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A simulation study on optimal oil spraying mode for high-speed rolling bearing

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Analysis and modelling

ABSTRACT

Purpose: In this study, a numerical simulation model of the oil spraying system is established.
Design/methodology/approach: Spraying lubrication is a common form of the rolling bearing lubrication. But with the increase of the bearing speed, the roller cage is frequently shattered, which may lead to failure of the bearing. The shatter of roller cage may be related to the spraying mode of oil. For high-speed rolling bearing, the roller cage shatter can be cracked due to the shortage of oil, caused by lubricating oil not sprayed into the roller cage shatter. This condition can be ameliorated by changing the spraying mode of oil supply system. The model considered the spraying speed, spraying angle, oil pressure, oil viscosity, structure of roller cage shatter, rotating speed as the main parameters. By optimization, the best way of oil spraying was obtained which can meet lubrication requirement of high-speed rolling bearing. At the same time, the numerical simulation results also revealed that the optimal spraying mode is different for different rolling bearings.
Findings: The simulating results indicate that due to the effect of the air pressure and airflow thickness, the optimal spraying position is at a region closer to the inner ring of the bearings.
Practical implications: This paper will provide useful information to applying numerical simulation of the oil spraying system.
Originality/value: The computer simulation allows to better understand the interdependence between parameters of process and choosing optimal solution.
Keywords: High-speed rolling bearing; Roller cage shatter; Optimal oil spraying mode; Numerical simulation

1. Introduction

Grease lubrication and oil lubrication are both commonly used in rolling bearings. However, when the temperature and operating speed are high, the base oil of the lubricating grease may evaporate and be oxidized, and lubrication performance may deteriorate rapidly. For this condition, the lubrication performance of bearings may be improved by using circular lubrication, oil-mist lubrication and oil spray lubrication. When operating speed of bearings is very high, bearings must have a sufficient, but not excessive amount of oil to ensure that the bearing is sufficiently lubricated and exorbitant temperature. Oil spray lubrication is an especially effective method in such situations.

In oil spray lubrication, oils are injected into bearing from one side of the roller cage shatter. When bearing operates in high speed, the high strength gas flow is formed around the rolling element and the roller cage shatter through which oil is sent to bearings using ordinary lubrication methods. Therefore, oil spray lubrication can be used, and the speed of oil must reach certain value so that it can drill through the hydraulic flow layer under high speed conditions.

In this study, the numerical simulation model of the oil spraying system is established, with spraying speed, spraying angle, oil pressure, oil viscosity, structure of roller cage shatter, rotating speed as the main parameters of the model. By optimization, the best parameters for oil spraying were obtained which can meet lubrication requirement of highs-speed rolling bearing.

2. Operating principle of oil spray lubrication

Oil spraying is mostly used in high-speed bearing. Fig. 1 shows the typical structure of such bearings. Such a bearing is equipped with oil spray lubrication. There is an injecting nozzle through which oil is sprayed out with certain pressure and is distributed to the guide face of the inner circle and roller cage shatter, and be sent to the interior of bearings. When bearing works in high speed condition, oil hardly enters into the bearing because of the difficulty penetrating the gas-wall. Aiming at this condition, the spraying speed of oil should be 20% above the guide face speed of the roller cage shatter. Adding the number of injecting nozzles may also help to improve lubrication performance because a large quantity of oil sprayed will reduce the mixing resistance and enlarge oil drain, effectively releasing a large quantity of heat by forcing a convective heat transfer.

