Numerical evaluation of number of textures in slip-textured lubricated contact

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Abstract. Surface texturing with slip can have a significant effect on the lubrication performance in hydrodynamic bearing. In the present paper, the texture shape consisting of parabola, rectangular, and triangular for partially texture bearing is of particular interest. Number of the texture cells are also varied to obtain the optimal tribological performance in terms of load support and friction force. The slip is located at the leading edge of the contact to achieve the highest performance. The modified Reynolds equation with slip is adopted and discretized using finite volume method. The tridiagonal matrix algorithm is used to solve this equation. The numerical results show that the number of texture cells has a significant effect on the load support as well as the friction force. However, it is also found that there is no texture shape which is superior for all performances. Thus, a particular care must be chosen with respect to the number of textures as well as the texture shapes to obtain the optimal tribological performance. This finding can be used as a guideline to design the bearing with optimal performance.

1. Introduction

For more than a century, with increasing the demand for energy-saving, there has been a growing application of surface texturing due to its good behaviour in enhancing the performances of lubricated tribological pairs. A number of surface texturing researches were carried out by tribologists numerically and experimentally to solve the lubrication problem. Brajdie-Mitidieri et al. [1] used CFD analysis to investigate the friction coefficient of the pocketed pad bearing varying convergence ratios. They found that at high to medium convergence ratios, a suitably positioned pocket in the high pressure region of the bearing reduces the friction coefficient. Tala-Ighil et al. [2] analysed numerically the cylindrical texture shape effect on the performance of a hydrodynamic journal bearing. It was found that an appropriate arrangement of the textured area on the contact surface leads to a significant improvement of the performance. Later, Uddin et al. [3] based on the steady-state Reynolds equation investigated the effect of surface texture shape, geometry and orientation on hydrodynamic lubrication performance. It was found that the performance of the triangle, the chevron and the ellipse was significantly affected by their orientation with respect to the sliding direction.

In recent years, in addition to surface texturing, there is also a growing interest in creating the lubricated contact with boundary slip which is induced by (super)hydrophobic coating. In several cases, this hydrophobic coating is combined with the texturing to obtain more positive effect of the lubrication performance. It has been proven that partially slip-textured parallel slider bearing has a
potential to generate load support and reduce coefficient of friction [4-7]. Tauviqirrahman et al. [6] confirmed that introducing the boundary slip at the leading edge of the textured contact was more efficient than extending the slip to the textured region with respect to the load support and friction force. Susilowati et al. [7] evaluated the effect of gap ratio of the lubricated contact on the performance of slip-textured bearing. Based on modified Reynolds equation, they concluded that the gap ratio appears to contribute to the generated friction force and the volume flow rate more than the boundary slip. In recent lubrication, in more detail work, Muchammad et al. [8] analytically developed new lubrication model based on first order Reynolds theory to study the texturing parameters as well as the slip parameter of lubricated contacts. Main interesting result was that adding slip over the whole surface could retard the presence of cavitation.

Extending the previous work of the authors in [6], the main objective of this paper is to investigate the effect of number of texture cells on the performance of the slip-textured contact in which the slip is located at the leading edge of the contact. Modified Reynolds equation considering cavitation is used to solve this case based on the finite volume method. The load support as well as the friction force as indicator of the lubrication performance of the slip-texture contact is of particular interest varying the texture shapes. The results may provide a more realistic guideline of the actual surface texture alternative in bearing.

2. Methodology
It is known that the rectangular is the most common shape of texture used in modeling the slider bearing. However, other texture shapes can also be used to represent the texturing technique. In the present study, the numerical analysis for the case of the multiple textured pattern (Fig. 1) varying texture shapes is carried out pointing out the effect of the number of texture cells on the lubrication performance.

![Figure 1. Multiple texture pattern with the slip at the leading edge of the contact and with three different shape textures cell (not a scale)](image)

In the present work, the shape considered here is triangular, rectangular, and parabola as seen in Figure 1. For all following computations, the parameters used with respect to the slip-textured characteristics as well as their operating conditions are described in detail in Table 1. The bearing configuration studied here as reflected in Fig. 1 is multiple textured contact which consists of number of texture cells with slip introduced at the leading edge of the contact for improved load support [6]. In this work, the number of texture cells varying texture shapes is of particular interest. For all following
computations, the texture density is set to 0.5, while for texture aspect ratio is 400. It is also assumed that the exit length is constant. In the present study, the Reynolds cavitation model is adopted.

