



Performance Analysis of Mechanical Seal Face Enhanced with Micro Dimples

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ABSTRACT

The last few decades has witnessed an intense study of mechanical seals with modified surfaces to enhance performance and reliability. Studies have shown that some modifications to the surfaces, such as grooves [1], asperities [2] and dimples [3], tend to improve performance of seals by increasing wear resistant ability and load capacity. To this end, laser surface texturing has received significant attention [4].

According to [3,4], significant improvement can be achieved in seals load capacity, wear resistant and friction properties when an array of dimples is applied on one of the surfaces of the seal-ring pairs. The mechanism for this performance enhancement is thought to be the formation of cavitation generated inside the dimples.

Figure 1 shows our laboratory experimental pictures that attest to the formation of cavitation inside dimples when running and its disappearance when the operation is stopped. To examine this phenomenon, the so-called half-Sommerfeld condition and Reynolds boundary condition have been used to understand the nature and predict the performance of cavitation in dimples in previous studies [5, 6]. However, those theories tend to oversimplify the problem and cannot accurately predict cavitation inside a dimple.

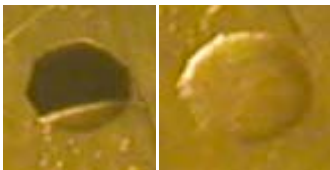


Figure 1. Dimples with cavitation (left) when running and without cavitation (right) when stopped.

In current research, we use the cavitaiton theory proposed by Floberg and Jakobsson[7] and Olsson[8], which is also known as JFO theory. The basic assumption of the theory are 1) in the cavitaited region within the lubrication film, the oil flows in narrow strips, 2) within the cavitaited region the pressure remain constant denoted by P_c , and 3) on the boundary between full and cavitaited oil flow, the pressure gradient is zero. Thus, at the location of film rupture, we have:

$$\frac{\partial P}{\partial n} = 0$$

At the film reformation locus:

$$\frac{h^2}{12\mu} \frac{\partial P}{\partial n} = \frac{V_n}{2} \left(1 - \frac{\rho}{\rho_c}\right)$$

The method we have applied is based on the algorithm proposed by Vijayaraghavan and Keith [9-11]. It incorporates a switching function in the Reynolds equation to automatically separate the full film region from the cavitaited region. The governing equations and related boundary conditions are discretized using the finite difference method and multigrid method is used to increase the convergence speed.

Figure 2 shows the contour plot of a typical dimple pressure distribution obtained using the current method. It clearly shows that a cavitation area exists inside dimple with pressure equal to 0.9×10^5 Pa. The cavitation takes most of the dimple area with highest pressure located in the downstream side of the dimple rim.

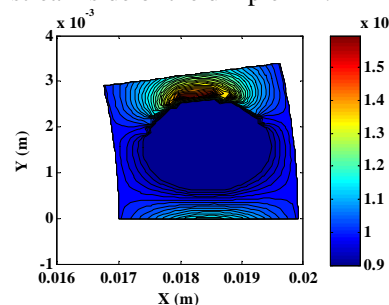


Figure 2. Single dimple pressure distribution.

Work is progress to better understand the nature of load-carrying capacity in the presence of micro dimples. For this purpose, a parametric study is being performed to determine the optimum size and depth of the dimple.

Figure 3 shows the dimple depth and load capacity relationship for different rotation speeds. Except for the 300 rpm curve, all the curves show an upward trend in load capacity with the increase the dimple depth, and the slope of the curve becomes smaller as the dimple depth increases. The 300 rpm curve shows that a maximum load capacity is reached when dimple depth is around $11 \mu\text{m}$. Examination of the other curves reveals a similar trend. The simulations

also reveal that at each rotational speed, there exists a specific dimple depth with which the load capacity is maximum. Results also show that the dimple depth corresponding to the maximum load capacity increases as the rotational speed increases.

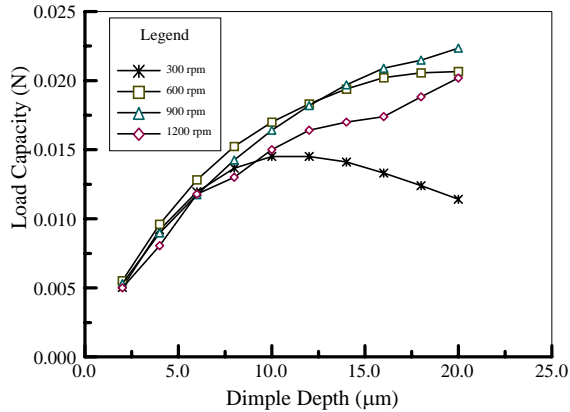


Figure 3. Dimple depth and Load capacity relationship

Figure 4 shows a parametric study for dimple area density with fixed dimple depth and film thickness. Since the dimple is circular in shape, the dimple density cannot exceed 0.79. Three curves in the figure represent three rotational speeds. From this figure, one cannot find an ‘optimized’ dimple density for seal load capacity. The load capacity increases as the dimple density increases. The highest load capacity occurs at the highest dimple density. The load capacities for all speeds are close in magnitude.

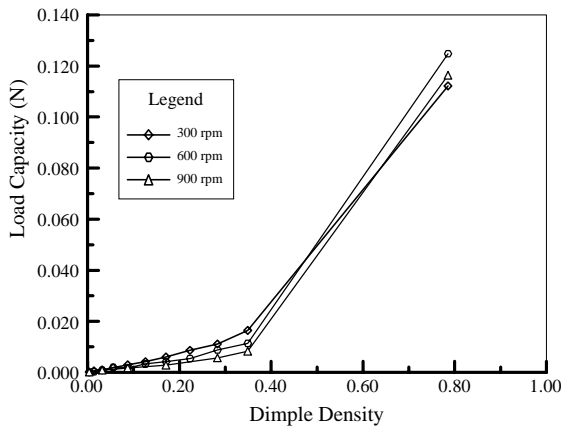


Figure 4. Dimple density and load capacity relationship

Finally, the relationships of oil viscosity and load capacity, film thickness and load capacity, cavitation pressure and load capacity, ambient pressure and load capacity and ambient pressure and leakage are also being analyzed in the current study. These parameters will provide valuable insight for the future implementation of the micro dimple structures in mechanical seals.

ACKNOWLEDGMENTS

The author would like to thank his advisor, Dr. Khonsari, for his constant guidance and support. He also likes to thank all his colleagues in LSU Center for Rotating Machinery (CeRoM).

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