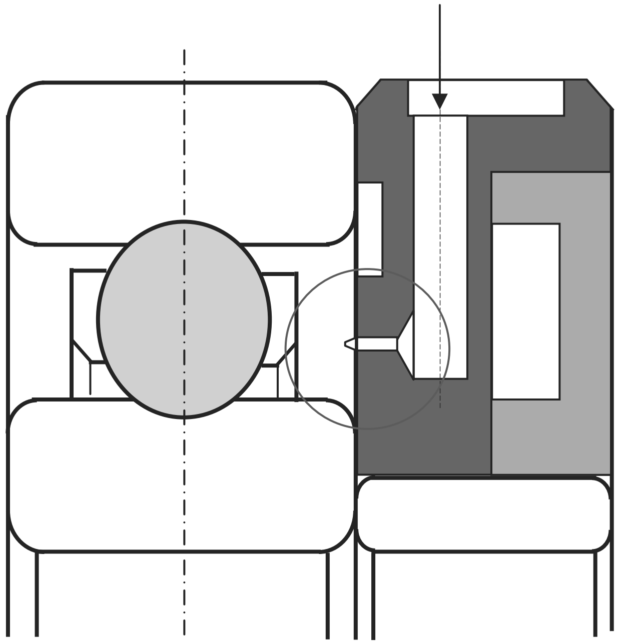

Fig. 1. Diagrammatic Sketch of the oil supply system

3. Establishing simulation model

3.1. Physical model

In this paper, to be specific, 204 deep groove ball bearings is used for calculation. According to the configuration of deep groove ball bearings, a three-dimensional geometrical model of the bearings is drawn with CATIA V5R18. With millimeter (mm) as the unit, the bearing’s outer diameter is 47, its inner diameter is 20, its central diameter is 34.5, its breadth is 47, the diameter of steel balls is 7.938 and the number of balls is 8.

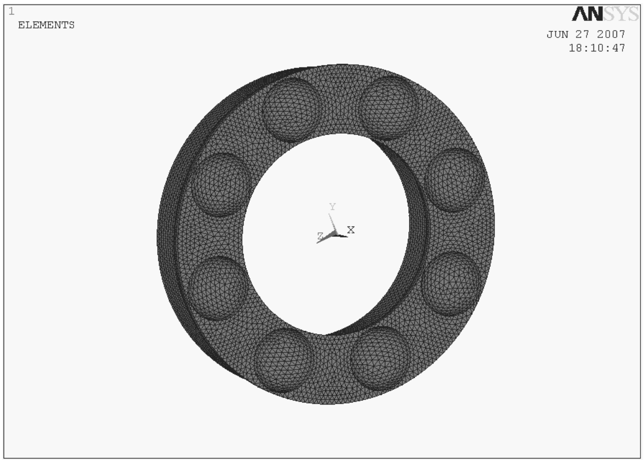

Fig. 2. The finite element model of bearings

3.2. Establishing finite element model

In the finite element analysis, the element type FLUID 142 is selected. This is a three-dimensional eight-node hexahedron fluid element. To ensure precision of computation, the element can change into various anomalistic shapes in order to be consistent with displacement shapes and to be compatible with the curve boundary. Every node has three degree of freedom along R, θ, Z directions. We define the element’s properties --- density, viscosity, thermal conductivity, and specific heat --- with a series of FLDATA commands. Only one fluid can be analyzed, and it must be in a single phase. Thermal conductivity and specific heat are relevant only if the problem is thermal in nature. The properties can be a function of temperature through relationships specified by the FLDATA7, PROT command or through a property database. In addition, the density may vary with pressure if the fluid is specified to be air or a gas. The density of normal condition air is 1.29 Kg/m, and the viscosity μ is 1.81×10-5Pa when ambient temperature is 293 K.

Before meshing the model, and even before building the model, it is important to think about whether a free mesh or a mapped mesh is appropriate for the analysis. A free mesh has no restrictions in terms of element shapes, and has no specified pattern applied to it. A mapped mesh is restricted in terms of the element shape it contains and the pattern of the mesh. A mapped area mesh contains either only quadrilateral or only triangular elements, while a mapped volume mesh contains only hexahedron elements. In addition, a mapped mesh typically has a regular pattern, with obvious rows of elements. In order to use this type of mesh, it is necessary to have a geometry as a series of fairly regular volumes and/or areas that can accept a mapped mesh. In this paper, the free mash model is used, and the finite element model of bearings is as Fig.2.

