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# CFD Analysis of Journal Bearing with Oil Supply Groove Considering Two-Phase Flow

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## Abstract

Bearing characteristics of journal bearing vary remarkably from cavitation area but calculation method in detail cavitation area have not proposed. In this study, cavitation area in small-bore journal bearing under flood lubrication and starved lubrication are analyzed with CFD analysis of two-phase flow using VOF (Volume of fluid) method. Moreover, the impact of influence of setting condition of VOF, surface tension, and vapor pressure was studied and analysis results is compared with experiment. As results, the analysis results and the experimental visualization results, the analysis results of VOF of considering the vapor pressure and surface tension agree well with the visualization results both under flooded and starved lubrication conditions. From these results, CFD analysis of two-phase flow of VOF considering the vapor pressure and the surface tension is possible to calculate cavitation area of journal bearing under flood lubrication and starved lubrication.

**Keywords:** journal bearing, CFD analysis, two-phase flow, cavitation, starved lubrication

## 1 Introduction

Bearing characteristics of journal bearing vary remarkably from cavitation area. For example, it is known that the cavitation area of journal bearing under starved lubrication expands, and therefore the stability under starved lubrication increases and while friction torque decreases. The stability characteristics under starved lubrication have been studied theoretically and experimentally by Hashimoto and Ochiai [1]. Moreover, Naruse and Ochiai have reported that the cavitation has a cooling effect of oil film in starved lubrication [2]. The characteristics of temperature and friction under starved lubrication have been conducted experimentally but these findings have not been examined theoretically [3] because calculation method in detailed cavitation area have not been proposed. Generally, Reynolds equation have been used to analyze journal bearing and the simplest method for determining cavitation area is to consider Half-Sommerfeld's condition or Swift and Stieber condition for Reynolds equation [4,5]. However, these method ignore oil film of spreading clearance because the negative pressure area is assumed to be the cavitation area. Coyne and Elrod condition is used as an advanced method than Half-Sommerfeld's and Swift and Stieber condition. Coyne and Elrod have proposed calculation model that assumes the flow of oil film rapture to be two-phase flow by surface tension between oil film and cavitation [6,7]. Coyne and Elrod condition is nearer the practical bearing than the Half-Sommerfeld's and Swift and Stieber condition, however, a calculation of the cavitation area of the entirety in journal bearing is impossible. Therefore, boundary condition models of considering the cavitation have been proposed by many researchers. For example, Ikeuchi and Mori have analyzed the area of oil film and cavitation by modified Reynolds equation [8,9]. The modified Reynolds equation is derived from considering the two-phase flow as averaged one-phase flow of oil and air. However, it is difficult to converge the theoretical model in case of high eccentricity ratio and starvation conditions using the model of Ikeuchi and Mori. Moreover Ikeuchi and Mori did not confirm how well their analysis results are with an actual cavitation area. On the other hand, Boncompine et al. and Hatakenaka et al. have proposed analysis method that assumes the shape of finger type cavitation [10,11]. However, bearing designers is not able to estimate the variation of cavitation area that changes by the supplied amount of oil lubricants. Moreover, a journal bearing have an oil filler port and the bearing characteristics are changed by installation angle of oil filler port [12]. However, the internal flow of oil filler port and bearing clearance is not able to be solved by Reynolds equation. Therefore, a different approach from Reynolds equation is required to analyze the journal bearing including internal flow of oil filler port. The effective approach for analyzing journal bearing including of the internal flow of the oil filler port is conducted in this paper's CFD analysis.

In recent years, two-phase flow CFD analysis with consideration for the vapor pressure and interfacial transport equation have been proposed. VOF (volume of fluid) method has good convergence among others and it is possible to evaluate bearings relatively in shorter time. Moreover, VOF method is competent to be adapted for journal bearing's environments because it has an advantage to analyze slag flow. Up to now, analysis with VOF has been used for studying the characteristics of journal bearing and the analysis results have been reported [13]. However, the surface tension has not been considered, and moreover, analysis result was not compared with experimental visualizations. Multiphase flow of liquid and gas are unable to disregard the influence of surface tension because surface tension has influence in a narrow clearance of journal bearings.

Under these background, in this study, cavitation area in small-bore journal bearing under flood lubrication and starved lubrication are analyzed with VOF method. Moreover the impact of influence of setting condition of surface tension, and vapor are studied and the analysis results were compared with experimental verifications.

