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Numerical analysis of plain journal bearing under hydrodynamic lubrication by water

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ABSTRACT

The article aims to provide references for designing water-lubricated plain journal bearings. Considering the differences between the physical properties of the water and of the oil, the effects of eccentricity ratio on pressure distribution of water film are analyzed by computational fluid dynamics (CFD). Then numerical analysis of journal bearings with different dimensions is undertaken under different rotational speeds. Based on the analysis, a reference is produced for selecting the initial diameter dimension which is used to design an efficient water-lubricated plain bearing under the given load and rotational speed. At last, the reference is verified by an experimental case.

1. Introduction

Saving energy and reducing the amount of pollution released to the environment have increasingly become the most concerned issues in machine design [1]. Water-lubrication becomes a tendency for its convenience, green, safe and energy saving. The application of water-lubricated journal bearings is widespread, such as shipbuilding, industrial machinery and equipment, transportation industry, food industry, and pharmaceutical industry [2–4]. So far, studies of water-lubrication are mainly about tribology behavior of sliding surfaces of cermet or polymer in water, only a few of them involve bearing performances including load carrying capacity and friction performances [5–8].

The disadvantage of water as a lubricant is that its viscosity is much lower than that of oil and grease [9]. It contributes to low hydrodynamic load carrying capacity of a water-lubricated plain bearing. Little research has been made to improve hydrodynamic load carrying capacity of plain journal bearings. Most of the researchers were greatly interested in investigating the theories and experiments of hydrodynamic lubrication and paid no attention to how to improve hydrodynamic load carrying capacity of a journal bearing. Sivak and Sivak [10] obtained a numerical solution of the Reynolds equation by the modified Ritz method and Sfyris and Chasalevris [11] achieved a path of obtaining the exact analytical solution of the Reynolds equation for the lubrication of journal bearings with finite length. Kingsbury [12] determined the pressure distribution by means of an experimental electrical analogy and Christopherson [13] determined the pressure distribution by utilizing the mathematical model of “relaxation”. Tayal et al. [14] investigated the effect of nonlinearity on the performance of journal bearings with finite width by using the finite element method.

There are two modeling approaches for hydrodynamic flow issue. On one hand, there are some models based on the Reynolds equation [15–17]. On the other hand, there are models based on the Navier–Stokes system of equations [18–20]. Recently, with the rapid development of computer technology and hardware, many researchers used commercial computational fluid dynamics (CFD) programs in their investigations [21–23]. Computer programs by CFD provide a useful design service but are generally time consuming and not every designer has access to them. Thus it is necessary to draw on the results from such programs in order to develop the reference for designing plain bearings, which cover a wide range of plain bearing geometries and operating conditions [24]. The CFD package, FLUENT, is a suitable software for numerical simulating and analyzing the flow problem.

Generally, the design procedure of plain journal bearings starts with selecting the bearing dimensions, such as journal diameter (D), bearing length (L) and radial clearance (C). At first, the designer is more interested in load carrying capacity (W) of plain bearing which mainly depends on the basic dimension, namely journal diameter (D). However, there is no design reference for selecting an initial diameter dimension of a water-lubricated plain journal bearing under hydrodynamic lubrication.

One important design decision is the selection of length over diameter ratio (L/D). It is obvious that a long bearing has a higher load capacity in comparison to a shorter bearing. However,a long bearing increases the risk of bearing failure due to misalignment errors. In addition, a long bearing reduces the amount

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Nomenclature

C	radial clearance of bearing
D	diameter of journal
e	eccentricity of journal
F_{cond}	condensation coefficient
F_{evap}	evaporation coefficient
h_{min}	minimum film thickness
I	unit tensor
ε	eccentricity ratio
L	bearing width
N	rotational speed of journal
P	static pressure
p	local far-field pressure
p_b	bubble surface pressure
R_B	bearing radius
R_J	journal radius
R_b	bubble radius
R_e,R_c	mass transfer source terms connected to the growth and collapse of the vapor bubbles, respectively
t	time
W	load carrying capacity
ρ	fluid density
ρ_l	liquid density
ρ_v	vapor density
ε	eccentricity ratio
μ	fluid viscosity
ϕ	attitude angle of the journal
θ	angular coordinate
$\overrightarrow{v}$	fluid velocity vector
$\overline{\overline{\tau}}$	stress tensor
a_v	vapor volume fraction
a_{nue}	nucleation site volume fraction
v_v	vapor phase velocity
σ	liquid surface tension coefficient

