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ANALYSIS OF OIL - GAS INTERACTION IN THE AERO-ENGINE BEARING CHAMBER

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ABSTRACT

Flow field calculation of oil-gas two-phase is the basis of the heat and mass transfer study in the aero-engine bearing chamber. In order to analyze the oil-gas interaction in two-phase flow field, the oil /air two-way coupled numerical model is proposed in this paper, the distributions of vortex, velocity and turbulence kinetic energy in a simplified bearing chamber are calculated, and the comparison between two-way and one-way coupled calculation results is carried out. Results show that the addition of oil has a great influence on the two-phase flow field, the mainstream difference between two-way and one-way coupled calculation is at least 10%, and therefore the effect of oil droplets to air flow cannot be ignored in the calculation of two-phase flow. Furthermore, the flow vortex and turbulence kinetic energy will also change with the effect of oil droplets.

INTRODUCTION

Failures such as oil coking and oil fire in the bearing chamber have been one of key factors restricting the development of domestic and overseas advanced aero-engine. Therefore, studies on oil-gas two-phase flow and heat transfer in bearing chambers are of great significance in the development of future high performance aero-engine[1]. To be specific, these studies focus on two major aspects. The first aspect mainly puts emphasis on the oil-gas two-phase flow, including the movement of oil droplets in bearing chambers and the droplet size distribution in different working conditions, etc. The second aspect is research of the oil droplet impingement characteristics, which contains physical phenomena of impact and changes in motion before and after the impact, etc.

In the aspect of oil-gas two-phase flow in the bearing chamber: Glahn et al. [2-4] carried out a series of experiments on droplet generation mechanism and size distribution, and obtained the distributions of oil droplet velocity and diameter released from a rotating cylinder; In the aspect of the oil droplet impingement characteristics: Mundo et al. [5] conducted the experimental study of single droplet impingement characteristics on the liquid film surface, and proposed criteria of splash, spread, etc. utilizing high-speed photography, etc. Farrell et al. [6] and Chengxin Bai et al. [7] established impingement calculation models of various phenomena which contain adhesion, rebound, spread and splash based on experimental results.

In this paper, the oil /air two-way coupled numerical model was established. The oil/gas two-phase flow field is calculated, and the comparison between two-way and one-way coupled calculation results is carried out.

NUMERICAL MODEL

Two-way coupling calculation of the air field and oil droplet motion that is solved by using Lagrange method is adopted, as shown in Fig.1. The oil droplet (the dispersed phase) motion will be influenced by that of the continuous one (air flow) and vice versa via displacement and interphase momentum, mass and heat transfer effects.

Air Flow model

Two-way coupling calculation of the air field and oil droplet motion is adopted here. The governing equations of the airflow can be written in the general format as follows:

$$\frac{\partial(\rho\phi)}{\partial t}+div(\rho\boldsymbol{U}_a-\Gamma_\phi\,\mathrm{grad}\,\phi)=S_\phi \tag{1}$$

Where ϕ represents each of 1, air velocity components and air temperature. Γ is the effective exchange coefficient for the dependent variable ϕ . S_ϕ is the source term of the general equation.

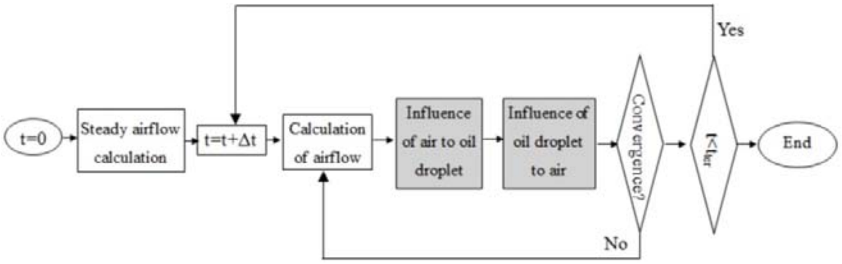

Fig.1 Calculation of two-way coupling model of oil and air

Particle phase model

The droplets are modeled as rigid spheres with a low droplet loading in the chamber, and the oil droplets neither coalesce nor break up. Considering the oil droplet diameter size which ranges from 14 to 500μm in the bearing chamber and working conditions of oil droplets, the viscosity drag is considered as the dominant force on the droplet, while the pressure gradient force, the added mass force, Basset acceleration force, Magnus force, Saffman force, and buoyancy can be ignored [8], so individual particle movement can be calculated according to the Newton's second law:

