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Numerical Investigation of the Heat-fluid Characteristic inside High-speed Angular Contact Ball Bearing Lubricated with Grease

B. Wang*, Z. Wang, C. Sun, Y. Wu

School of Mechanical & Electrical Engineering, Lanzhou University of Technology, Lanzhou 730050, China

P A P E R   I N F O

A B S T R A C T

The development of special grease makes it possible for angular contact ball bearings to operate at high speed and temperature; so, it become necessary to investigate thermal-fluid characterisics inside high-speed angular contact ball bearing lubricated with grease. In this paper, a simulation model for angular contact ball bearing was established with CFD software Fluent, the heat-fluid-solid coupling method was used to analyze the distribution and flow of grease, heat transfer, and temperature field inside the bearing chamber. The results showed that, grease distribution inside bearing chamber was very inhomogeneous, most of grease was distributed on the both sides of the rolling elements along outer raceway and its flow velocity was very low, only a little grease was adhered on the surface of rolling elements, cage, and inner ring, its flow velocity was high; grease distribution inside bearing chamber becomes more inhomogeneous with the increase of bearing speed; in bearing heat transfer conduction was dominant and grease plays a key role, convection of air and grease was insignificant; affected by heat transfer condition the temperature rise of bearing components was obviously different, rolling elements have the highest temperature, the temperature of inner ring was slightly lower than that of rolling elements, and temperature of outer ring was the lowest. Bearing temperature experiment was conducted on self-made test rig and verified the validity and accuracy of numerical simulation. The results of this study will provide some reference for lubrication design and thermal analysis of high speed angular contact ball bearing lubricated with grease.

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NOMENCLATURE

H	friction heat generation of tested bearing	f_0	a factor depending upon bearing type and lubrication method
n	bearing rotation speed	v_0	the kinematic viscosity of lubricant
M	bearing frictional torque	N_u	the Nusselt number
M_l	bearing frictional torque due to load	R_e	the Reynolds number
M_v	bearing frictional torque due to lubricant	P_r	the Prandlt number
f_l	a factor depending upon bearing type and load	ω	inner ring speed
p_l	bearing load	v	kinematic viscosity of air
d_m	bearing mean diameter	d	diameter of main shaft

1. INTRODUCTION

Rolling bearing is a critical component of many modern engines and machinery, it can reduce the friction and ensure rotary accuracy [1, 2]. Lubrication, as an effective way to reduce friction, is one of the important issues in rolling bearing. With an increase in bearing speed and load, lubrication performance has become more and more demanding. According to available findings, grease lubrication has been widely used in high-speed rolling bearing because of its good sealing performance, wide application and convenient operation [3-5]. However, it is difficult for a grease-lubricated rolling bearing to dissipate heat by friction because of the

*Corresponding Author Institutional Email: wbm2007@163.com (B. Wang)

limited flow ability of grease, high temperature rise often results in premature failure of rolling bearing [6]. Hence, it is very important to investigate the thermal behavior and fluid characteristics of greases in operating rolling bearings.

Considerable efforts have been devoted to investigate the work mechanism [7-9] and rheological behavior [10-12] of grease lubrication in high-speed rolling bearing. Thermal characteristics of rolling bearing has also attracted much attention due to the industrial demands for high speed and long working life. Ma Fangbo et al. [13] provided a calculation model for heat generation rate in a grease-lubricated spherical roller bearing (SRB) by adopting the local heat source analysis approach, the heat generation rates of roller-raceway contact, cage and inner ring land contact, roller and cage pocket contact, and power loss of roller churning were calculated. Wurzbach et al. [14] investigated the thermal behavior, flow characteristics of the non-Newtonian greases, and changes in grease properties in operating rolling-element bearings. Neurouth et al. [15] analyzed the heat transfer inside a grease lubricated thrust ball bearing, two models were developed using the thermal network method. Based on generalized Ohm's law, Siyuan et al. [16] developed a thermal network model for double-row tapered roller bearing lubricated with grease, bearing temperature at different speeds, grease filling ratios, and roller large end radius was investigated. Fangbo et al. [17] developed a transient thermal model for a grease-lubricated spherical roller bearings-shaft-bearing housing system using a thermal network method, the effect of rotating speed, radial load and grease filling ratio on bearing temperature rise was analyzed. Xue et al. [18] conducted the temperature performance tests of high-speed sealed angular-contact ball bearings using different grease filling rate, the temperature performance of bearing with different grease filling rate was compared and analyzed under different working conditions.

