# 축방향 예압을 받는 각접촉 볼베어링의 마찰열 예측 모델 검증에 관한 연구

# A Validation of Prediction Model for the Frictional Heat Generation in the Angular Contact Ball Bearings under Axial Preload

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## 1. Introduction

Angular contact ball bearings are the essential mechanical elements reducing rotational friction, while supporting axial and radial preloads, in many industrial applications such as high precision machine tools. Still, frictional heat can occur between the rolling elements and raceways in the cases of high speed rotation and/or high preload.

An excessively high temperature increase due to the frictional heat could shorten the bearing life and ultimately cause the bearing failure. Also, if not treated properly, high frictional heat could adversely affect the high precision operation, since the temperature increase will cause the expansion of the bearing components. Therefore, it is important to predict the bearing temperature due to the frictional heat reasonably and appreciate the effects of frictional heat on the conditions of a bearing to ensure the high speed machining with high precision.

In this study, the thermal analysis has been carried out for an angular contact ball bearing which is subjected to the frictional heat at high speed rotation and high axial preload to assess the effect of rolling element expansion due to the bearing temperature increase.

## 2. Thermal Modeling and Analysis

The generation of heat in an angular contact ball bearing during its operation mainly comes from several different types of frictional torques (N·m) and it is estimated in this study by including the viscous friction ($M_v$), friction due to applied load ($M_l$), friction due to ball spinning ($M_s$), and friction due to gyroscopic motion of balls ($M_g$).(1) The total heat generation (in W) from those frictional torques is now found as

$$H_{tot} = 1.05\times 10^{-4}[n(M_v + M_l + M_g) + Zn_s M_s] \quad (1)$$

where $Z$ is the number of balls in the bearing and $n$ and $n_s$ are the bearing rotational speed and spinning speed (in rpm) of the bearing balls, respectively.

The dissipation of frictional heat is quite complicated, since there are many possible heat transfer mechanisms, however, the convection by the air and oil flows are expected to be the most dominant heat dissipation routes. Therefore, for those convective heat dissipation modes, the heat transfer coefficients are estimated from the empirical formulas and the modeling details are presented in the authors' previous study.(2) Also, lumped thermal model of bearing is used for the prediction of bearing temperature.

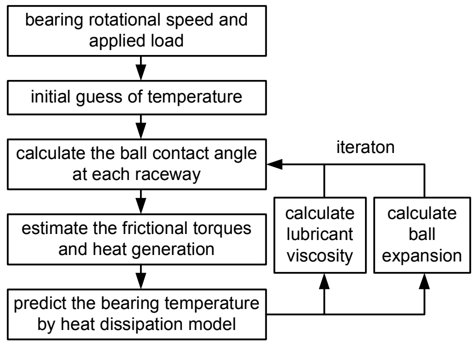


Fig. 1 Iterative calculation procedures of thermal analysis on the bearing temperature prediction.

Temperature dependence on the lubricant viscosity should be considered, since its viscosity exhibit a drastic change with the temperature increase. The lubricant viscosity is approximated by

$$\nu = \exp(a_1 + a_2 \ln T) \quad (2)$$

The calculation procedures used here are summarized in Fig. 1. The dynamic contact angles are first calculated using the method by Harris,[1] and then the frictional heat and the resulting temperature are estimated from the balance of heat generated and dissipated. In order to incorporate the ball expansion in the analysis, the iterative scheme is necessary to resolve the nonlinear relationship between the bearing temperature and the amount of ball expansion. Note that the temperature increase will cause the ball expansion, which in turn will affect the bearing geometry and the total heat generation. The expansion of ball diameter is simply estimated by using the thermal expansion coefficient of steel ($12\times10^{-6}$ /°C).

## 3. Results and Discussion

The angular contact ball bearing used is the NSK 7010C model. The number of the balls is 20. The pitch diameter is 65 mm and the ball diameter is 8.25 mm. The reference temperature is set to be 30°C. Oil mist type is selected for the lubrication method.

Figs. 1 and 2 show the effect of the axial preloads on the increase of bearing temperature and subsequent expansion of ball diameter, respectively, due to frictional heat generated at 5,000, 10,000, and 20,000 rpm. When compared, the inclusion of ball expansion in prediction presents noticeable difference in temperature rise from the case where ball expansion is not considered and the difference becomes larger both with the increase of bearing speed and axial preload. The ball diameter expansion does not look significant in Fig. 3, however, even the minute variation in the size of the rolling elements could cause a drastic change in bearing stiffness and hence the performance.

## 4. Conclusions

The present study presents the temperature prediction of angular contact ball bearing with the consideration of the temperature increase and the thermal expansion of balls due to frictional heat. Thermal expansion of rolling elements could significantly affect the bearing conditions such as frictional heat and the bearing stiffness and should be considered.

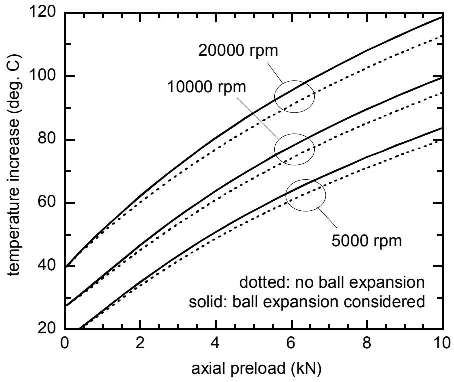


Fig. 2 The effects of the bearing speed and the axial preload on the bearing temperature increase.

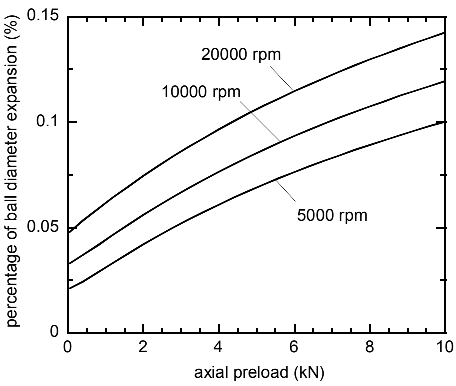


Fig. 3 The effects of the rotational speed and the axial preload on the ball diameter expansion.


## Acknowledgements

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