



# TRIBOLOGY OF PARTIAL PAD JOURNAL BEARINGS WITH TEXTURED SURFACES

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**Keywords:** Surface texturing, tilting pad arc journal bearing, friction, load carrying capacity

## 1 INTRODUCTION

A simple partial tilting pad journal-bearing rig is developed. The journal diameter to pad width is so chosen as to render a short width bearing. The attitude angle is recorded by reading from a graduated scale. The journal surface is immersed into a bath of lubricant. The supply of lubricant into the conjunction can be varied. The combination of journal speed and immersion depth determines the state of inlet supply. Simple analysis is used to obtain the journal eccentricity ratio and in turn viscous friction.

A suitable combination of journal speed and supply volume assures a fully flooded inlet. However, at low speeds and sufficiently high loads, thinner hydrodynamic films result at high eccentricity ratios, increasing the chance direct contact of surfaces. To mitigate such cases, it is surmised that some distributed surface features may be included to increase the load carrying capacity. The small surface features introduced by an indentation process act as reservoirs of lubricant and create their own individual micro-wedges.

Tests show reduced attitude angles and increased eccentricity ratio for a textured journal. However, this is a function of a combination of journal speed and the supply volume of lubricant. For a given journal speed, there is a limiting volume above which oil loss would take place through side leakage. Conversely, a reduction in the supply volume for a given speed can lead to incipient starvation.

It is widely accepted that the tribological performance of load bearing contacts can be improved by the process of surface texturing, when very thin films may be encountered, leading to direct interaction of surfaces [1-5]. Often direct contact between the surfaces occurs due to the diminished lubricant film. This is caused by the cessation or significant reduction of the main mechanism of fluid film formation; entraining motion of the lubricant into the contact due to relative motion of the contiguous surfaces. The increased friction adds to the parasitic losses, for example increasing engine inefficiency.

One way of mitigating the effect of friction is to modify the bounding solid surfaces through introduction of engineered surface features which act as tiny reservoirs of lubricant. These features include very shallow grooves or alternatively convex features such as dimples may be used (all with dimensions in the region of a few (micrometres). These may be introduced by laser texturing or micro-indentation techniques, or even by deposition methods.

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Different contact conditions call for optimisation of surface texturing parameters [6]. For example, Uehara *et al* showed that changing the density and diameter of dimples on the load bearing surfaces had a significant effect in reduction of friction. They then determined the dimple diameter and distribution density which resulted in the minimisation of friction. It was also shown that certain sliding velocities would produce a negative effect due to mechanisms such as side leakage.

Surface texturing can also affect the regime of lubrication [7]. Kovalchenko *et al* [7] showed that by introducing dimples through laser surface texturing (LST) the hydrodynamic regime can be extended for a greater range of speed and load. It was also shown that a lower coefficient of friction was attained with an LST surface when compared with a polished surface. With thin films, the chance of adhesion increases dramatically with polished surfaces. Rahnejat *et al* [4] also showed a 4% reduction in friction from piston-bore conjunction with LST.

The load carrying capacity of a journal bearing can also be improved by surface texturing [8]. Sinanoglu [8] showed a micro-hydrodynamic wedge effect during conditions that pertain to hydrodynamic regime of lubrication and the reservoir effect during starved conditions, both improving the bearing load carrying capacity.

It has been shown that key dimensions of the applied surface texture can be optimized for improved tribological conditions. Rahmani *et al* [9] showed through an analytical investigation into surface texturing on slider bearings, that the shape and type of the applied texture are of particular importance.

Little research has been conducted into the influence of combining different journal speeds with a varying supply of lubricant into a conjunction and the effects these would have on the tribological performance.

## 2 EXPERIMENTAL WORK

The partial (180 degrees) tilting arc pad journal bearing rig (figure 1) comprises an aluminium journal and a toughened acrylic arc pad in close contiguity. The journal is rotated by an electric motor with a electronic speed control. The pad is loaded against the journal with hanging weights. With an applied load and journal rotation, the generated friction tilts the pad. A pointer attached to the pad assumes an orientation which signifies the line of centres (LOC). The angle of LOC to the applied vertical load is the attitude angle, a direct measure of friction torque. This angle is read from a fine graduated scale.