The studies mentioned above investigated the bearing thermal characteristics and fluid properties of grease. However, fluid flow and heat transfer are not two independent processes [19, 20], the flow of fluid contributes to heat transfer, the temperature change of fluid will affect its viscosity, and then affects its flow in turn; so, the flow and heat transfer of fluid interact with each other [21, 22]. But few studies have been done on the coupling relationship between them and didn't consider the heat transfer between grease and bearing components, the exact behavior of greases in operating rolling bearing needs to be well understood. Therefore, in this paper a simulation model for angular contact ball bearing was established with CFD software Fluent, based on this model, the distribution and flow of grease, heat transfer, and temperature field inside the bearing chamber were analyzed using the heat-fluid-solid coupling method. A bearing test rig was designed and

manufactured, bearing temperature measurement was conducted to verify the validity and accuracy of numerical simulation.

2. TEST RIG

In order to investigate the thermal behavior of high-speed angular contact ball bearing, some measurement of bearing temperature was conducted on self-made test rig. As shown in Figure1, the test rig is mainly composed of a test section and a motorized spindle unit. The test section is driven by the motorized spindle through a flexible coupling. The highest speed and rated power of the motorized spindle are 36000rpm and 5 kW, respectively. More detail of the tested bearings assembly is shown in Figure 2. The two tested bearings are B71909 angular contact ball bearings lubricated with grease; their major specifications are listed in Table 1. The tested bearings were press fitted onto the rotation shaft with back-to-back configuration, and the rotation shaft was supported by two pairs of ball bearings. Bearing loads were applied on tested bearing housing which installed between two tested bearings.

In experiments, motorized spindle rotates the inner ring of test bearings through the main shaft. The main shaft is connected with motorized spindle by a coupling. Special attention should be given to the coupling; design of flexible coupling was aimed to isolate test bearings
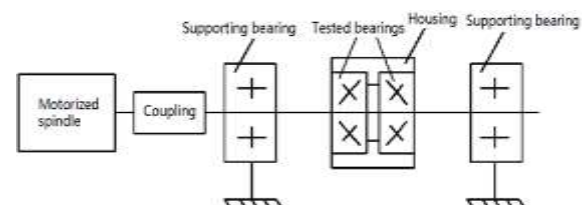
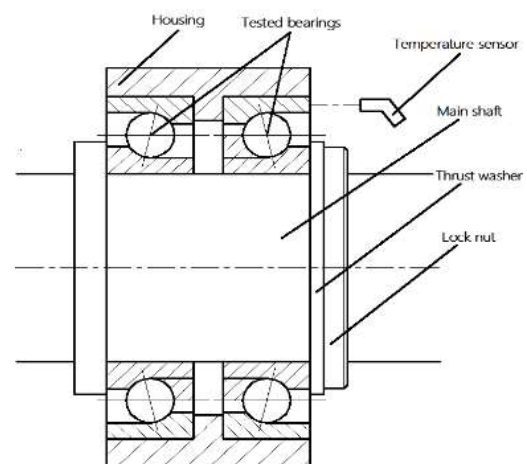

Figure 1. The structure diagram of test rig

Figure 2. Drawing of tested bearings assembly

TABLE 1. The parameters of tested bearing B71909

Parameter	Value
Bore diameter	45 mm
Outer diameter	68 mm
Width	12 mm
Initial contact angular	15 deg.
Number of rolling elements	20
Ring material	Steel
Density of rings[g/cm^3]	7.8
Heat capacity of rings [J/kg·K]	460
Thermal conductivity of rings [W/m^2·K]	30
Ball material	Si$_3$N$_4$
Density of ball[g/cm^3]	3.2
Heat capacity of ball [J/kg·K]	800
Thermal conductivity of ball [W/m^2·K]	20

from the vibration of motorized spindle as much as possible. The two parts of coupling are not directly contacted each other and connected through Nealon rope, so the torsional impact of motorized spindle cannot be transmitted to test bearings, this structure ensures the stability of test bearings.

In order to get the temperature data of test bearings, an infrared temperature sensor was fixed on a self-made bracket to monitor the temperature of the bearing inner ring, the bracket is easy to adjust sensor position according to the experimental requirements, as shown in Figure 3.