## 2 Experimental setup

**Figure 1** shows the geometry of the experimental setup of a journal bearing used in the experiments where its main dimensions are given in **Table 1**. The upper part of test bearing is provided with an oil filler port, which allows supplying lubricating oil from the oil filler port into the bearing clearance. The dimensions of the test bearing is the same as the calculated model, where the bearing diameter $D$, the bearing clearance $C_r$, the bearing wide $L$, the oil filler port diameter $D_g$, the wide diameter ratio $\lambda$, are 25.0mm, 125μm, 14.5mm, 8.2mm, 0.58, respectively. The bearing are made of transparent acryl, which allows observations of the formation of the oil film and the generation of cavitation.

**Figure 2** shows a schematic diagram of the whole experimental test rig. The test rig consists of a rotor installed in its central part and a revolving shaft supported by two bearings on its left-hand and right-hand sides, respectively. The test bearing which is for subjected for visualizations is installed on the right-hand side. The shaft is driven by a DC motor which can vary the number of revolutions continuously up to 10,000 rpm. Eddy-current type proximity probes are placed in the horizontal and vertical into the bearings, which allows measuring the positing of the journal position. An oil tank is placed on the top of the bearing, and the lubricating oil is supplied through a control valve, and leaking oil from the side of bearing is supplied oil tank by the pump. The viscosity grade of lubricant oil is VG22 and the temperature of supplied oil is fixed at 40°C. Application of a blue lubricant oil using xylene makes it possible to visualize the region where cavitation is generated. Control of the amount of lubricating oil supply is measured by the amount of oil leaking out from the bearing ends using the volumetric flow rate method and by manually changing the opening of a control valve. The halogen light is used as the light source of the light of visualization of cavitation area on the surface of the bearing. In the experimental conditions, the number of rotating speed, the volume of fluid under flooded lubrication, and the volume of fluid starved lubrication are 3500rpm, 2.6cm$^3$/s, and 0.5cm$^3$/s, respectively.

## 3 CFD analysis method

In this study, journal bearing is analyzed by ANSYS FLUENT 15.0. Instead of Reynolds equation, Navie-Stokes equation is used to analyze the journal bearing. CFD analysis can analyze the internal flow of oil filler port because the inertia term is considered on the basic equation. Moreover, pressure changes in direction of

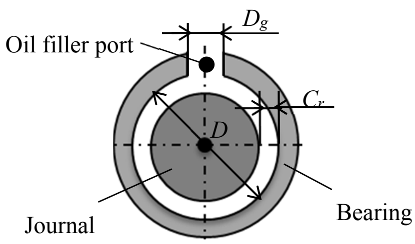



**Figure 1 Geometry of journal bearing**

**Table 1 Specification of bearing**

| | |
|---|---|
| Diameter $D$ [mm] | 25.0 |
| Length $L$ [mm] | 14.5 |
| Clearance $C_r$ [mm] | 0.125 |
| Diameter of oil filler hole $D_g$ [mm] | 8.2 |

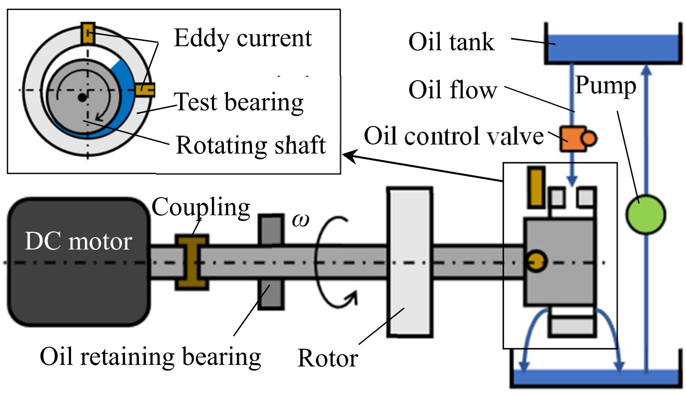



**Figure 2 Geometry of experimental test rig**

bearing clearance can be calculated.

**Figure 3** shows the bearing calculation model on the CFD analysis. The clearance of bearing, oil filler port, and oil supply groove are modeled, and the overall flow in the bearing can be calculate. The calculation model is configured as symmetrical from bearing center. The size of the calculated model is the same as the test bearing while the eccentricity ratio and the attitude angle of journal are determined based on the experimental result.

