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The Effect on the Friction Forces of Big-End Bearing by the Aerated Lubricant

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Linear and angular movements of many engine components make the lubricant absorb air and the aerated lubricant greatly influences the clearance performance of contacting behaviors of engine components such as big-end bearing, cam and tappet, etc. This study investigates the behaviors of aerated lubricant in the gap between con-rod bearing and journal which is one of the most frictional energy consuming components in the engine. Our assumption for the analysis of aerated lubricant film is that the film formation is influenced by the two major factors. One is the density characteristics of the lubricant due to the volume change of lubricant by absorbing the bubbles and the other is the viscosity characteristics of the lubricant due to the surface tension of the bubble in the lubricant. In our investigation, it is found that these two major factors surprisingly increase the load capacity in certain ranges of bubble sizes and densities. Frictional forces are also influenced by the aerated bubble size and density, which eventually enlarge the shear resistance due the surface tension. Modified Reynolds' equation is developed for the computation of fluid film pressure with the effects of aeration ratio under the dynamic loading condition. From the calculated load capacity by solving modified Reynolds' equation, journal locus is computed with Mobility method at each time step.

Keywords: dynamic loading bearing, aerated lubricant, journal locus, load capacity, friction force

1. INTRODUCTION

Many researches have shown that the aeration is considered undesirable for the lubricating mechanism of engine. This is the reason that when the bubbles collapse under the pressure, the fluid film cannot sustain the load and eventually the film thickness becomes less than otherwise. However, recent research [1] for the ideal case of journal bearing system analytically verifies that the surface tension by the formation of bubble interior of the lubricant increases the apparent viscosity although it decreases the density of the lubricant. Therefore, the load capacity of aerated lubricant is larger than that of pure lubricant under the dynamic loading condition.

The big-end bearing is operated with aerated lubricant due to the splash by the moving components in the engine. What is more, it is operated under the condition of highly fluctuating loads and is imposed by high-pressure gradient between the gap of journal and bearing at a short time interval during the engine cycle. Therefore, it is more severely influenced by the aeration in the big-end bearing system than the steady state condition.

In this work, the journal locus of big-end bearing is analyzed under the dynamic loading condition, because the engine bearing is one of the most severely loaded components in the engine with the aerated lubricant. In our analysis, the pressure gradients of both the radial and width directions are simultaneously considered by solving the modified Reynolds' equation for the aerated lubricant. The ratio of width and diameter of bearing, bubble size and aeration ratio are major input values in the computation of pressure distribution. The dynamic equation for the computation of journal locus is obtained by the Mobility method with the computation of the fluid film pressure over the bearing area by solving the modified Reynolds' equation.

2. MODELING OF AERATED LUBRICANT

The apparent viscosity and density of the aerated lubricant are modeled with the following assumptions. The first assumption is that the aerated air in the lubricant is considered the ideal gas and the other is that the bubbles are evenly distributed without touching others. The shape of the aerating bubbles in the lubricant is shown in Figure 1. The aerated ratio is described as r/d and the whole amount of air in the lubricant is $(400\pi/3)\,(r/d)^3$ [%].

With the assumption of no slip boundary condition at the interface between solid surface and, the shear resistance force is expressed by using the equation from [1]. The proposed density model [2] is related to the surface tension and the viscosity of lubricant, which is also used in this study.

In this work, the viscosity model of the aerated lubricant is considered only for two major effects. The one is the term caused by the aeration volume, which influences the density of the whole lubricant. The other is the term that the shear behavior of pressurized fluid film causes the deformation of each bubble inside of the lubricant, which eventually changes the surface tension of the bubble.

The apparent viscosity is the summation of the variation of viscosity due to the density change as well as the surface tension by the shear behavior.

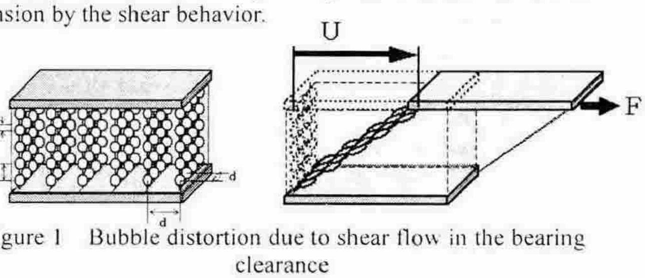

Figure 1 Bubble distortion due to shear flow in the bearing clearance

3. THE COMPUTATION OF FILM PRESSURE AND JOURNAL ORBIT

The journal locus is computed by solving the force equilibrium between applied force and load capacity with the computation of the pressure distribution over the bearing area. For the steep change of pressures near the minimum film thickness region. the dimensionless pressure is transformed into π ($=p^* h^{*3/2}$) term which attenuates the steep variation of fluid film pressure by relating fluid film pressure to the film thickness.