3. NUMERICAL SIMULATION

3. 1. Thermal Analysis Model   Due to the symmetrical structure of the tested bearings assembly, its half structure was modeled in order to save computing cost. Inside the chamber of tested bearings lubricated with grease, the heat transfers between the fluid and the solid is involved, however, it is difficult to be determined. So, the heat-fluid-solid coupling method is used in this numerical

Figure 3. The physical picture of test rig

simulation, this method is often used to solve the complex heat transfer problem, it can convert the complex outer boundary conditions between the fluid and the solid into a relatively simple inner boundary condition, and make the simulation more approach to practical condition. As shown in Figure 4, the simulation model of tested bearings assembly includes solid domain and fluid domain.

The structure of bearing chamber is very complicated. Therefore, in order to make finite element meshing easy, the bearing cavity is divided into multiple fluid domains. The domain among the balls is very irregular and meshed using tetrahedral elements. The domain along both sides of the balls is relatively regular and meshed using hexagonal elements. These fluid domains are connected with each other through an interface. The 3D grid model of fluid domain in bearing chamber is shown in detail in Figure 5. The final number of elements is 3215677, and the mesh quality is above 0.6.

3. 2. Boundary Conditions

3. 2. 1. Heat Generation   During bearing operation, bearing friction represents an energy loss and results in
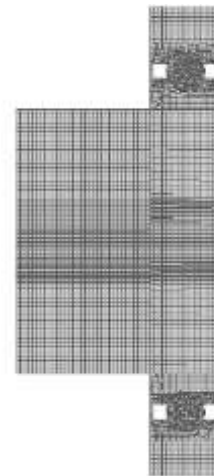

Figure 4. The heat-fluid-solid coupling model of tested bearings assembly

Figure 5. The 3D grid model of fluid domain inside bearing chamber

temperature rise. The friction heat generation of the tested bearing can be obtained by the following equation [23]:

$$H = 1.047 \times 10^{-4} Mn \tag{1}$$

where H is the friction heat generation of tested bearing (w), n is bearing rotation speed (rpm), M is bearing frictional torque (N·mm). The frictional torque M consists of two components stated as follows:

$$M = M_1 + M_v \tag{2}$$

where M_1 is bearing frictional torque due to load, and M_v is bearing frictional torque due to lubricant.

M_1 can be approximated by the following equation:

$$M_1 = f_1 p_1 d_m \tag{3}$$

where f_1 is a factor depending upon bearing type and load, p_1 is bearing load (N), d_m is bearing mean diameter (mm).

M_v can be calculated by the following equation:

$$M_v = 10^{-7} f_0 (v_0 n)^{2/3} d_m^3 \quad \text{if} \quad n \geq 2000 \tag{4}$$

$$M_v = 160 \times 10^{-7} f_0 d_m \quad \text{if} \quad n \geq 2000 \tag{5}$$

where f_0 is a factor depending upon bearing type and lubrication method, v0 is the kinematic viscosity of lubricant (mm^2/s).

In numerical calculation it's assumed that the bearing friction heat generation is divided into two equal parts, one half was applied to bearing rings and the other was applied to rolling elements in the form of heat generating rate [24].

3. 2. 2. Heat Transfer
According to the working conditions of the tested bearings assembly, convective heat transfer occurs on the outer surface of bearing housing and main shaft. The convection form of bearing housing is natural convection and the convection heat transfer coefficients is assumed to be 9.7 W/(m^{2}K) according to the practical experiences [25]. The convective heat transfer coefficients h_s of the main shaft can be obtained by the following equations.

$$N_u = 0.133 R_e^{2/3} P_r^{1/3} \tag{6}$$

$$R_e = \omega d^2 / v \tag{7}$$

$$h_s = \frac{N_u \cdot \lambda}{d} \tag{8}$$

where N_u is the Nusselt number, R_e and P_r are the Reynolds number and the Prandlt number, respectively, W is inner ring speed, v is the kinematic viscosity of air, d is the diameter of main shaft.

Inside bearing chamber heat transfer among grease, air

and bearing components is a heat-fluid-solid coupling process and cannot be specified in advance. So, under the FLUENT platform, in numerical calculation the contacting surfaces between fluids and solid were set as default coupling-surface, and the heat transfer was calculated automatically. Finally, the second-order upside-style discrete momentum equation and turbulence equation are used. The pressure term is discretized in the PRESTO! (pressure staggering option) format, and the phase volume fraction is discretized in the geometric reconstruction format, and then the Semi-Implicit Method for Pressure Linked Equations (SIMPLE) algorithm is used. Solve the discrete algebraic equation and converge when the residual value drops below 10^{-3}.