Two journals are used interchangeably. One is regarded as *smooth*, whilst the other comprises a mesh of micro-indentations introduced through use of a Vicker's indenter to ensure repeatability in indentation depth (figure 2). A series of tests are carried out at different speeds and loads with various immersion depth of the journal into a volume of lubricant in the sump.

A survey of similar previous work was undertaken to draw on experiences reported with regard to density distribution, depth and diameter of indentations [10-14]. The chosen values are shown in table 1. An image of the textured journal can be seen in figure 3.

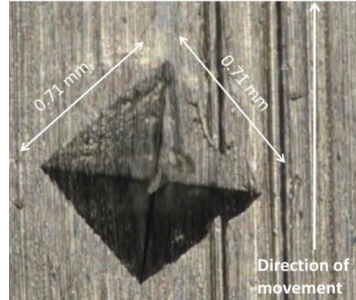
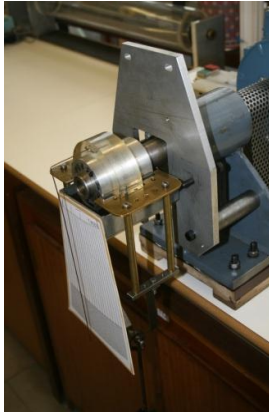


Figure 1: The journal bearing test rig

Figure 2 : An indentation feature

The lubricant used during testing was SAE-75-W90 transmission fluid. Its kinematic viscosity at 40 C° is  $76.1 \text{ mm}^2 \text{ s}^{-1}$  and a density of  $873 \text{ kg/m}^3$  at 15 C°.

Before a new experiment was conducted, the bearing pad and the journal were separated so that any debris produced from previous tests could be removed. After subsequent assembly, the rig was recalibrated; a weight is hung from the pad, which is centralized and allowed to hang freely. It was ensured that the attached pointer to the pad would read 0 degree on the graduated scale (indicating a attitude angle of zero degrees, the line of centres was assumed to be in the vertical direction with no journal rotation).

Density	2.5%Tx
Length x Width	1mm x 1mm
Depth	70 $\mu\text{m}$
Shape	Square
Distribution pattern	Standard Grid

Table 1. Surface Texture specification

A series of loads were tested in order to obtain the worst tribological conditions with the *smooth* journal (highest attitude angle, indicating worst friction). This was intentional, because it was surmised that the effect of surface features would then be easier to discern. These series of tests indicated that a light load of 1.4 kg represented the poorest lubrication condition, with friction torque becoming dominant in the contact condition. Then, Journal speed and quantity of lubricant in the sump was varied, to produce a range of boundary conditions.



Figure 3: Distribution of surface dimples on the journal face

From the attitude angle, it is possible to calculate the eccentricity ratio and in turn obtain friction analytically. The eccentricity ratio gives as an indication of the load carrying capacity of the journal.

Initially, the lubricant volume in the sump was kept constant. The lubricant volume produced the closest relationship with the related theory for a non-textured journal.

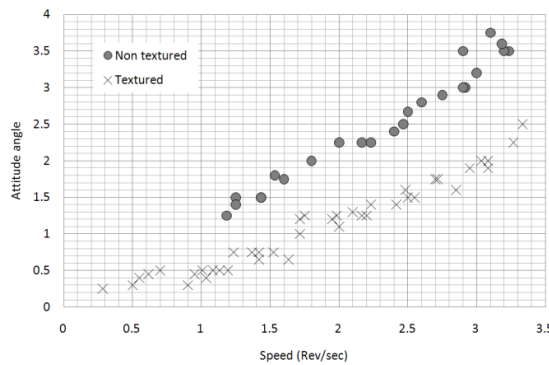


Figure 4: Attitude angle for textured and non textured surfaces at various journal speeds

The speed was increased in the range 0.5-3.5 Rev/s. This range was chosen after performing some initial testing, which showed prevalent starved lubrication conditions. In fact, 0.5 Rev/s was the limiting lowest speed used, where friction was at its maximum value. At speeds exceeding the upper bound of 3.5 Rev/s lubricant splashed out of the sump and resulted in inaccuracies in the results as the maintained constant volume of lubricant in the sump could not be assured.

