

Performance Prediction of Automotive Wheel Bearing Seals

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ABSTRACT

The primary functions of bearing seals are to prevent lubrication from escaping and foreign material from entering, the effectiveness of which is determined by the design of the seal lips. Bearings with low friction rotation are in great demand in the automotive market as a direct result of enforced vehicle fuel economy and reduced CO₂ emissions regulations. Therefore, bearings with good sealing function and low friction rotation are required. This makes designing a seal challenging as the ideologies of high seal-ability and low friction rotation tend to be contradictory. Current estimations of bearing seal friction or rotational torque require significant time and cost through empirical methods of trial and error. Research into the estimation of bearing rotational torque through numerical analysis, based on finite element methods, is the focal point of this paper. This development includes the calculation of bearing rotational torque using an axisymmetric model from the commercial software, ABAQUS. The seal rubber material properties were analyzed using hyperelastic methods for increased accuracy followed by seal rotational torque being calculated using the analysis results of the seal lip contact force. The theoretical results were compared to empirical results and strong correlation was confirmed.

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INTRODUCTION

Automotive wheel bearings play an important role through transmitting power and carrying vehicle weight. Within the automotive wheel bearings, the seals are installed in the bearing to prevent lubrication from escaping from within and foreign material from entering. [Figure 1](#) shows the configuration of a typical generation 3 automotive wheel bearings and wheel bearing seals. In the 1960s, wheel bearings were rapidly developed as a unit for lightweight and compact construction due to the development of a front wheel drive vehicle. Enhancements to wheel bearings include being greased and sealed for life for improved serviceability and function. The wheel bearing units have been further enhanced by incorporating wheel speed sensors and tone wheels. It also has transitioned into a more complex shape, because of its combination with surrounding components such as mounting flanges providing more complex functionality as shown in [Figure 2](#). In addition, as the warranty period of the vehicle increases, the life expectancy of the wheel bearings are required to be longer than that of the historical wheel bearings [1, 2, 3, 4].

Unlike other automobile parts, the durability of wheel bearings depends on, among other things, lubrication between the rolling elements and raceways. Degradation of this tribological system will negatively affect bearing life. One of the most influential factors for the reduction in service life is the foreign material introduced from outside, and the bearing seals play a role of preventing foreign material from entering. Since torque is generally inversely

proportional to sealing performance, lowering torque often deteriorates sealing performance for a given seal design. Therefore, proper design is required for optimal torque and sealing performance.

Recently, as the needs for electric vehicles and eco-friendly vehicles are emerging, reduction of fuel consumption and CO₂ emissions are becoming the most important issues of automobile companies.

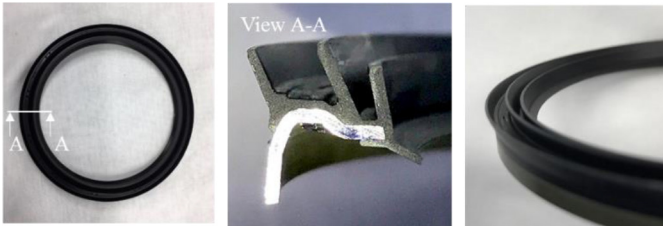
Although wheel bearings occupy a small portion of the fuel consumption of the entire vehicle, their importance is relatively large because they are rotating parts. The fuel consumption of wheel bearings is related to torque, which the seals play a key role among the many factors, hub surface finish, elastomer, and grease type, etc. It is necessary to investigate the seal to reduce the torque of wheel bearings.

Huh et al.[5] numerically calculated the contact normal force and starting torque of a lip for wheel bearings according to various design parameters. From the calculation results, they proposed a design value that satisfied the required design criteria for the starting torque and can exhibit sufficient sealing performance. Kim et al.[6] performed the deformation analysis of the wheel bearing seals and confirmed the reliability of the analysis results compared with the experiment results. Through the deformation analysis of the seal, the factors affecting the seal performance were predicted and the shape of each lip was optimized by applying the design of experiments to the obtained performance factors. Choi et al.[7] proposed a design to minimize the stress of seal lip and evaluated the seal performance through several experiments. However, in these studies, the reliability

of analysis was degraded by predicting the material properties of rubber, which is the most basic parameters of seal, only by testing uniaxial tension test or planar tension test.

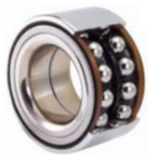


a. Configuration of automotive wheel bearings



b. Seal for automotive wheel bearings

Figure 1. The configuration of a typical generation 3 automotive wheel bearings and wheel bearing seals



a. Generation 1



b. Generation 2



c. Generation 3

Figure 2. Generation 1, 2, and 3 automotive wheel bearings

In this study, torque prediction of automotive wheel bearing seals was investigated. To predict the drag torque of the seal, numerical analysis based on finite element method was developed. The commercial software,

ABAQUS [8], was used. For evaluation of rubber material properties, uniaxial tension test, planar tension test, and equal-biaxial tension test were performed. The hyperelastic analysis was carried out by rubber material properties. To verify the reliability of analysis, drag testing was performed, and analysis results and test results were compared.

RUBBER MATERIAL

Hyperelastic Theory

A hyperelastic model is used to simulate the behavior of material, such as rubber, where large deformation occurs. The behavior of hyperelastic material is expressed as Equation 1 by using the concept that the rate of change of strain energy potential, U , per unit volume is equal to the rate of stress.

$$T = \frac{\partial U}{\partial \epsilon} \quad (1)$$

where, T is second Piola-Kirchhoff stress tensor and ϵ is the Green-Lagrange strain tensor.

Assuming that the deformation of rubber is to be elastic and isotropic, the strain energy potential, U , is expressed as function of invariant, I_1, I_2, I_3

$$U = U(I_1, I_2, I_3) \quad (2)$$

The strain invariant is expressed as principal stretch, λ , as follows:

$$\begin{aligned} I_1 &= \lambda_1^2 + \lambda_2^2 + \lambda_3^2 \\ I_2 &= \lambda_1^2 \lambda_2^2 + \lambda_2^2 \lambda_3^2 + \lambda_3^2 \lambda_1^2 \\ I_3 &= \lambda_1 \lambda_2 \lambda_3 \end{aligned} \quad (3)$$

In general, rubber material can be assumed to be incompressible so that the bulk modulus is considerably larger than shear modulus. Assuming the rubber material is incompressible, Equation 3 becomes 1, so Equation 2 can be expressed as function of I_1 and I_2 . Thus, the variance of strain energy potential, ∂U , can be expressed as Equation 4.

$$\partial U = \frac{\partial U}{\partial I_1} \delta I_1 + \frac{\partial U}{\partial I_2} \delta I_2 \quad (4)$$

As a material model to simulate hyperelastic behavior, various strain potentials such as Moony-Rivlin and Ogden in Equation 5, 6 are found [9], [10].

$$U = C_{10}(I_1 - 3) + C_{01}(I_2 - 3) + \frac{1}{D_1}(J^{el} - 1)^2 \quad (5)$$