3. 3. Solution and Parameters Set
Heat-fluid-solid coupling is an interaction process among fluid domain, solid domain and temperature field. So, in order to obtain the flow field and temperature field of bearing, it is necessary to connect them. In the heat-fluid-solid coupling model of tested bearing, heat transfers among temperature field, fluid domain and solid domain through the fluid-solid interface, the interface method was used to connect the solid domain with the fluid domain, and the standard wall function is used to deal with the flow boundary layer and the heat transfer boundary layer at the fluid-solid coupling interface, which ensures the continuity of temperature and heat flux. In order to obtain the grease distribution inside bearing chamber, the interface of grease air two-phase flow was captured by the VOF method which is specifically used to solve the flow interface position of two immiscible fluids. The VOF method is from Europe Derived from Euler method, it is based on observation points, rather than following a fluid particle for research. In the flow field of bearing grease lubrication, the boundary of the two-phase flow is judged by solving the volume fraction of the two phases at the observation point. The turbulence inside bearing chamber was simulated by the RNG k-ε model which is suitable for analyzing turbulent motion in complex regions.

Moreover, the reference pressure was set as atmospheric pressure, and the air was selected incompressible gas model, non-equilibrium wall function was selected and solved by pressure velocity coupling equation. In the numerical simulation, the control variable method was used to simulate the flow field of the bearing chamber. The specific parameters of grease are shown in Table 2 [9].

4. RESULTS AND DISCUSSION

4. 1. Grease Distribution inside Bearing Chamber
In the process of bearing operation, the bearing speed has a very important influence on the distribution of grease. When grease filling ratio is 0.3, under different rotation speed the grease distribution inside bearing chamber is

TABLE 2. The specific parameters of the grease

Grease	Lithium base grease
The consistency of grease	NLGI 3
The rheological model of grease	Herschel-Bulkley flow model
Viscosity coefficient k	20.5
Rheological index n	0.71
Yield stress τ_0	1076
Density [kg/m³]	872
grease filling ratio	0.3
Heat capacity [J/kg·K]	2000
Thermal conductivity[W/m²·K]	0.14

shown in Figure 6. It can be seen that the grease distribution was very inhomogeneous inside bearing chamber, grease was mainly distributed over the both sides of the rolling element along outer raceway, a small amount of grease was adhered on the inner side of the cage, grease adhered on the surface of rolling elements and inner raceway was very little due to centrifugal effect. It's also noted that the grease distribution inside bearing chamber become more inhomogeneous with the increase of bearing rotation speed, more grease is adhered on the outer raceway, the volume fraction of the grease between inner raceway and cage was accordingly decreased. It is perhaps a further finding that at high rotation speed bearing outer raceway is in full lubrication, meanwhile, bearing inner raceway is in starved lubrication.
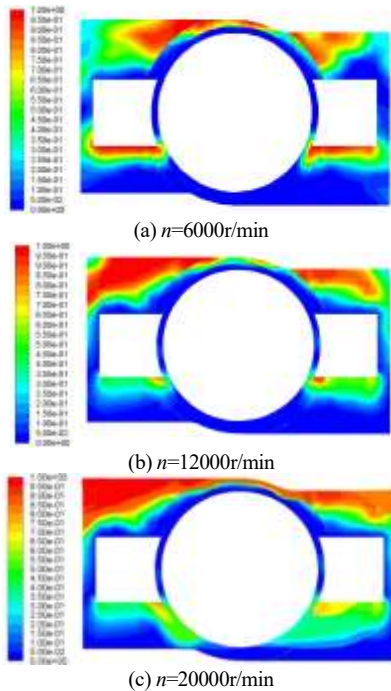
4. 2. Flow Velocity of Grease inside Bearing Chamber

The flow velocity of grease inside the bearing chamber is shown in Figure 7. It is shown that grease adhered on the outer raceway was in viscous state, its flow velocity was very low; however, the flow velocity of grease adhered on inner ring and cage was relatively high, grease between cage and rolling elements has the highest flow speed. It's also found that, with the increase of bearing speed, the flow velocity of grease between inner raceway and cage increases obviously; however, an increase in bearing speed has very little effect on flow velocity of grease adhered on outer raceway.