**Table 2** shows the calculation conditions. In this study, VOF method is used to analyze the journal bearing. In the case of considering of the surface tension, the tension between oil and air are also being considered. The value of surface tension is set to 0.04 N/m. The value is measured using the du noüy method. The model of Brackbill [14] is used as the surface tension model. In the case of considering the vapor pressure, the volume of air of dissolving in oil expands when negative pressure occurs in journal bearing. In this study, the value of vapor pressure is set to zero. The flow of oil is laminar and analysis condition is at steady-state.

# 4 Result

**Figure 4** shows the experimental visualization results of cavitation area. **Fig. 4 (a)** indicates the result of under flooded lubrication, while **fig. 4 (b)** indicates the result of under starved lubrication. The yellow area is the phase of cavitation and air, while the other area is the oil film. From fig. 4(a), In case of under flooded lubrication, the air phase occurs at the area of the side bearing between 0° and 135° and the oil film exists at other area. The air phase is considered to be the atmosphere which regurgitated from the side of bearing by negative pressure. In fig. 4(b), in the case of under starved lubrication, the area of air phase is larger than the bearing under flooded lubrication and the cavitation occurs at the bearing center between 260º and 0º, and the streaky of oil film exists. The cavitation is considered to be the gaseous cavitation which are separated from the oil by negative pressure.

**Figure 5** shows analysis results of volume fraction distribution of oil under flooded lubrication. In this figure, the area of red color means full oil while blue color means full air. **Fig. 5(a)** indicates the results using VOF, **fig. 5(b)**

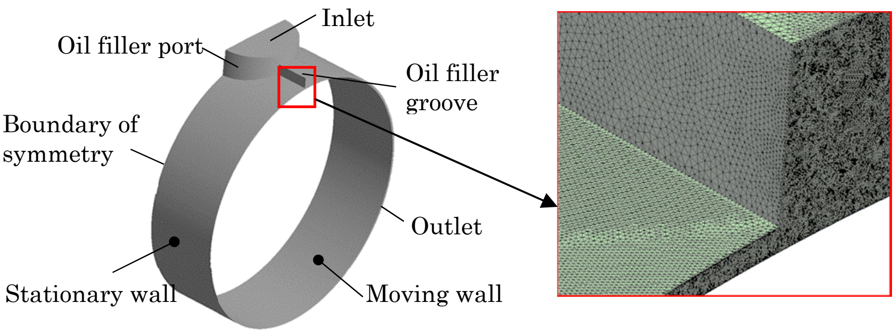
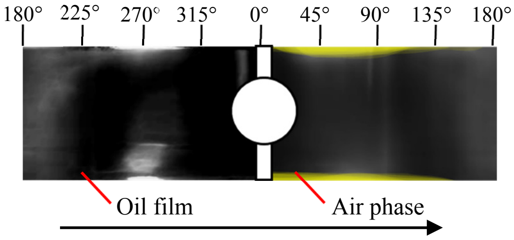


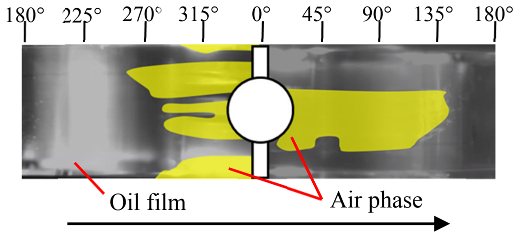

**Figure 3 Calculation model of bearing**

**Table 2 Calculation condition**

| | | | |
|---|---|---|---|
| Multiphase model | | | Volume of fluid |
| Calculation procedure | | | Implicit method |
| Calculation condition | Vaporization pressure $P_v$ [Pa] | | 0 |
| Fluid property | Density $\rho$ [kg/m$^3$] | Oil | 860 |
| | | Air | 1.23 |
| | Viscosity $\mu$ [Pa • s] | Oil | 0.019 |
| | | Air | $1.75\times10^{-5}$ |
| | Surface tension $T$ [N/m] | | 0.04 |




**(a) Flooded lubrication**




**(b) Starved lubrication**

**Figure 4 Visualization result of cavitation zone**

indicates the results of VOF with surface tension. **Figure 5(c)** indicates the results of VOF with vapor pressure, while **fig. 5(d)** indicates the results of VOF with vapor pressure and surface tension. Contour one of volume fraction means full with oil film while zero means full of air phase. The arrow indicate rotating direction while the chain line indicates the minimum clearance and maximum clearance of this analysis. 0° indicates the most upper part of bearing and oil filler port exist at this 0° location. The results of CFD analysis vary between rotating shaft and bearing. In this study, the results of surface rotating shaft are presented.