3.3. The mathematical models

The standard k–ε model performs well in predicting flows without a swirling flow within the region calculated. The Reynolds stress model is a more effective model for simulating the strong swirl flow. However, the Reynolds stress model is difficult to apply widely due to an enormous amount of computation required. In order to conquer the limitations of the standard k–ε model and the Reynolds stress model, the RNG k–ε model was used as an alternative to the standard k–ε model for simulating flows with swirl in engineering.

The RNG k–ε model is modified with renormalization group theory by Yakhot and Orszg, which is the same as the k–ε model with regard to the equation. In the RNG k–ε model, the general conservation equation of 3-D turbulent flow takes the form

$$\frac{\partial}{\partial x}(\rho u\varphi)+\frac{1}{r}\frac{\partial}{\partial r}(r\rho v\varphi)+\frac{1}{r}\frac{\partial}{\partial \theta}(\rho\varpi\varphi)=\frac{\partial}{\partial x}(\Gamma_\varphi\frac{\partial\varphi}{\partial x})+\frac{1}{r}\frac{\partial}{\partial r}(r\Gamma_\varphi\frac{\partial\varphi}{\partial r})+\frac{1}{r^2}\frac{\partial}{\partial\theta}(\Gamma_\varphi\frac{\partial\varphi}{r\partial\theta})+S_\varphi \quad (1)$$

where φ is the all-purpose variable, Γφ is the diffusion coefficient, Sφ is the source item, ρ is the density of air, μ is the viscosity of air, and u v and w are the velocity components of air along x, y, and z direction, respectively. Other parameters can be found in user's manual of ANSYS.

When the spraying oil traverses the high strength gas flow, it would be atomized and deposited under the effect of gravity and resistance. There are also some states that mass transfer, heat transfer and momentum interchange would happen. The physical model of calculating hydromechanics must be considered in the simulation, and the form of equation is as follow

$$\frac{\partial(\rho\varphi)}{\partial t}+div(\rho u\varphi)=div(\Gamma_\varphi grad\varphi)+S_\varphi \quad (2)$$

where the definitions of parameters are the same as in Equation (1).

3.4. Boundary conditions

In this paper, flow of the gas is taken into account under different velocity. The velocity of inner diameter gas and outer diameter gas are 0 m/s and 25 m/s approximatively, respectively. A fully developed flow was assumed for the condition of the outlet of the precalciner. The flow in the walls was decided by the no-slip condition, and the mesh near the walls are modified by the wall function.

3.5. Computational method

Convection and diffusion of the conservation equations were discretized with the volume finite element method. The SIMPLE method had been employed to determine velocities and pressures using a non-staggered grid system in Cartesian coordinates. The equations were computed with low relaxation factors, iteration of TDMA and the standard wall function, convergent criterion is controlled to less than 10-4 of all the residuals.

4. Simulation results and analysis

4.1. High-speed gas pressure simulation

Due to the asymmetry of the physical model and effect of the impact between inner air and outer air, the flow characteristics in the bearing are computed by a 3-D simulation. The modeling results are described by the sectionwise and the simulation results are listed in Figs. 3.

Fig. 3 shows the fluid velocity of one circulatory cell chosen from the whole circumference for gas fluid calculation models. From the calculated value of whole fluid velocity, it is seen that the velocity increases in rotational direction, and the maximum velocity is reached at the top of roller. Because the fluid velocity figure varies continuously, it is insignificant to adjust the spraying position of oil in rotational direction.

In order to find the right spraying position, it is necessary to obtain the gas pressure distribution along the diametrical direction. First, gas pressure distribution of the whole region is calculated, and some pivotal point can be chosen. Then, the pressure distribution of diametrical direction is obtained by numerical computation.