4. 3. Heat transfer Coefficient on inner Surface of Bearing Chamber

In the working process of the bearing, heat is an important factor affecting the performance of the bearing. Heat will dilute the grease and reduce the lubrication efficiency of the bearing. Figure 8 shows heat transfer coefficient on the interface between the fluid domain and the solid domain inside bearing chamber at different speeds. It's shown that, heat transfer coefficient was high on the area of outer raceway surface where more grease was adhered on; heat transfer coefficient was also high on rolling elements surface which frequently contact with raceway, cage and grease; heat transfer coefficient was the lowest on inner raceway where little grease was adhered while its velocity was high, which was due to the fact that air convective heat transfer inside bearing chamber was
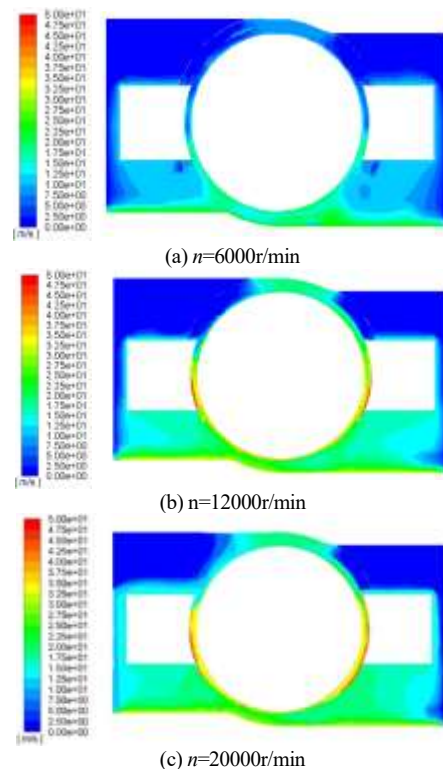

(a) n=6000r/min

(b) n=12000r/min

(c) n=20000r/min

Figure 6. Grease distribution inside bearing chamber at different rotation speed

(a) n=6000r/min

(b) n=12000r/min

(c) n=20000r/min

Figure 7. The flow velocity distribution of grease inside bearing chamber at different speeds

very small; heat transfer coefficient was high on the area of inner and outer raceway surface where rolling elements pass. It also can be seen that with the increase of bearing speed heat transfer coefficient was accordingly increased on surface of outer raceway and rolling elements, which was due to the temperature rise of bearing components.

It can be concluded that inside bearing chamber conduction heat transfer is dominant in which grease plays a key role, the convective heat transfer of air and grease is insignificant.

4. 4. Temperature Rise of Bearing   The temperature distribution of tested bearing is shown in Figure 9. It can be seen that bearing temperature field was nonuniform. The temperature of rolling elements was the highest, its heat mainly transfers to outer raceway through grease between rolling elements and outer raceway; the heat transfer condition of inner ring was poor, the temperature of inner ring was also high and slightly lower than that of rolling elements; outer ring has an effective heat transfer way, its heat can conduct to bearing housing and then transfer to ambient air, so the temperature of outer ring
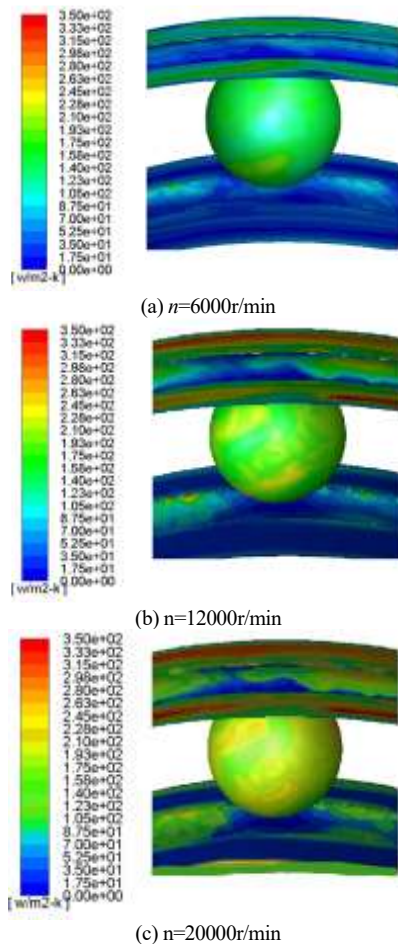

