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Theoretical and Experimental Study of the Frictional Losses of Radial Shaft Seals for Industrial Gearbox

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

The improvement of the energy efficiency of industrial gear motors and gearboxes is a common problem for many gear unit manufacturers and users. As other mechanical components, the radial lip seals used in such units generate friction and heat and contribute to the energy losses of the mechanical systems. Today, simulation tools are today helping to improve the efficiency of mechanical systems, but accurate models for seal frictional losses need to be developed.

In this paper SKF presents an engineering model for radial lip seal friction based on a physical approach. The friction model includes the generation of friction due to rubber deformation and lubricant viscous shear between the surfaces of a seal and a shaft. The friction model is coupled with heat generation and seal thermal model. Indeed, seal friction and seal temperature are closely related: the heat generated in the sealing lip is conducted through the seal and shaft and dissipated into the environment. This increases the temperature of the lubricant, changing its viscosity and the temperature of the seal, changing the material properties.

The model is verified step by step in an extensive experimental study. Measurements of seal friction, seal temperature and lubricant film thickness have been performed for various industrial seals. The analyzed parameters are: surface speed, oil viscosity, seal material, seal size, seal lip type and duty cycles. The comparison between model predictions and experimental friction measurements shows a very good correlation. The model enables the use of the model to predict seal frictional losses in application and identify key parameters to design low friction sealing solutions.

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Introduction

Industrial gear units are widely used in power transmission systems. They are composed of shafts, gears, rolling elements bearings and dynamic lip seals. The performance of the seals is critical for the proper functioning of the system. The primary functions of the seals are to prevent the leakage of oil to the environment and to avoid the ingress of water or other contaminants into the mechanical system. Both can lead to a premature failure of the gear unit. In addition, the seals influence the system by generating friction and heat. The heat generated by the friction of the seals has an impact on the operational temperature of the gear unit as well as on the viscosity of the lubricant inside the unit. Moreover the seals contribute to the total energy losses of the mechanical system.

The improvement of the energy efficiency of industrial gear motors and gearboxes is a common challenge for OEMs and end-users. For instance energy efficiency classes are defined for electrical motors and gear motors. Moreover the power losses of gear units and seals can impact the total energy bill of an industrial installation. Therefore understanding seal friction generation and reducing it are essential challenges for seal manufacturers.

Simulation tools are commonly used to design mechanical components and systems. For the prediction of specific parameters like seal temperature or friction torque, specific models and calculation tools need to be developed. In this paper SKF presents an engineering model for the prediction of radial lip seal friction based on a physical approach. The friction model includes the generation of friction due to rubber dynamic deformation and lubricant viscous shear between the surfaces of a seal and a shaft. The friction model is coupled with a heat generation and seal thermal model. Indeed, seal friction and seal temperature are closely related: the heat generated in the sealing lip is conducted through the seal and shaft and dissipated into the environment. This changes for instance the lubricant viscosity.

The model is verified step by step in an extensive experimental study. Measurements of seal friction, seal temperature and lubricant film thickness have been performed for various dynamic lip seals. The analyzed parameters are: surface speed, oil viscosity, seal material, seal size, seal lip style and duty cycles. The correlation between model predictions and experimental friction measurements can therefore be verified.

This unique modelling capability allows selecting or developing shaft seals which would meet and exceed the demands of modern gearbox applications. It also enables gearbox manufacturers to bring to the market better performing and more reliable gearboxes.

Seal friction modeling

Physical phenomena influencing seal friction

The friction force, F_T , is the force resisting the relative motion of two bodies when a normal force, F_N , is applied to the contact between these bodies. The coefficient of friction, μ , can be defined as:

$$\mu = \frac{F_T}{F_N} \quad (1)$$

The coefficient of friction is not constant for radial shaft seals, which makes the prediction of seal frictional torque much more complicated. This has been demonstrated in various studies. In 2005, Plath [1] developed a seal friction model based on finite element analysis. They assumed initially a constant coefficient of friction for the seal-shaft contact. However this led to inaccurate results and they demonstrated that it was necessary to take into account the variation of temperature of the seal due to the generated frictional heat to accurately predict seal friction.