From fig. 5(a) and fig. 5(b), in the case of using VOF and VOF with surface tension, the volume of fraction of the bearing side decreased between 270° and 135°, and the volume of fraction of the remaining area is one. The range of the decrease of volume of fraction between 270° and 0° increases in the vicinity of oil filler port and the range of the decrease of volume of fraction between 0° and 135° increases in the nearby degree values of 135°. As can be seen from fig. 5(c), in the case of VOF with vapor pressure, the volume of fraction of the bearing side slightly decreases between 300° and 100°. The range of decrease volume of fraction in results of VOF with vapor pressure is smaller compared to the results of using VOF and VOF with surface tension. In fig. 5(d), in the case of VOF with vapor pressure and surface tension, the volume of fraction of the bearing side is slightly decreasing between 300° and 0°. This range of decrease of volume fraction has the same scales as the results of VOF with vapor pressure. On the other hand, the range of the decrease of volume of fraction between 0° and 135° is larger than the results of VOF with vapor pressure which becomes the widest at the position of maximum clearance.

From these results, in the case of using VOF and VOF with surface tension, the air phase occurs at the bearing side. The air phase is considered as the atmospheric pressure which are regurgitated from the bearing side by negative pressure. Moreover, oil film contract to the bearing center by the influence of negative pressure. In the case of VOF with vapor pressure, the range of air phase of the bearing side become smaller because the negative pressure is not generated by the considered vapor pressure. However, in the case of VOF considering the vapor pressure and surface tension, the air phase occurs at the side of bearing of the wedge side. This phenomenon is the impact of the interface of air phase from the bearing side.

**Figure 6** shows the volume of fraction distributions of oil under starved lubrication condition. Analysis result of under starved lubrication condition is different from the result of under flood lubrication where the volume of fraction varied with calculated condition. From fig. 6(a), in the case of VOF, the volume of fraction is 1 between 180° and minimum clearance and the range of the decrease of volume fraction increase for the remaining ranges. The volume of fraction in the wedge side of the bearing decreases compared to the opposite wedge side and increases between bearing center and its side. In fig. 6(b), in the case of VOF considering the surface tension, the range of the decrease of volume of fraction between the minimum clearance and 0° has the same tendency as for the case of VOF. However, the volume of fraction of the wedge of bearing center decreases compared to the case of VOF. In the case of VOF considering the vapor pressure, the volume of fraction of bearing of the opposite wedge side increases and the volume of fraction between 0° and 130° decreases at a greater rate than the case of VOF and VOF considering the surface tension. On the other hand, in the case of VOF considering vapor pressure and surface tension, the range of decrease of volume of fraction between the bearing center and its side increases and the streaky of oil film (a concentrated striped band of oil) exist at the bearing center vicinity. The volume of fraction of the center of bearing between 0° and 120° is zero and this range is the phase of full air. In comparison of the analysis results and the experimental visualization results, the results of VOF with vapor pressure and surface tension is in agreement with the visualization results under the flooded