(a) *n*=6000 r/min

(b) n=12000 r/min

(c) n=20000 r/min

Figure 9. Temperature field of tested bearing at different rotation speed

(a) *n*=6000r/min

(b) n=12000r/min

(c) n=20000r/min

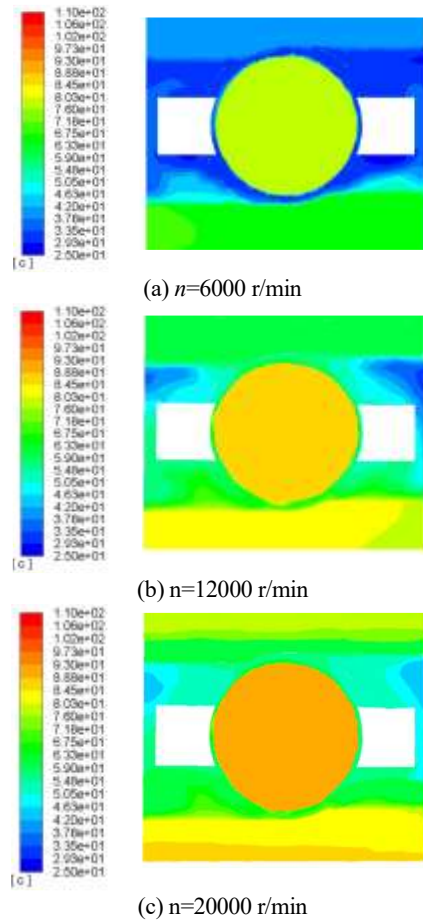**Figure 8.** The heat transfer coefficient inside bearing chamber at different rotation speed

was the lowest. With an increase in rotational speed bearing temperature was increased, the temperature of grease adhered on outer raceway was also increased, which indicated that more grease involves in conduction heat transfer.

4. 5. Verification   In order to verify the validity and accuracy of numerical simulation, bearing temperature rise was measured on a self-made test rig. In the experiment, bearing axial load is 200N, and radial load is 100N, the tested bearing was started to run from zero speed to 9000 rpm, after running for 300 seconds at 9000 rpm, it was turned off. The measured data and simulation data of bearing temperature are shown in Figure 10. It's indicated that the simulation results were in good agreement with the experimental results, the residual error was below 8%, and the maximum residual error happened after bearing stop rotating. When bearing stops rotating, the natural convection of bearing housing plays a dominant role in bearing temperature, and the natural convection heat transfer coefficients come from experiences, this value 9.7 $W/(m^2 \cdot K)$ is not very accurate. This is one reason of residual error. The other reason is nonlinear effects of
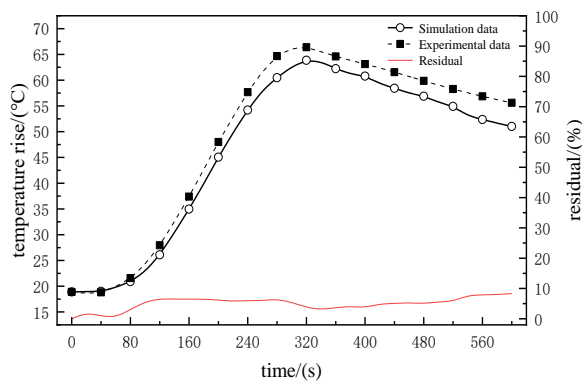
Figure 10. Bearing temperature measurements for the validation of numerical simulation

bearing temperature rise. Regardless of all these effects, numerical simulation showed good validity and accuracy.

5. CONCLUSION

The thermal-fluid characteristics of angular contact ball bearing lubricated grease was analyzed using thermal-fluid-solid coupling method. It was concluded that, grease distribution inside bearing chamber is very inhomogeneous, most of grease was distributed over the both sides of the rolling element along outer raceway, grease adhered on the surface of rolling elements, cage, and inner ring is very little, which becomes more inhomogeneous with the increase of bearing speed; grease adhered on the outer ring was in viscous state; however, it plays a dominant role in bearing heat transfer, convective heat transfer of air and grease was insignificant; affected by heat transfer condition the temperature rise of bearing components was obviously different, the temperature rise of rolling elements was the highest, the temperature of inner ring was slightly lower than that of rolling elements; outer ring has the lowest temperature.

The results provide some reference for lubrication design and thermal analysis of high-speed angular contact ball bearing. The method in the paper is also applicable to the analysis of heat-fluid behaviors of oil-air or oil lubricated rolling bearings. In this study bearing temperature experiment was conducted on self-made test rig and verified the validity and accuracy of numerical simulation, grease flow experiment can be considered in the future work.