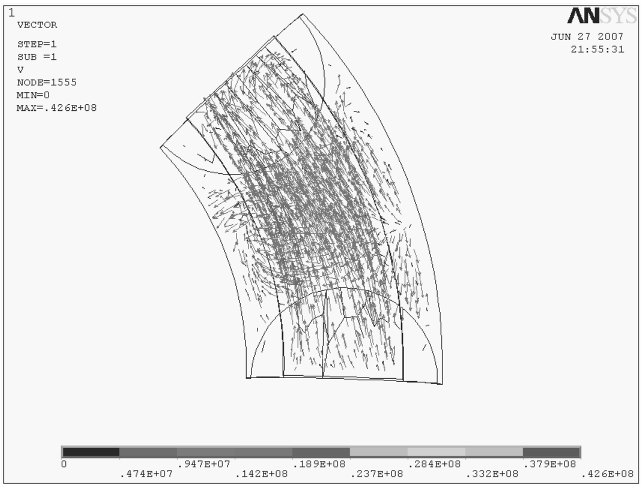

Fig. 3. The finite element model of bearings

Fig. 4 shows the results of the pressure distribution in the diametrical direction, where the tangential velocities of outer ring are u = 25 m/s, 20 m/s and 15 m/s. It is seen from Fig. 4 that the flow field was influenced mostly by the velocity boundary due to hydrodynamic action of air flow. The first pressure peak is formed in the middle of the gas model after the circumferential flow was pushed into the top of roller, the circumferential velocity of middle line decreases with the axial position of the bearing. In the inner circle of the flow gas, the gas pressure is low. Another high-speed zone was formed on the side closed to the outer circle of the model due to the effect of drive of the high-speed rotating bearing outer ring where the peak velocity reaches 21.88 m/s. Moreover, the velocity is positive to increase the gas pressure of the outer air, but the pressure peak value is less than the middle pressure peak, which indicates that there is low extruding action of gas (as shown in Fig. 1). Also it is shown that the pressure of diametrical direction starts to decrease with the rotating speed of bearings, and the distribution of pressure remains the same.

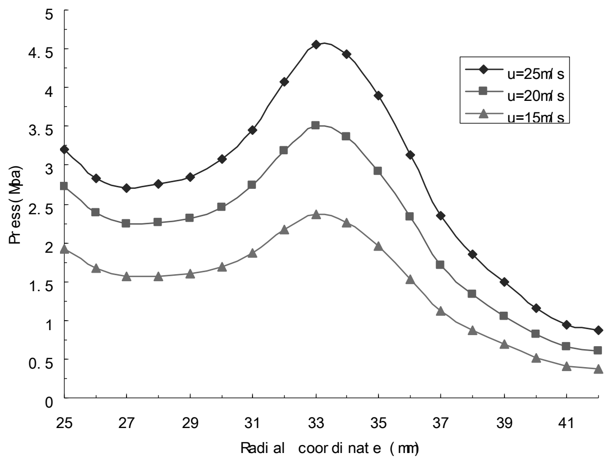

Fig. 4. The pressure distribution of diametrical direction

4.2. Oil spraying simulation

In order to reach better consistency between oil spraying simulation andthe gas pressure simulation, the parameters of gas phase and liquid flow phases are assumed as Table 1 in oil spraying simulation.

According to the parameters in Table 1, the atomizing ratio of the spraying oil is calculated, and Fig. 5 shows the results of the atomizing ratio distribution along the radial coordinate between r = 25 and r = 42. The simulation results indicate that due to the effect of the air pressure and airflow thickness, the pattern of penetration by the high speed oil through the airflow is complex. In order to carefully analyze the impact mechanism, this whole zone is divided into four sections a, b, c and d.

Section (a) is the region closer to the internal insulation of bearing outer ring. It is indicated that the spraying oil is affected by velocity of airflow, so the atomizing ratio is high.

Section (b) is near the aperture between outer ring and roller. The spraying oil is obviously affected by swirl flow of the air, and is disorganized in this section. This is shown in Fig. 5(b). The atomizing ratio distribution of the spraying oil has a peak value in this section, where the lubricating oil cannot be sprayed into bearing.

