WEAR AND FAILURE MODEL FOR LIFETIME ESTIMATION OF SOLID LUBRICATED ROLLING CONTACTS

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ABSTRACT
Solid lubricants are applied in rolling bearings when conventional oil and grease lubrications do not meet the advanced requirements of modern technology. One factor which limits the application of solid lubricated rolling bearings is the absence of lifetime estimation. In contrast to conventional liquid lubricated rolling bearings, for which the lifetime can be calculated with the Lundberg and Palmgren theory based on contact fatigue, there is no calculation available for solid lubricated rolling bearings. In this paper, a prediction method of lifetime based on wear and failure models is represented. A modified dynamic four ball tester, used in testing dry lubricated rolling contacts, is also introduced.

KEYWORDS
Solid lubrication, wear model, lifetime estimation

INTRODUCTION
There are many machine elements with rolling contacts. Rolling bearings are machine elements commonly used with these sorts of contacts. Most rolling bearings are lubricated with oils and greases. Solid lubricants are seldom applied in rolling bearings, because they are generally more expensive than conventional oils and greases, and require expert attention both in mechanical design and in coating application techniques [1]. Solid lubricants in rolling bearings are applied only when conventional oil and grease lubrications do not meet the advanced requirements of modern technology. They are applied to areas where fluid lubricants are undesirable or ineffective, when it is necessary to avoid contaminating a product or a system, to provide prolonged storage or stationary service, or to work in a high vacuum and under extreme temperatures.

PROBLEM DEFINITION AND OBJECTIVE
One factor which limits the application of solid lubricated rolling contacts and rolling bearings is the absence of their lifetime estimation. In contrast to conventional liquid lubricated rolling bearings, for which the lifetime can be calculated with the Lundberg and Palmgren [2] theory, there is no available calculation for solid lubricated rolling bearings.

The well-known equation for calculating the nominal life of rolling bearings cannot be used in the case of solid lubrication due to:
- Different failure characteristics which determine the lifetime. The lifetime of rolling contacts coated with solid lubricants (graphite, MoS2, silver, gold, etc.) is determined by the thickness of these coatings. The rolling contact fails when the coating is worn out.
- Different wear mechanism of solid lubricated rolling bearings compared with oil and grease lubricated bearings. There is always a fluid film in rolling contacts lubricated by oil or grease. In contrast to conventional lubrication, the usage of dry lubrication in rolling contacts is associated with solid friction.

The main goal of this research project is to develop a prediction method for lifetime estimation of rolling contacts lubricated by solid lubricants, taking into consideration of the specific aspects of solid lubrication.

METHODOLOGY
The lifetime estimation of a technical wearing product can be carried out if the wear laws are known. There are two different ways to investigate wear laws [3]:
- Wear as a deterministic process
- Wear as a stochastic process

A more justified and faster lifetime prediction of rolling dry lubricated contacts can be made, if both approaches to wear study are combined. Thus, the developed prediction method is based on a mathematical wear model and a failure model which considers the stochastic phenomena of wear.

To achieve a good result, a systematic treatment of the problem is carried out which includes the following steps:
1) Wear analysis and determination of influence factors
2) Elaboration of wear model
3) Elaboration of failure model
4) Working out a prediction method for lifetime estimation.
Wear analysis of dry lubricated rolling contacts

To develop a wear model, the tribological processes of the system should first be meticulously examined. A physical model of dry lubricated rolling contacts is worked out, which makes it possible to ascertain the influence factors on wear (Figure 1).

**Fig. 1. Physical model of dry lubricated rolling contacts**

This model allows for the consideration of all phenomena which occur during the friction and wear processes. It shows micro and macro-contacts of rubbing surfaces, heat exchange, volumetric and adhesion interaction. If there is no physical model, researchers cannot examine the problem in detail. Thus the risk exists that only one aspect which seems more important to researchers will be considered [4].

**Wear model**

Generally the wear processes of dry lubricated rolling contacts can be described by the following formula:

\[
y = \left( v, t, p, \tau, \beta, \theta, \mu, E, H, R, \rho, A, \phi, \rho, \text{ worn} \right)
\]

(1)

\( y \) is the examined factor. In this case, it is the volume of materials worn away which also defines the thickness of the remained coating. The factors on the right side of the formula (1) determine the wear amount. These factors usually result from the property of rubbing couple, lubricants, and operating conditions. To reduce the number of factors which determine the wear, a dimensional analysis is applied. In this way non-dimensional criteria are generated which have a physical explication. By applying the method of Drozdov [5] and Brown [4], which is based on a similar theory, a connection is established between the non-dimensional criteria. As a result, a mathematical model of wear is developed.

**Failure model**

The friction and wear processes have a stochastic behavior [6]. The failure of the dry lubricated rolling contact is caused by continuous variation of the examined factor \( v \), respectively the thickness of the coating. The failure model is built on mathematical statistical methods and includes stochastic factors like wear velocity, tolerance of coating and running-in. The application of the failure model allows one to determine the reliability of rubbing contacts and to estimate their lifetime.

**Prediction Method**

Finally, on the basis of wear and failure models a prediction method is developed. Prediction is based on the physics of failures when parametric failures are primarily considered. The calculation takes into consideration all the factors which determine the working capacity of dry lubricated rolling contacts, and as a result, reliability indexes can be calculated.

**RESULTS AND CONCLUSION**

In this contribution, a procedure for the calculation of reliability and lifetime estimation of dry lubricated rolling contacts is proposed. The application of this method leads to the reduction of examined variables so that the number of trials decreases. This procedure simplifies the lifetime estimation of dry lubricated rolling contacts and makes it possible to find the non-linear relation between examined factors with the aid of linear methods.

For accelerated rolling wear tests with different solid lubricant coatings, the Institute of Product Development and Machine Elements has constructed a modified dynamic four ball tester (abbreviated as VKA), whose construction will be also explained.

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**REFERENCES**