More recently, the studies from Haas [2, 3] have revealed the influence of surface roughness and of the duty parameter G (representing the lubricant viscosity, angular speed and contact pressure) on the

friction coefficient. Their papers show that the friction coefficient follows a Stribeck-like curve (see Figure 1). A transition between mixed and fully lubricated regime is clearly shown in the evolution of the friction coefficient.

The variations of coefficient of friction in a radial lip seal contact can be attributed to three phenomena:

- The variation of lubricant viscosity as a function of temperature. Typical curves for standard gearbox oils are shown in Figure 2.
- The variation of the coefficient of friction between rubber and steel. As shown by Grosch [4] and Hermann [5], the coefficient of friction varies significantly, between 0.1 and 3 in extreme cases, as a function of temperature, sliding speed and pressure in dry and lubricated conditions. This is due to the fact that for rubbery material, friction is essentially governed by the dissipation of energy during the dynamic deformation of the rubbery material on the counter-face.
- The variation of rubber modulus with temperature. A typical curve is shown in Figure 3.

Therefore the prediction of seal friction is a complex task and requires a model being able to predict the temperature in the seal and in the contact and to take into account the variations mentioned in the previous paragraph.

Friction model

The friction between the seal and shaft is considered to be generated by two main governing phenomena:

- Lubricant viscous shearing. This takes place in the contact between the lip and the shaft surface. The frictional force produced in this manner is defined as F_{lub} .
- Viscoelastic losses. This is due to dissipation in the rubber as its surface is dynamically deformed by the shaft roughness asperities. The frictional force generated by the rubber material is referred as $F_{material}$.

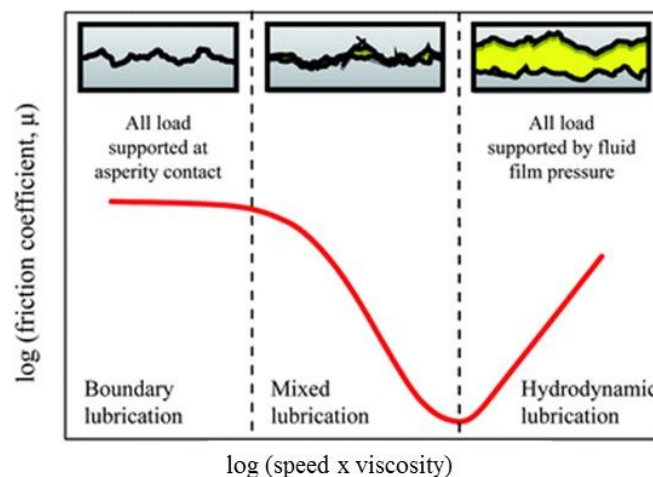


Figure 1. Stribeck curve: coefficient of friction as a function of contact speed and lubricant viscosity

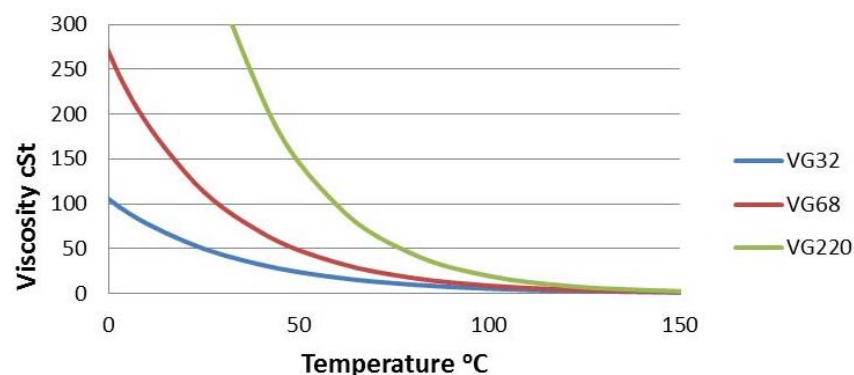


Figure 2. Lubricant viscosity as a function of temperature for VG 32, VG68 and VG220 oils