Section (c) is near the top of the roller. The spraying oil cannot be disorganized in this section because the thickness of airflow is thin. The effect of velocity magnitude is primarily in the zone of the two sides of the top roller, which indicates that there is no zones of swirl flow, a high-speed zone was formed due to extrusion effects, and the peak value reaches 3.51 Kpa. The high-intensity airflow can be unpropitious to oil sprayed into the bearings.

Section (d) is the region closer with the inner ring of bearings, where the velocity of the airflow is low. So the atomizing ratio is the lowest in the whole calculating zone. Because the spraying oil is affected by swirl flow air also, the atomizing ratio distribution of the spraying oil has a peak value in this section.

According to above the analysis about distribution rules of the atomizing ratio of the spraying oil, it can be seen that the optimal spraying position is at the region closer to inner ring of bearings.

Table 1.
Parameters of gas and liquid phases used in simulation

Gas phase		Liquid phase	
Item	Parameter	Item	Parameter
Temperature/K	293	Temperature/K	293
Density/(kg/m^3)	1.29	Density/(kg/m^3)	996
Viscosity(Pa.s)	1.81×10^{-5}	Viscosity(Pa.s)	0.023
Mole mass (g/mol)	29.8	Mole mass (g/mol)	16.5
Turbulent intensity/%	30	Volatility/K	273
Velocity/(m/s)	20	Fluidization point/K	373
Relative moisture/%	15	Surface tension/(N/m)	7.26×10^{-2}

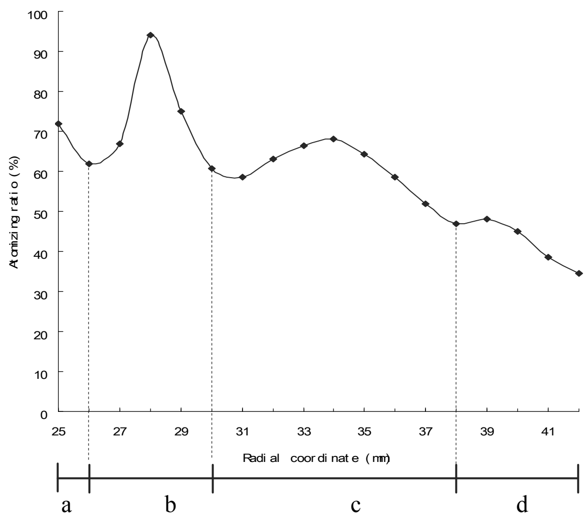

Fig. 5. The atomizing ratio distribution of the spraying oil

5. Conclusions

The velocity increases in the rotational direction, and the maximum value appears at the top of roller. The flow field was influenced mostly by the velocity boundary due to hydrodynamic action of the air flow. The pressure long the diametrical direction decreases with the rotating speed of bearings and the distribution regularity of pressure remains the same.

The simulating results indicate that due to the effect of the air pressure and airflow thickness, the optimal spraying position is at a region closer to the inner ring of the bearings.

Acknowledgements

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References

[1] Y.T. Su, Signature analysis of roller bearing vibrations. Lubrication effects, Proceedings of the Institution of Mechanical Engineers, Part C: Mechanical Engineering Science 206/3 (1992) 193-202.

[2] J.W. Wang, Behavior of oil-air lubrication using in roller bearings system, Journal of East China University of Science and Technology 33/3 (2007) 436-440.

[3] J. Tsay, H.E. Ozkan, R.D. Brazee, et al., CFD simulation of mechanical spray shields, Transactions of the ASAE, 45/5 (2002) 1271-1280

[4] J.R. Tsay, L.S. Liang, L.H. Lu, Evaluation of an air assisted boom spraying system under a no2canopy condition using CFD simulation, Transactions of ASAE, 47/6 (2004) 1887-1897

[5] J. Tsay, H.E. Ozkan, R.D. Brazee, et al., CFD Simulation of moving spay shields, Transactions of ASAE, 45/1 (2002) 21-26

[6] W. Zhao, Z. Li, Numerical simulation of gras turbulence flow in FIS precalciner, Ind Furnace 24/2 (2002) 45-47.