of fluid circulating in the bearing, which results in a higher peak temperature inside the lubrication film and the bearing surface. A general rule-of-thumb is that the length over diameter ratio (L/D) should be between 0.5 and 1.5 [25]. Short bearings (L/D between 0.5 and 0.7) are recommended for designing the conventional oil and grease lubricated bearings. As mentioned, the limitation of replacing oil and grease by water is its low viscosity. In order to improve load capacity of water-lubricated plain bearing, length over diameter ratio (L/D) should be higher than that of the conventional oil and grease-lubricated bearings. In present work, L/D is fixed to 1.0 for researching the performance of water-lubricated plain bearing.

Radial clearance (C) is an important design parameter for determining the load carrying capability of plain bearing. Smaller clearances generate higher load carrying capacity of a bearing for the same operating conditions. However, misalignment, solid contaminants and roughness of the bearing surfaces pose some limitations on minimizing radial clearance (C). Experience over the years has resulted in a guide for most designers that radial clearance (C) for a bearing is taken as one thousandth of journal radius [26]. In this work, the performances of water-lubricated plain bearings are studied under the radial clearance of one thousandth of the journal radius.

Except for journal diameter (D), bearing length (L) and radial clearance (C), eccentricity ratio (ε) plays an important role in load carrying capacity of plain journal bearing. In order to study the reference for designing water-lubricated plain journal bearing, the paper investigates the relationship between eccentricity ratio (ε) and distribution of pressure produced by hydrodynamic lubrication.

In the present research three-dimensional CFD models are developed, using the FLUENT package, to investigate hydrodynamic performances of water-lubricated plain journal bearings. Then a reference is produced for selecting the initial diameter dimension which is used to design an efficient water-lubricated plain bearing under hydrodynamic lubrication.

2. Plain journal bearing model

Fig. 1 shows the coordinate and the schematic of a simple plain journal bearing in a steady-state configuration. The plain journal bearing is submersed in water. The hydrodynamic action generates dynamic pressure in water, primarily in the convergent part of the journal-bearing gap, to counteract the load thereby separating the journal surface from the bearing surface with a thin lubricant film. The hydrodynamic pressure eventually terminates in the divergent part of the gap, where the pressure might fall below the vapor pressure of water, and cavitation occurs. When steady state is reached, the journal is displaced from the bearing with a center distance (e), which is referred to the journal eccentricity. The eccentricity ratio (ε) and the radial clearance (C) are important measures of the load carrying capacity of the bearing. They also provide the measure of the thickness of the lubricant film which separates the journal and the bearing.

3. Theoretical considerations

3.1. Governing equation

For all flows, FLUENT solves conservation equations for mass and momentum [27]. For flows involving heat transfer or compressibility, an additional equation for energy conservation is solved. For flows involving species mixing or reactions, a species conservation equation is solved, or, if the non-premixed combustion model is used, conservation equations for the mixture fraction and its variance are solved. Additional transport equations are also solved when the flow is turbulent. In the present work, the conservation equations for laminar flow and cavitation model are presented based on the above assumptions.

3.1.1. Mass conservation equation

The equation for conservation of mass, or the continuity equation, can be written as

$$\frac{\partial \rho}{\partial t}+\nabla(\rho \overrightarrow{v})=0 \tag{1}$$

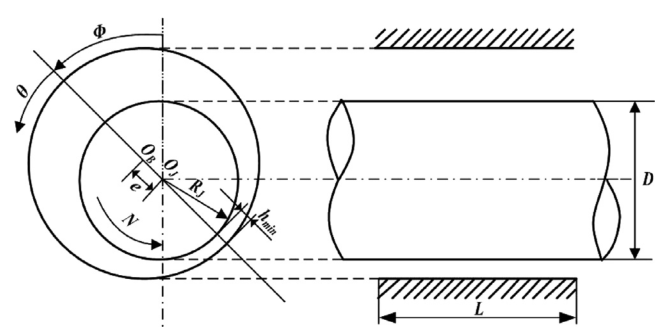

Fig. 1. Definition of the coordinate and the schematic of a simple plain journal bearing.