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Influence of an applied electric field on the torque of rotary lip seals on metal shafts. Part I: Effects of lip seal type

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Abstract

The paper presents some results of experiments on the tribocharging of selected engine oil and on the effect of an auxiliary external DC electric field on the work of machines which contain rotating parts such as shafts, crankshafts, etc. The research was especially aimed at the braking torque of a rotating metal shaft sealed with a lip seal and a possibility of reduction in the torque under external DC electric fields. DC voltage was applied between the stiffening ring of four different lip seals under test and a rotating, earthed shaft in a metal shaft-oil film-lip seal system. The relationships of the torque to the voltage of positive and negative polarities were established on the basis of measurements of the torque under steady-state conditions for a constant oil temperature and given different angular shaft velocities. In general, it was found that positive and negative DC electric fields produce adverse effects on the torque depending on the type of oils and on the material of which the lip seals were made. In only one case, the torque decreased with the increasing absolute value of the negative voltage applied.

Keywords: Tribocharging; DC electric field; Lip seal; Braking torque

1. Introduction

Lip seals are used for sealing the rotating parts and protecting against the leakage of oil out of the engine interior and the penetration of impurities from the outside. During the operation of a system: rotating shaft–oil–lip seal intense friction and irreversible energy losses occur. The lip seals are still being improved through the modification of the shape of a lip and of the material of which the seal was produced [1,2]. Moreover, the additives to oils are selected to reduce friction between a shaft, an oil film, and a seal [3].

The research, some results of which are presented here, was aimed at looking for the optimum combination of different lip seals and oils, as used in real engines, machines, and devices in which rotating parts occurred, for which an auxiliary external DC electric field could cause the braking torque of rotating shafts, crankshafts, etc. to be reduced [4]. A decrease in the torque means the reduction of friction, energy losses, and finally operating expenses.

The former research results [5] suggested the tribocharging in the oil film between a rotating shaft and a lip seal exert a rather significant influence on an increase in the torque. The tribocharging, also known as frictional electrification or frictional charging, or triboelectrification, occurs when two contacting surfaces of similar or dissimilar materials (insulator–insulator, insulator–conductor, conductor–conductor) "come together in a way that makes a certain amount of rubbing inevitable" [6]. This means that when rubbing or friction occurs between the contacting surfaces then both (or more) materials become charged. The natural tribocharging had the adverse effect on the operation of the system especially that the torque increased with the increasing level of electrification and temperature of the oils tested [5,7].

Also the authors found that an external DC electric field should play a role in the whole process and affect the

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operation of the system [4]. The application of a DC voltage to compensate for the adverse effect of natural electric fields established between the rotating shaft and lip seal (or rather its earthed metal seating) on the torque produced a negative, undesirable outcome. The DC electric field enhanced the adverse effect in some cases. Only one lip seal, that was used in the experiments and when was in contact with all the oils under test, revealed a positive and promising result which will be shown below and in Part II of this paper [8].

While the metal shaft rotates, in the interfaces: shaft–oil film and oil film–lip seal and in the inside of the oil film some various types of charging occur at the same time and exert an influence on the whole process considered. Depending on the type and quality [9] of oils used, the oil temperature, the material and state of a surface (roughness) [10] of a shaft, the material of which a given seal is made, and the intensity and way of contacts (friction) between the bodies, the different tribocharging of individual phases occurs since the contribution of each of the charging mechanisms to the total charging is different, as supposed.

If the movement of the charged oil particles from the middle part of an oil film towards the interfaces is possible, it is interesting whether or not an external electric field could enhance this process and, if so, under which conditions, and what the result would be. As supposed, under specific conditions an electric field could act as a field that compensates for the natural one of the net charge in the space between the shaft and seal.

2. Experimental methods and set-up

2.1. Methods

The various lip seals tested have stiffening rings and compression springs. The cross-section of such a typical lip seal is shown in Fig. 1. In our experiments, a stiffening ring was an electrode to measure the potential induced by the net charge of oil particles in the oil film between a rotating shaft and a lip seal. Also the ring served as another electrode to generate a DC electric field; that means that the voltage U_{DC} was applied between the same stiffening ring and the earthed rotating shaft to establish an external electric field across both interfaces and the oil film.

The torque M of the rotating shaft was measured with a torquemeter under steady-state conditions that is when the constant oil temperature T, the stable shaft's angular velocity n, or the constant voltage U_{DC} were reached.

The torque M was measured without any external electric field ($U_{DC} = 0$) for the natural tribocharging. After the voltage had been applied and the conditions stabilised, torque measurements were taken. Both torques were measured as a function of the voltage for the constant oil temperature (80 °C) while the angular shaft velocity was regulated within a range from 500 to 2000 rpm. The voltage could be controlled over a range of ± 1800 V.

2.2. Experimental set-up

The experiments on the influence of the external electric fields on the torque of rotating shafts for different engine oils and lip seals were performed in the experimental set-up built on the basis of a model engine. The whole experimental facility is shown in Fig. 2 and was built for investigating the friction, friction and torques, friction losses of rotating parts of machinery and for testing the lip seals for sealing these parts.

The schematic diagram (Fig. 2) shows the whole experimental facility which consists of: the housing of an oil chamber (1); a lip seal (2); the seal's stiffening ring (3); an oil tested (4); an air bearing (5); the sensor of a torquemeter (6); an electric motor (7); a steel shaft (8); a microprocessor-based system for controlling the angular velocity n and for measuring the torque M of the shaft and temperature T of oil (9); an oil heater (10), and a DC power supply (11). The chamber was filled with the oil tested up to a geometrical axis of the rotating shaft. The whole chamber was a model of part of a real engine.

The DC power supply (± 1800 V) energized the stiffening ring of a lip seal to produce an electric field between this ring and the rotating shaft. The electric field of two polarities was expected to compensate for the natural electric field of the net charge of oil particles to reduce the torque.

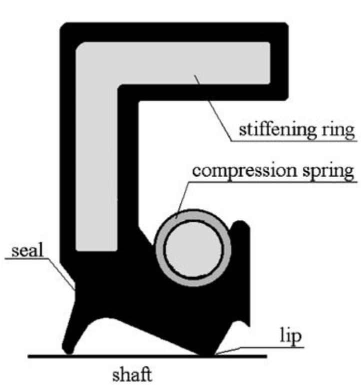

Fig. 1. Cross-section of a lip seal.

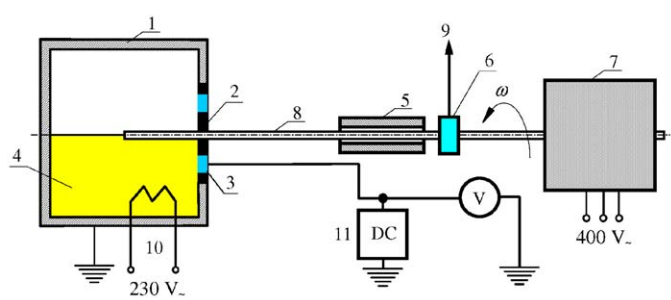

Fig. 2. Schematic diagram of the model engine and experimental set-up.