NUMERICAL STUDY ON THE EFFECT OF OIL REMOVAL FROM AERO-ENGINE BEARING CHAMBER AND IMPROVEMENT

Lyu Yaguo, Zhao Jingyu, Liu Zhenxia, Ren Guozhe
School of Power and Energy, Northwestern Polytechnical University, Xi’an, China

ABSTRACT
Effective oil removal from the scavenge is essential to improve the oil distribution in the bearing chamber and avoid excessive heat generation, especially under the high rotation speed. In this paper, based on an simplified bearing chamber, two oil-return structures for scavenge offtakes (ramp sump and eccentricity sump) are designed and improved, the oil-gas two-phase flow model with Volume of Fluid (VOF) is proposed, and characteristics of two-phase flow field and oil-return efficiency from the scavenge are calculated in ANSYS-Fluent version 14.5. The results show that it is effective to maintain the high oil-return efficiency under the high rotation speed by improving oil-return structures, and the oil film accumulation on the bearing chamber wall can also be improved to a certain extent.

INTRODUCTION
In order to keep the high scavenge efficiency under different working conditions, improve the unreasonable accumulation of oil film, and avoid excessive heat generation in the bearing chamber, etc., it is imperative to study and design the oil return structure of scavenge offtake reasonably and efficiently, and besides, this is also one of the latest research directions in the field of oil return in the aero-engine bearing chamber.

According to the structure and position of scavenge offtake in the bearing chamber, the present study focuses on different types of scavenge offtakes: ramp, sump and eccentricity with arc facet, etc., and experiment study is the main research means. Kurz et al. [1-2] designed the ramp scavenge offtakes, and studied the ratio of oil-gas in the vent/scavenge offtakes and the film thickness of oil accumulation on the bearing chamber wall. Chandra et al. [3-4] designed the sump scavenges of different depths without changing the arc wall, then they selected water as the working medium instead of lubricating oil, and studied the characteristics of residence volume and film thickness for several sump structures under different working conditions.

Numerical simulation has the incomparable advantage over experiment study, and is gradually applied in the study on the oil return performance of scavenge offtake in the bearing chamber. VOF (Volume of Fluid) method is widely adopted currently, which can accurately simulate the oil-gas flow in the vicinity of scavenge offtake, especially for the capture of oil-gas interface. Alexandre et al. [5] establish unsteady oil-gas two-phase calculation model based on the adaptive grid technique and VOF method, and studied the oil-gas movement and oil distribution in the initial stages. Moreover, Adeniyi et al. [6] also employed VOF method to carry out the study of unsteady oil film distribution and heat transfer in the bearing chamber of eccentricity offtake with arc facet.

The aim of the present work is to figure out and compare the oil return performances of different designed scavenge offtakes.

NUMERICAL MODEL
In this study, CLSVOF (coupled level set and Volume of Fluid) method is adopted to calculate oil-gas two-way coupling flow and the oil return performance. Considering the characteristics of oil-gas two-phase flow in the bearing chamber, two assumptions are made as follows: 1) the lubricating oil phase is Newtonian fluid and incompressible; 2) the oil and air are immiscible.
CLSVOF method is an interface tracking method combining the advantages of Level-Set and VOF methods: on the one hand, the mass nonconservation of Level-Set method in the solving process is overcome; on the other hand, the deficiency of discontinuous interface and computational instability using VOF method are also resolved.

Control equations:

\[ \frac{\partial \rho(\Phi)}{\partial t} + \nabla \cdot (\rho \mathbf{U}(\Phi)) = 0 \]  
(1)

\[ \frac{\partial \left( \rho(\Phi) \mathbf{U} \right)}{\partial t} + \nabla \cdot \left( \rho(\Phi) \mathbf{U} \mathbf{U} \right) = -\nabla p + \rho(\Phi) g \]  
(2)

\[ \frac{\partial \left( \rho(\Phi) E \right)}{\partial t} + \nabla \cdot \left( \left( \rho(\Phi) E + p \right) \mathbf{U} \right) = -\nabla \cdot \left( \mathbf{k}_{eff} \nabla T \right) + S_h \]  
(3)

Where, \( p \), \( g \), \( E \), \( k_{eff} \) and \( S_h \) stand for pressure, gravity, the internal energy, effective thermal conductivity, and the source term. \( F_\sigma \) is surface force, and CSF (continuum surface force) model is adopted in this paper [7]:

\[ F_\sigma = \sigma \kappa \delta(\Phi) \nabla \Phi \]  
(4)

\[ \delta(\Phi) = \begin{cases} 
\frac{1 + \cos(\pi \Phi/a)}{2a}, & |\Phi| \leq a \\
0, & \text{Otherwise}
\end{cases} \]  
(5)

CONFIGURATION OF OIL RETURN STRUCTURES

In this study, a typical bearing chamber configuration from Karlsruhe Institute of Technology (KIT) [8] is selected as the baseline structure (Baseline). Figure 1 shows the simplified computational domain of baseline, and the main dimensions are defined as follows: the radius of rotating shaft (\( r_{sh} \)) is 62 mm, the height of bearing chamber (h) is 28 mm, and the diameters of vent port and scavenge offtakes are both 17 mm, the heights are both 40 mm.