$$\frac{\partial}{\partial\theta}\left(\Gamma\frac{\partial\Pi}{\partial\theta}\right)+\left(\frac{R}{L}\right)^2\frac{\partial}{\partial z^*}\left(\Gamma\frac{\partial\Pi}{\partial z^*}\right)-\frac{3\Pi}{2h^{*3/2}}\left\{\frac{\partial}{\partial\theta}\left(\Gamma h^{*1/2}\frac{\partial h^*}{\partial\theta}\right)\right\}$$
$$=\left(\frac{6\Lambda(\omega_a+\omega_b)}{h^{*3/2}}\right)\frac{\partial}{\partial\theta}\left(\rho^* h^*\right)+\left(\frac{12\Lambda\omega_a}{h^{*1/2}}\right)\frac{\partial\rho^*}{\partial t^*}$$
$$+\left(\frac{12\Lambda\rho^*\omega_a}{h^{*3/2}}\right)\left[\frac{d\varepsilon}{dt^*}\cos\theta+\varepsilon\frac{d(\phi+\psi)}{dt^*}\sin\theta\right] \qquad (1)$$

The load capacity calculated from the pressure distribution is compared with the applied load at every time step of the cycle. Solving the equations of force balances gives the information of the journal traces in the clearance at a certain time step as well as squeezing and rotational velocities ($d\varepsilon/dt$, $d\phi/dt$) of journal for the next time step. This is a marching out problem[3]. which can be easily solved by 4^{th} order Runge-Kutta method. The applied load and load capacity in ε and ϕ directions are described by the following equations:

$$F_\varepsilon = F\cos\phi = -\int_s P\cos\theta\, ds = -W_\varepsilon \qquad (2)$$

$$F_\phi = -F\sin\phi = -\int_s P\sin\theta\, ds = -W_\phi \qquad (3)$$

4. RESULTS

It is found that smaller bubble size provides higher load capacity under the condition of the same amount of air inside of the lubricant as depicted in the Figure 2. This is the reason that smaller bubble size can make larger surface area due to more number of bubbles, which in turn cause higher surface tension forces. Therefore, larger surface tension increases apparent viscosity and the load capacity increases accordingly.

The friction force is also directly influenced by the bubble size, which increases the surface tension and apparent viscosity with more surface area on the bubble. Therefore, under the condition of the same amount of air inside of lubricant, smaller bubble size can make more friction forces as shown Figure 3.

5. CONCLUSION

In this work, we developed the lubrication theory under the dynamic loading condition with the aerated lubricant of which the bubble size is about $1\sim1000\mu m$ and where the total amount of air is below 10% of the volume of lubricant. The pressure distributions over the bearing area are computed by solving the modified Reynolds' equation, which considers the effect of bubble behaviors in the lubricant. For the journal locus, the applied load is compared with the load capacity in terms of Mobility value. From the computed results, we find that aerated lubricant has higher load capacity and frictional force than pure lubricant under the dynamic loading condition. This is the reason that smaller bubble size makes more surface area, which eventually causes larger surface force and apparent viscosity.

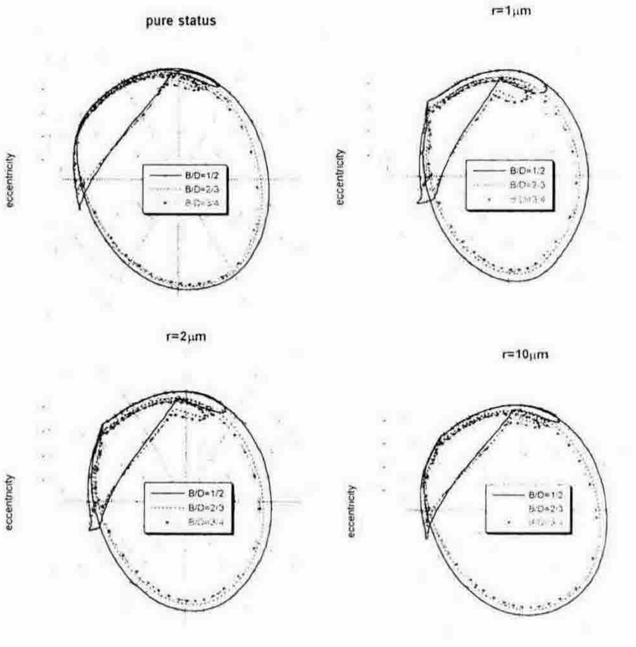

Figure 2 Journal traces for aerated oil with the variations of bubble size and B/D

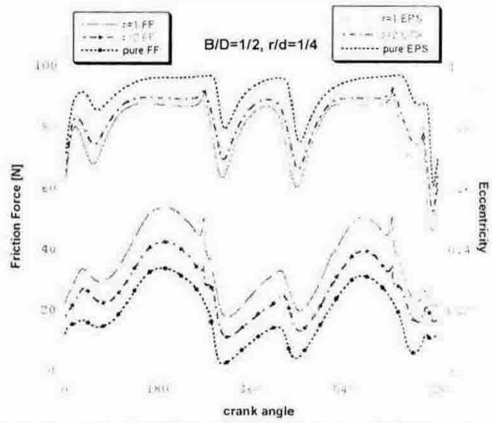

Figure 3 Friction forces according the bubble sizes at r/d=1/4 and B/D=1/2

6. REFERENCES

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7. ACKNOLEGEMENT

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