$$\frac{d\boldsymbol{U}_d}{dt}=-\frac{3\mu C_D Re_d}{4\rho_d D_d^2}(\boldsymbol{U}_d-\boldsymbol{U}_a)+\boldsymbol{g} \tag{2}$$

Where ρ_d, D_d and μ stand for the oil droplet density, diameter and viscosity respectively, Re_d is relative Reynolds number which represents the ratio of inertia force and viscous force when the air flow moves around the oil droplet, C_D is the viscosity drag coefficient.

Considering the integrity of the impact object, the comprehensiveness of the impact phenomenon and the working condition of the bearing chamber, the model adopted here is developed by Chengxin Bai[7].

CONFIGURATION OF BEARING CHAMBER

Bearing Chamber 2 from the literature [9] is simplified to obtain the computational domain, as shown in Fig.2. The main dimensions of the computational domain are as follows: the diameter of rotating shaft is 128mm, the height of bearing chamber is 10mm, the width is 15mm, and the diameters of vent port and scavenge port are both 10mm, the heights are both 40mm.

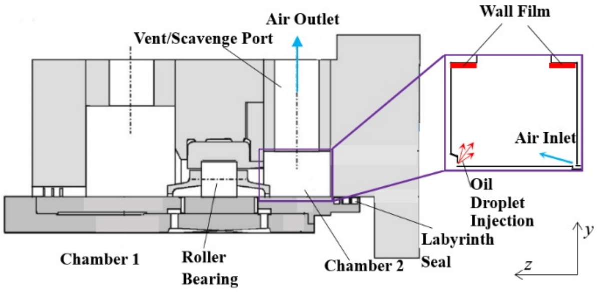

Fig.2 Schematic of typical bearing chamber

RESULTS AND DISCUSSION

Considering the experimental data was obtained from the middle section (normal to *Z* axis) of the bearing chamber wall, so the data in this paper was also taken from the middle section of the chamber wall. By the way, the definition of the circumferential angle θ increases in the direction of the rotating shaft which is also consistent with the literature, just as shown in Fig. 3.

Particle tracks

Fig.3 shows the computed particle tracks of the released oil droplets in initial stage when the rotation speed is 8000 r/min, and the oil flow is 100 L/h. At this moment, the oil film has not been formed. As can be seen from the figure: After oil droplets impact with the wall, the oil droplet splash and secondary oil droplet generation occurred; And before the oil droplets impact with the wall, the trajectories of the majority of oil droplets have little difference compared with initial velocity, only a very few oil droplets (shown in blue trajectories) move irregularly in the bearing chamber, and fly out through the vent and scavenge port. This is because the sizes of the majority of oil droplets are relatively bigger, so the effect of air to oil droplets is very little, which can be neglected; while the other part of oil droplets are relatively smaller (including splash of secondary oil droplets), which are affected by the air field significantly.

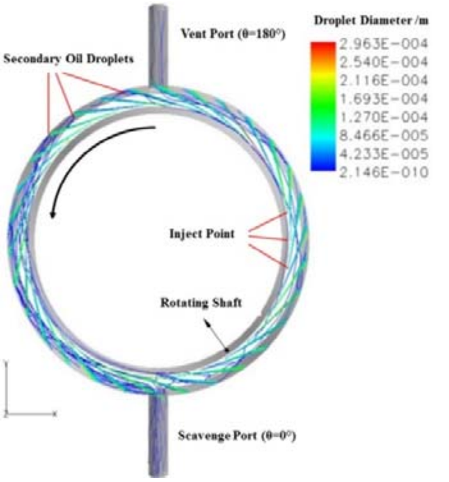

Fig.3 Particle tracks of oil droplets (8000r/min, 100L/h)