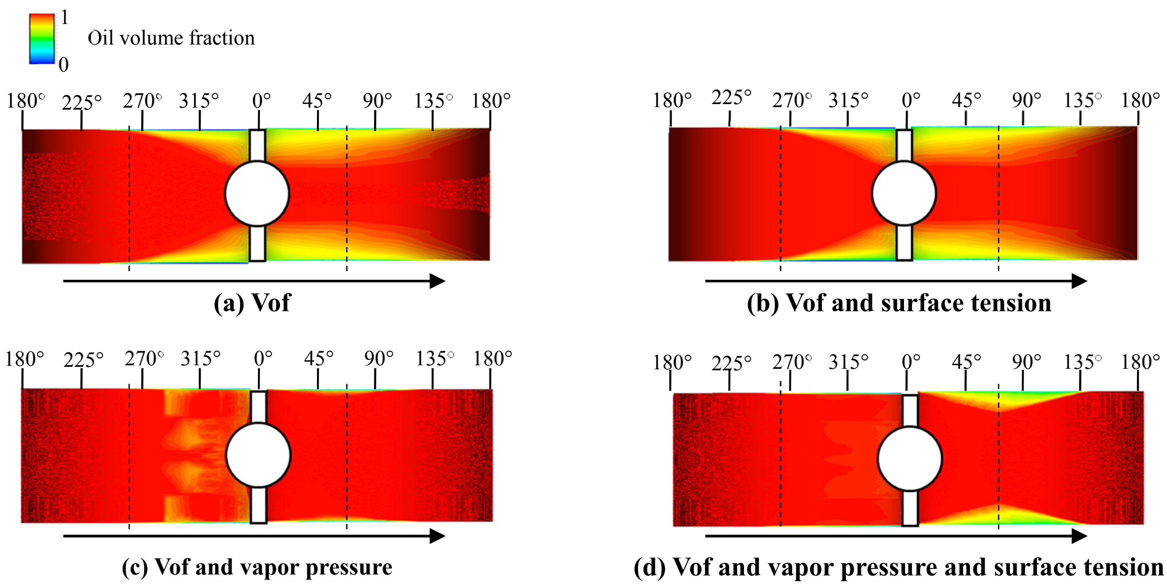
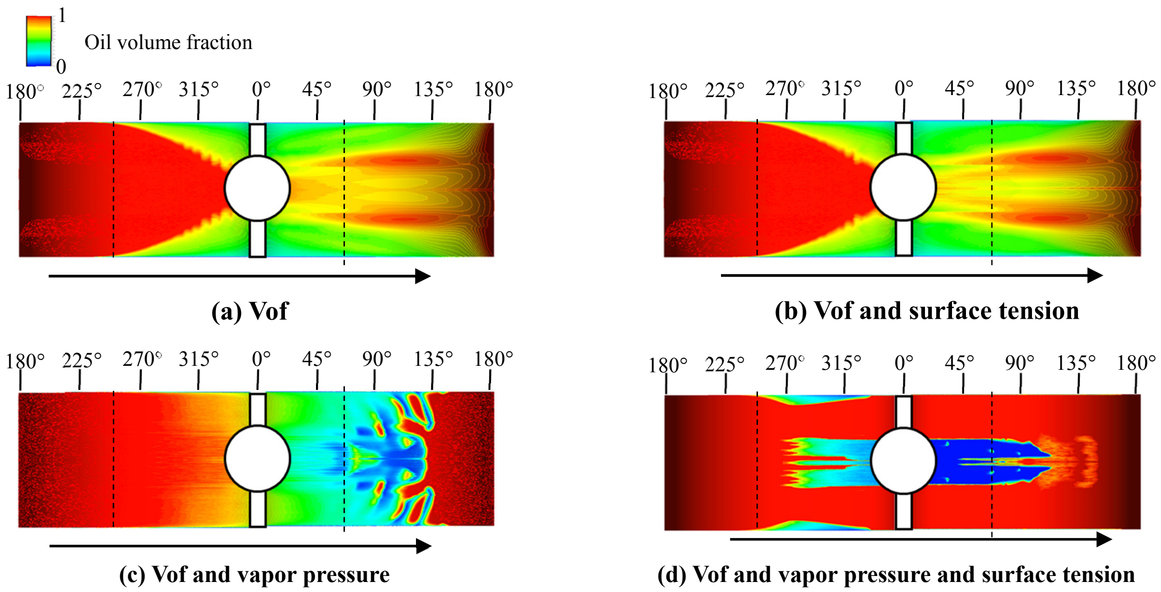



**Fig. 5 Counter of oil volume fraction under flooded lubrication**




(a) Vof

(b) Vof and surface tension

(c) Vof and vapor pressure

(d) Vof and vapor pressure and surface tension

**Fig. 6 Counter of oil volume fraction under starved lubrication**

lubrication and starved lubrication conditions.

## 5 Conclusions

In this study, the area of cavitation on journal bearing was analyzed by a two-phase flow CFD analysis. The effect of vapor pressure, surface tension and wettability on cavitation were studied. Moreover, these analysis results were compared with experimental visualizations. It was found that the two-phase flow CFD analysis considering the vapor pressure, surface tension and wettability is significant to predict the area of cavitation under flood lubrication and starved lubrication conditions.

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