According to the current literature and the rationality of numerical simulation, oil return structures of ramp sump and eccentricity sump offtakes are designed in this paper, as shown in Figure 2. It is noted that the circumferential angle \( \theta \) is defined as follows: the angles of scavenge and vent offtakes are 0° and 180° separately, and the rotation direction of main shaft is clockwise.

RESULTS AND DISCUSSION

Figure 5 shows oil distribution results of fluctuation stability state under different rotation speeds (4kr/min and 8kr/min), and the dotted lines indicate the movement trend of oil film.
Overall, the oil accumulation morphology on the chamber wall is basically formed, and film fluctuations occur, which is mainly caused by two factors below: one is the impingement between wall film and lubricating oil thrown from the bearing, and the other is the interaction of air shear force and inertia force acting on the oil. Meanwhile, the rotation speed difference is compared. At the lower rotation speed (4kr/min), oil recirculation is formed within the range of 0°-90°, and oil stripping from the chamber wall occurs within the range of 90°-180°. However, oil recirculation and stripping are gradually disappeared with the increasing of rotation speed, and the lubricating oil also has good adherence effect on the wall. This is because the directions of shear force and gravity force components are opposite along the wall. At low rotation speeds, the interaction of two forces results in poor oil adherence, but with the increasing of rotation speed, the effect of air shear force increases, and the ability of overcoming gravity force is correspondingly enhanced, which is beneficial to control the oil adherence and movement on the wall. It should be noted that the formed oil recirculation zone and stripping at low speeds is not conductive to the cycle of lubricating oil and the heat transfer of bearing chamber.

Fig. 3 Oil distribution of baseline bearing chamber

In order to evaluate the oil return effect quantitatively, scavenge efficiency ($\eta_{sc}$) is introduced, which refers to the ratio of discharged oil from scavenge offtake ($V_{l,sc}$) and the total discharged oil flux from two offtakes ($V_{l,in}$), expressed as:

$$\eta_{sc} = \frac{\dot{V}_{l,sc}}{\dot{V}_{l,sc} + \dot{V}_{l,vt}}$$

Where, $V_{l,sc}$ and $V_{l,vt}$ stand for the discharged oil flux from scavenge and vent offtakes respectively. $V_{l,in}$ is the total oil flux. In this paper, the discharged oil flux is obtained by integration, expressed as:

$$\dot{V} = \frac{1}{T} \int_{t}^{t+T} \dot{m} dt$$

Fig. 4 Scavenge efficiency variation with rotation speeds
Figure 4 shows the scavenge efficiency variation of three structures with rotation speeds. The scavenge efficiency all decreases with the increasing of rotation speed, but combined with the results of baseline structure, the results of the other two oil return structures are bigger at high rotation speeds (n>8kr/min), such as at 14kr/min, 42% for baseline, 67% for ramp, and 77% for eccentricity. This means that the design of ramp and eccentricity sump structures can improve the scavenge efficiency to some extent, especially at high rotation speeds. And combined with the other two oil return structures, scavenge efficiencies are all more than 70% under different rotation speeds, which means that the design of eccentricity sump offtake newly proposed in this paper is best in three types of oil return structures.

CONCLUSION

Two different oil return structures (ramp sump and eccentricity sump offtakes) are designed and improved, and oil return characteristics for different scavenge offtakes are analyzed. For three different oil return structures, the scavenge efficiency all decreases with the increasing of rotation speed. Moreover, both the designs of ramp and eccentricity sump structures can suppress the problem of the rapid decline of scavenge efficiency at high rotation speeds to some extent. Especially, the design of eccentricity sump offtake newly proposed in this paper is best in three types of oil return structures.

FUNDING

The work has been supported by the Project Supported by Natural Science Basic Research Plan in Shaanxi Province of China, contact 2015JQ5194, and the Fundamental Research Funds for the Central Universities, contact 3102015ZY090.

REFERENCES


Keywords: bearing chamber; oil/gas two-phase flow; scavenge efficiency; eccentricity sump offtake; volume of fluid