished surface exhibited extremely low friction and showed nearly flat friction response curves. At low velocities corresponding to 0.3Hz, the adherence to the Stribeck curve phenomenon was seen for all three topographies. It was also observed that a critical film thickness had to be exceeded for this phenomenon of friction reduction to take place. It was found that either an increase in sliding speed or an increase in the oil viscosity enabled the tribo-system to achieve this minimum critical film thickness.

Critical three-dimensional areal surface parameters were found out for these topographies using an optical profilometer, and a few parameters governing the shape of these frictional plots were identified. It was found that surface parameter ratio S_{pk}/S_k, where S_{pk} is the reduced peak height and S_k is the core roughness depth, could predict the shape and magnitude of the frictional F_x forces under sliding reciprocating motion for the above tribo-system. Conventionally S_{pk}/S_k ratio is used to distinguish surface topographies which cannot be distinguished by the characteristic average surface roughness and root mean square surface roughness parameters. S_{pk}/S_k highlights the importance of peak structures on a topography. The volume occupied by the peaks in relation to the core roughness and the symmetry in the texture amplitude increased with increase in this surface parameter ratio.

Three different types of topographies generated using the same abrasive disc: P320, by using different amounts of grinding fluid (here water) were studied. Conventional surface parameters like average surface roughness and root mean square roughness could not distinguish these three surfaces. However, using the ratio S_{pk}/S_k, it was found that two of these surfaces had S_{pk}/S_k ratio less than 1, and the other surface had this ratio greater than unity. Where the ratio S_{pk}/S_k was less than 1, the frictional force plots did not reduce with the number of cycles and showed adherence to classical Stribeck curves with alternating "M" and "W" shapes. Where S_{pk}/S_k ratio was greater than 1 the friction force reduced with the number of cycles, as seen in figure I and almost became flat and near zero at steady state.

It was found that the topography of the stainless-steel countersurface had an influence on the evolution of the aluminum pin topography during sliding. Where the friction force curves resembled figure I, the pin topographies got modified as the S_{pk}/S_k value shifted to a value greater than 1; it was also observed that an evenly spread layer of iron was dispersed on the pin face after the system reached steady state. Where the friction force curves did not reduce with the number of cycles (figure II), there was neither a change in the pin topography nor formation of any tribo-layer as noted above. It was also found that this progressive tribo transfer layer was selectively formed on the pin surface when the friction was extremely low. Some physical explanations have been developed for why the value of the S_{pk}/S_k parameter is important in determining friction in this mating combination.

The importance of the pin topography and tribo-layer was evident from different shapes of the frictional force plots with changing pin topographies. When a mild abrasive was used to abrade the pin face after the system reached the steady state, the tribo-layer formed on the pin face was removed and the topography also changed. An immediate shift in the shape of the force plots when the test resumed. Here it was also found that rubbing such a pin on a "used" flat face did not bring the system back to steady state even after continued sliding in successive tests. However, shifting the pin to a "virgin" flat face on the same topography brought the system back to steady state. The sharp tipped peaks on "virgin" stainless-steel flat topography fractured while in sliding contact with the pin and contributed to the quick reformation of the tribo-layer on the countersurface of the pin. It was also found that wear debris did not have any contribution to the shape of the F_x plots. It follows that a combination of the pin topography observed at steady state and the tribo-layer is responsible for reduction in sliding friction to such a low level for certain topographies.