The results in Figure 4 show that the textured journal produced a reduced attitude angle, a direct indication of reduced friction. The textured surface allowed data to be collected for the full range of speeds, whereas at lower speeds the non-textured journal moved erratically, indicating stick-slip motion due to boundary interactions. Therefore, reliable readings from the graduated scale could not be found in these cases. The introduction of surface texturing, therefore, increased the range of hydrodynamic lubrication in this instance.

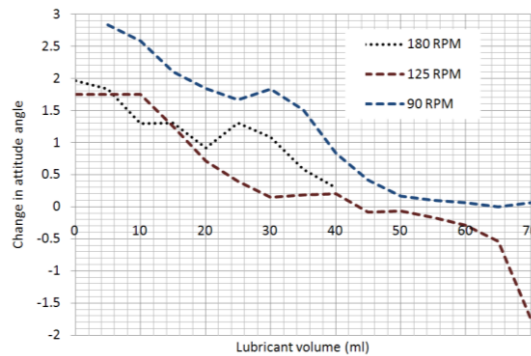


Figure 5: Change in attitude angle from smooth to a textured journal surface

Figure 5 shows the change in attitude angle between the non-textured (smooth) and textured journals. When the volume of lubricant in the sump is relatively low, an interrupted (not coherent) film of lubricant is formed with the smooth journal. Therefore, the regime of lubrication is mixed on the account of starvation. Under such conditions surface textures show the greatest improvement through their lubricant retention as micro-reservoirs. This is true of all the journal speeds shown in

figure 5. As the lubricant volume in the sump increases (a greater depth of journal immersion in the bath of oil) the effect of the surface texture becomes less pronounced. In fact, for flooded conditions the increased gap with textured surface can lead to reduced eccentricity ratio from that of a smooth surface. This is because an increased gap causes side leakage of lubricant from the conjunction.

The change in eccentricity ratio from a smooth to a textured journal was then calculated for the same set of data to investigate the effect of surface texturing on the load carrying capacity.

With starved conditions, caused by low volumes of lubricant in the sump, there is a significant increase in the eccentricity ratio with a textured journal (figure 6). This shows that under starved conditions the reservoir effect helps maintain hydrodynamic lubrication.

As the volume of oil in the sump is further increased, the change in eccentricity becomes negative, meaning reduced load carrying capacity with a surface textured journal. Side leakage (described previously) promotes this side leakage, which reduces the generated contact pressures, thus the load carrying capacity. The change reaches a minimum, and thereafter recovers. This recovery is because the performance of smooth and textured journals become very similar at thicker films, both suffering significant side leakage.

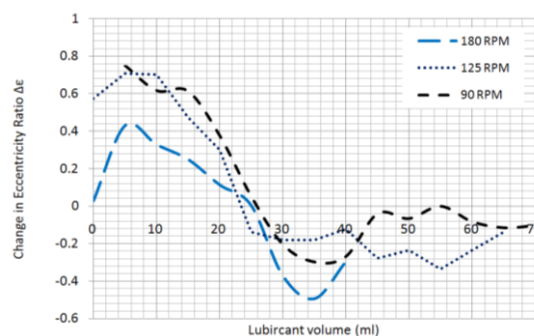


Figure 6: Change in the eccentricity ratio between smooth and textured surfaces

### 3 CONCLUSION

The experiments confirm the findings of others with regard to increase load carrying capacity and reduced friction, particularly at low speeds of entraining motion. With indentations and other forms of concave features there is further improvement due to retention of micro-reservoirs of lubricant. An important additional finding is that surface texturing is only effective for cases of starved or parched lubrication. For flooded inlets their effect is diminished, and in fact can be detrimental in the form of increased oil loss due to side leakage. In some cases, such as piston compression ring conjunction this may lead to undesired effects such as blow-by.

### 4 ACKNOLEDGEMENTS

The authors wish to express their gratitude to the Engineering and Physical Sciences Research Council (EPSRC) for the financial support extended to the Encyclopaedic Program Grant. Thanks are also due to all project partners, especially in this instance to Aston Martin.

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