Table 1. Multiple textured bearing configuration

| Parameter                      | Value               |
|--------------------------------|---------------------|
| Bearing length                 | B = 0.02 m          |
| Inlet length                   | a = 0.0004 m (a/B = 0.02) |
| Pocket length                  | b = 0.006 m (b/B = 0.3) |
| Sliding velocity               | U = 1 m/s           |
| Viscosity                      | η = 0.01 Pa s       |
| Atmospheric pressure           | P_{atm} = 100 kPa   |
| Minimum film thickness         | h_{o} = 1 µm        |
| Pocket depth                   | h_{d} = 2.5 µm      |
| Texture cell length            | L_{c} = 1 mm        |
| Dimple length                  | L_{d} = 2 mm        |
| Exit length                    | L_{e} = 0.2*B       |
| Number of texture cells        | n = 2-9             |
| Slip coefficient               | α = 0.02 m^{2}/s/kg |

The model of lubrication presented here is based on the fact that slip at the interface between lubricant and surface will exist. It is worth noting that the slip length model is used to address the modeling of the boundary slip for the hydrodynamic analysis. The lubrication model based on modified Reynolds theory can be described as follows [6]:

\[
\frac{\partial}{\partial x} \left( \frac{h^3}{\eta} \frac{\partial p}{\partial x} \left( 1 + \frac{3\alpha \eta}{h + \alpha \eta} \right) \right) = \frac{\partial}{\partial x} \left( 6Uh \left( 1 + \frac{\alpha \eta}{h + \alpha \eta} \right) \right) \quad (1)
\]

The physical meanings of the symbols in Equation 1 are as follows: \( h \) the film thickness (gap) at location, \( p \) the lubrication film pressure, \( \alpha \) the slip coefficient, and \( \eta \) the lubricant viscosity.

For solving these problems studied here, the modified Reynolds equation (Eq. (1)) is discretized over the flow using the finite volume method, and is solved using tridiagonal matrix algorithm (TDMA). By employing the discretization scheme, the computed domain is divided into a number of control volumes using a grid with uniform mesh size. The grid independency is validated by various numbers of mesh sizes.

3. Results and Discussion

This section presents a detailed investigation of the effect of several geometrical configurations on the hydrodynamic performances (load support, and friction force) of a slip-textured parallel bearing. The most important parameters analysed are the texture cell number and texture shape. Two lubrication performances, i.e. the load support and the friction force are of particular interest. The load support is
defined as the integration of pressure over surface area, whilst the friction force is obtained by integrating the shear stress along the surface area.

### 3.1. Effect of number of texture cells on the load support

Figure 2 presents the effect of the number of texture cells on the load support. It can be observed that there is “increase-then-decrease” characteristic of the load support with increasing the texture cell number. This trend prevails for all texture shapes studied here. It indicates that for each of texture shapes there is an optimal value of texture number. It seems that six texture cells become the optimal value which lead to the highest load support whatever the texture shape.

The numerical results based on Fig. 2 also show that the triangular shape gives the highest load support for all value of the texture numbers. On the other words, either in single texture cell or in multiple texture cells, textured bearing with triangular shape is preferable to other shapes. The interesting finding is that the rectangular shape produces the lowest load support. From the physical point of view, the most possible explanation is that the rectangular shape makes the texture cell receive more lubricant. If the lubricant supply is constant, the rupture film leading to the cavitation effect may present. This leads to the reduced hydrodynamic pressure and thus the lower load support.

![Figure 2](image)

**Figure 2.** Effect of number of texture cell on the load support varying texture shapes

### 3.2. Effect of number of texture cells on the friction force

Figure 3 reflects the correlation between the friction force and the number of texture cells. It can be seen that increasing the texture cell number will reduce the friction force. This trend prevails for all texture shapes studied here. Contrary to the result in terms of load support, the texture shape of rectangular generates the positive lubrication performance in terms of friction force, that is, lowest friction force. It seems that the rectangular shape produces the lowest shear stress profile than the others. Otherwise, the triangular shape leads to highest friction force for values of texture number.

Based on the Figure 3, it is also found that the higher the number of texture cell, the lower friction force. However, it should be noted that the multiple textured pattern studied here is partial texturing,
which means that the number of texture cell cannot be unlimited. There is a range value of texture cell number related to this finding, as indicated in Table 1.

Based on the numerical results mentioned earlier, it seems that from manufacturing point of view, the rectangular shape of texture may be easier to manufacture in real application compared to other shapes. By laser surface texturing, the texture cell can be created in more detail way but with high precision. Regarding with enviromental issue, the use of rectangular shape of texture can be a promising way for saving energy. This is because the resulted friction force in bearing can be minimized so that the life time of the bearing can be longer. As a consequence, the use of resources for manufacturing the bearing can be reduced.

**Figure 3.** Effect of number of texture cell on the load support varying texture shapes

### 4. Conclusion

In the present work, the slip-textured contact varying the number of texture cells with three different shapes (triangular, rectangular, and parabola) was evaluated based on the modified Reynolds equation. The finite volume method combined with tridiagonal matrix algorithm was used to solve the lubrication problem. Based on the numerical analysis presented here, the conclusions can be drawn as follows:

1. The texture shape of rectangular generates the best lubrication performance in terms of friction force.
2. In terms of load support, the triangular shape is recommended to use.
3. A particular care must be chosen with respect to the number of textures as well as the texture shapes to obtain the optimal tribological performance

This findings can be used as guideline to design the textured bearing for achieving the longer life time of the bearing.
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