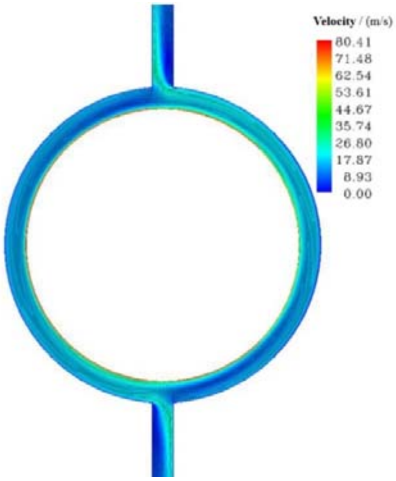

Fig.4 Contours of air velocity

Effect of oil droplets to velocity distribution

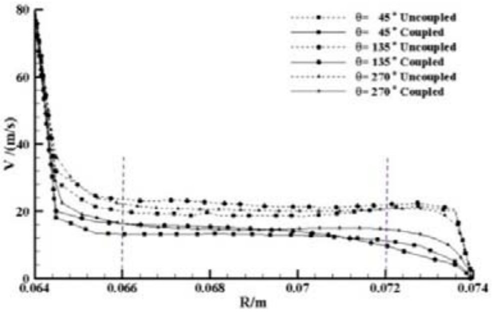

Fig.5 Radial distribution of air velocity

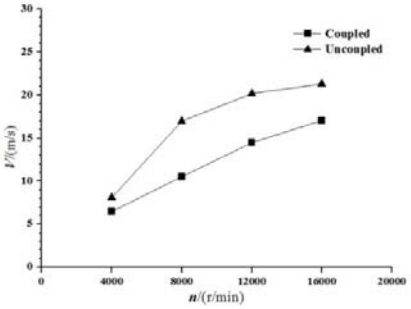

Fig.6 Air velocity of core area at different rotation speeds

Fig.4 shows the contours of air velocity computed by two-way coupling model in the middle section of the chamber when the rotation speed is 12000 r/min, and the oil flow is 100 L/h. And to analyze differences between the two kinds of calculation models quantitatively, the air velocities at different circumferential angles (45 °, 135 ° and 270 °) on a cross-sectional view were compared along a radial distribution, as shown in Fig.5. In the figure, R = 0.074m is at the bearing chamber wall, while R = 0.064m is at the shaft wall.

Analysis of three circumferential orientation calculation results, it can be seen: (1) Velocity in a radial direction can be roughly divided into three zones: R = 0.064 ~ 0.066m zone contains a shaft wall boundary layer, and the velocity decreases from rotation velocity of shaft; R = 0.066 ~ 0.072m zone is mainstream area, the changes of velocity in this region is relatively small, so the velocity in the middle of this region is chosen to represent the velocity of this zone in the following analysis; while R = 0.072 ~ 0.074m zone contains the bearing chamber wall boundary layer, and the velocity decreases to zero rapidly. (2) Comparing the one-way and two-way coupling calculations shows that the trend of two calculation results is similar, but the two-way coupling calculation velocity is significantly lower in each point, and two-way coupling calculation results of core flow area are about 30% smaller than the results of one-way method, which means that the effect of oil droplets to air flow cannot be ignored in the calculation of two-phase flow.

Further, the flow velocities of mainstream area at different speed conditions are analyzed, as shown in Fig.6, and the circumferential Angle is 270 °. It can be seen from the figure, the flow velocity of mainstream area shows the trend of increasing with the increasing of shaft speed, and the results of two-way coupling is at least 10% smaller than that of one-way coupling. Wherein n=8000r/min, the velocity difference is 38% to the maximum.

CONCLUSION

Based on one-way coupling of air/oil in bearing chamber, interaction between oil drops and air in chamber is analyzed systematically and the two-way coupling calculation model is built. Results show that the flow velocity of air and turbulent kinetic energy are affected greatly by the motion and evaporation of oil drops. Particularly, airflow speed of mainstream area in chamber decreases by at least 10%, and therefore the effect of oil droplets to air flow cannot be ignored in the calculation of two-phase flow.

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