6. ACKNOWLEDGEMENTS

7. REFERENCES

1.   Koulocheris, D., Stathis, A., Costopoulos, T. and Tsantiotis, D., "Experimental study of the impact of grease particle contaminants on wear and fatigue life of ball bearings", *Engineering Failure Analysis*, Vol. 39, (2014), 164-180. doi: 10.1016/j. engfailanal. 2014.01.016.

2.   Patil, S. and Phalle, V., "Fault detection of anti-friction bearing using ensemble machine learning methods", *International Journal of Engineering*, *Transactions B: Applications,* Vol. 31, No. 11, (2018), 1972-1981. doi: 10.5829/ije.2018.31. 11b.22.

3.   Lugt, P.M., "A review on grease lubrication in rolling bearings", *Tribology Transactions*, Vol. 52, No. 4, (2009), 470-480. doi: 10.1080/10402000802687940.

4.   Jang, J. and Khonsari, M., "Performance analysis of grease-lubricated journal bearings including thermal effects", (1997). doi: 10.1115/1.2833897.

5.   Wu, Z., Xu, Y., Liu, K. and Chen, Z., "Numerical analysis of grease film characteristics in tapered roller bearing subject to shaft deflection", *International Journal of Engineering*, *Transactions A: Basics,* Vol. 33, No. 7, (2020), 1403-1412. doi: 10.5829/ije.2020.33.07a.28.

6.   Kim, K.-S., Lee, D.-W., Lee, S.-M., Lee, S.-J. and Hwang, J.-H., "A numerical approach to determine the frictional torque and temperature of an angular contact ball bearing in a spindle system", *International Journal of Precision Engineering and Manufacturing*, Vol. 16, No. 1, (2015), 135-142. doi: 10.1007/s12541-015-0017-1.

7.   Cann, P. and Lubrecht, A., "An analysis of the mechanisms of grease lubrication in rolling element bearings", *Lubrication Science*, Vol. 11, No. 3, (1999), 227-245. doi: 10.1002/ls. 3010110303.

8.   Pan, J., Cheng, Y., Zhu, Z. and Yang, J., "Flow characteristics of grease in circular pipeline at varied temperatures", *CIESC Journal*,   Vol. 65, No. 6, (2014), 2063-2069. doi: 10.3969/j.issn.0438-1157.2014.06.016.

9.   WU, Z.h., XU, Y.q., LIU, K.a. and ZHAO, X., "Thermal film-forming ability of grease lubrication at roller-raceway pair in tapered roller bearings", *Journal of ZheJiang University (Engineering Science)*, Vol. 54, No. 3, (2020), 459-466. doi.

10.   Singh, J., Kumar, D. and Tandon, N., "Development of nanocomposite grease: Microstructure, flow, and tribological studies", *Journal of Tribology*, Vol. 139, No. 5, (2017). doi: 10.1115/1.4035775.

11.   Su, B. and Lu, X.-t., "Study on the traction characteristics and model of a special grease for middle-low speed bearings", in 6th International Conference on Mechatronics, Materials, Biotechnology and Environment (ICMMBE 2016), Atlantis Press.

12.   Xu, N., Wang, X., Ma, R., Li, W. and Zhang, M., "Insights into the rheological behaviors and tribological performances of lubricating grease: Entangled structure of a fiber thickener and functional groups of a base oil", *New Journal of Chemistry*, Vol. 42, No. 2, (2018), 1484-1491. doi: 10.1039/C7NJ04833E.

13.   Ma, F., Li, Z., Wu, B. and An, Q., "An accurate calculation method for heat generation rate in grease-lubricated spherical roller bearings", *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, Vol. 230, No. 4, (2016), 472-480. doi: 10.1177/1350650115604873.

14.   Wurzbach, R.N., Bupp, E.W. and Williams, L.A., "Monitoring and thermal effects of relubrication of greased bearings", in Thermosense: Thermal Infrared Applications XXXIV, International Society for Optics and Photonics. Vol. 8354, 83540L.

15.   Neurouth, A., Changenet, C., Ville, F. and Arnaudon, A., "Thermal modeling of a grease lubricated thrust ball bearing", *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, Vol. 228, No. 11, (2014), 1266-1275. doi: 10.1177/1350650114526387.

16.   Ai, S., Wang, W., Wang, Y. and Zhao, Z., "Temperature rise of double-row tapered roller bearings analyzed with the thermal network method", *Tribology International*, Vol. 87, (2015), 11-22. doi: 10.1016/j.triboint.2015.02.011.

17. Ma, F., Li, Z., Qiu, S., Wu, B. and An, Q., "Transient thermal analysis of grease-lubricated spherical roller bearings", *Tribology International*, Vol. 93, (2016), 115-123. doi: 10.1016/j.triboint.2015.09.004.

18. Xue, J., Zhang, Y. and Wang, L., "The effects of grease filling amount on temperature performance of high-speed sealed angular-contact ball bearings", in 6th International Conference on Mechatronics, Materials, Biotechnology and Environment (ICMMBE 2016), Atlantis Press., 317-321.

19. Sengupta, A.R., Gupta, R. and Biswas, A., "Computational fluid dynamics analysis of stove systems for cooking and drying of muga silk", *Emerging Science Journal*, Vol. 3, No. 5, (2019), 285-292. doi: 10.28991/esj-2019-01191.

20. Jung, S., Peetz, S. and Koch, M., "Poeam–a method for the part orientation evaluation for additive manufacturing", in Sim-AM 2019: II International Conference on Simulation for Additive Manufacturing, CIMNE. 440-443.

21. Dirbude, S.B. and Maurya, V.K., "Effect of uniform magnetic field on melting at various rayleigh numbers", *Emerging Science Journal*, Vol. 3, No. 4, (2019), 263-273. doi: 10.28991/esj-2019-01189.

22. Touaibi, R., Koten, H. and Boydak, O., "Parametric study of an organic rankine cycle using different fluids", *Emerging Science Journal*, Vol. 4, No. 2, (2020), 122-128. doi: 10.28991/esj-2020-01216.

23. Harris, T.A., "Rolling bearing analysis, John Wiley and sons, (2001).

24. Burton, R.A. and Staph, H., "Thermally activated seizure of angular contact bearings", *ASLE Transactions*, Vol. 10, No. 4, (1967), 408-417. doi: 10.1080/05698196708972200.

25. Tong, B., Wang, G. and Sun, X., "Investigation of the fluid-solid thermal coupling for rolling bearing under oil-air lubrication", *Advances in Mechanical Engineering*, Vol. 7, No. 2, (2015), 835036. doi: 10.1155/2014/835036.

Persian Abstract

چکیده

تولید گریس ویژه این امکان را برای بلبرینگ های ساچمه ای با تماس با زاویه در سرعت و دما بالا فراهم می کند. بنابراین لازم است که خصوصیات گرمایی درون یاتاقانهای توپی زاویه دار با سرعت بالا و روغن کاری شده با گریس را بررسی کنیم. در این مقاله ، یک مدل شبیه سازی برای یاتاقان ساچمه ای زاویه ای با نرم افزار *CFD Fluent* ایجاد شد ، از روش اتصال کوپلینگ مایع و گرما برای تجزیه و تحلیل توزیع و جریان چربی ، انتقال گرما و میدان حرارت در داخل استفاده شد. تحمل چمبر. نتایج نشان داد که ، توزیع گریس در داخل محفظه تحمل بسیار ناهمگن است ، بیشتر چربی در دو طرف عناصر نورد در امتداد مسیر بیرونی توزیع شده و سرعت جریان آن بسیار کم است ، فقط کمی چربی روی سطح چسبیده شده است عناصر نورد ، قفس و حلقه داخلی ، سرعت جریان آن زیاد بود. توزیع چربی در داخل محفظه تحمل با افزایش سرعت تحمل ناهمگن تر می شود. در انتقال حرارت تحمل غالب بود و گریس نقش اساسی دارد ، همرفت هوا و گریس ناچیز بود. تحت تأثیر شرایط انتقال حرارت ، افزایش دما اجزای تحمل آشکارا متفاوت بود ، نوردهای نورد بالاترین دما را دارند ، دمای حلقه داخلی کمی پایین تر از عناصر نورد است و دمای حلقه خارجی پایین ترین است. آزمایش دمای تحمل بر روی دکل آزمایشی خود ساخته انجام شد و اعتبار و صحت شبیه سازی عددی را تأیید کرد. نتایج این مطالعه مرجعی برای طراحی روغنکاری و آنالیز حرارتی یاتاقان های توپ با زاویه تماس با روغن روانکاری شده با گریس فراهم می کند.