ISSN 2079-1372 Problems of Tribology, V. 30, No 4/118-2025, 31-36

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2025-118-4-31-36

Optical interferometry for assessing lubricating film properties

V. Akhmatov0009-0003-6325-5262**, D. Stetskyi**0009-0005-2610-1947

National Transport University, Ukraine
E-mail: vladislavakhmatov1@gmail.com

Received: 05 September 2025: Revised 30 September 2025: Accept: 15 October 2025

Abstract

The study investigated the influence of rolling speed and lubricant properties on the formation of a lubricating film in point contacts. The film thickness was measured using optical interferometry, which provides high-precision, real-time data. Experimental tests were conducted on a specially designed rig simulating rolling conditions in bearing assemblies. Analysis of various lubricants showed that kinematic viscosity, base oil type, and chemical composition significantly affect the lubrication behavior and film formation regime. It was found that increasing rolling speed leads to a transition from boundary to hydrodynamic lubrication, with substantial changes in film thickness. The results can be applied to optimize lubricant selection in bearings of precision mechanisms.

Key words: tribological system, point contact, friction unit, lubricating film, optical interferometry, EGD lubrication.

Introduction

Various methods are used in modern tribology to measure lubricating film thickness, differing in the physical principles that determine this parameter. One of the most precise methods is optical interferometry [1].

This technique is based on the phenomenon of light interference - the superposition of coherent waves forming an interference pattern. Using this method, it is possible to obtain data on changes in the lubricating film thickness with nanometer precision in real time, which is a critical aspect in studying tribological processes in precision mechanisms.

Experimental results obtained using interferometry are the most accurate among other widely applied optical methods for investigating lubricating film thickness.

The purpose of the work

The aim of this study is to evaluate the influence of rolling speed on the formation of a lubricating film in local contact zones when using lubricants with different operational characteristics.

This work also highlights the effectiveness of optical interferometry in tribological research. Wider adoption of this method allows for non-contact measurements and real-time data acquisition under dynamic conditions in rolling bearing mechanisms. This, in turn, improves the capability to accurately assess lubricant performance, supports the development of new lubricant formulations, and aids in predicting the service life of friction units.

Methodical

The optical interferometry method for measuring lubricant film thickness makes it possible to determine the value of the lubricating film while accounting for the pattern of lubricant supply and distribution in the vicinity of the friction contact and the actual contact area. The use of a glass disk or glass cylinder (transparent material) as the indenter, together with a steel ball or steel cylinder as the counterbody—whose properties are nearly identical—enables the optical interferometry method to find its widest application in model experiments.

To obtain a clear colored interference pattern, a white light source is required, unlike monochromatic light. Each color interferes at a specific wavelength, so each lubricating film thickness in the friction contact corresponds to a specific color [2].

The schematic diagram of the interferometric system is shown in

Fig. . To enhance visibility, a semi-transparent chromium coating, 170 A° thick, is deposited on the surface of the glass disk by vacuum evaporation. This provides an optimal reflectivity of approximately 18% (with an absorption of about 25%).

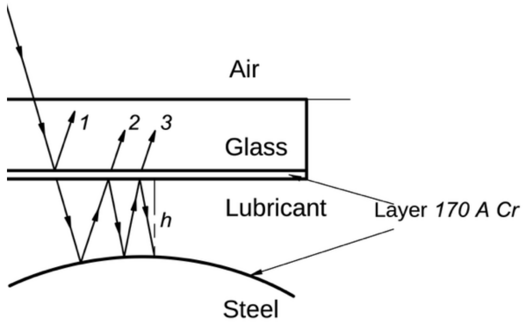

Fig. 1. Schematic diagram of the interferometric system

Investigation of the lubrication process in point contact using pptical interferometry

Experimental investigations were conducted using a test rig designed to enable precise measurement of ultrathin lubricating films via optical interferometry. The system accounts for the lubrication supply and distribution within the point contact region, as well as the actual contact area, and allows for real-time recording of results through video capture. The contacting pair, comprising a steel ball and a glass disk, is shown in **Fig. 3**. A general view of the test rig, which reproduces conditions analogous to the rolling contact between surfaces of the outer ring of a self-aligning ball bearing, is presented in **Fig. 2**.

Fig. 1. General view of the setup with auxiliary equipment

Fig. 2. Contacting pair: steel ball – glass disk

The object of investigation (**Fig. 3**) is the contact zone between a glass disk (1) and a standard steel ball (10) with a diameter of 25.4 mm and surface finish Ra < 0.025 µm, pressed against the disk by a load.

To enhance the visibility of interference fringes, a thin chromium layer of approximately 170 A° was deposited on the disk surface via vacuum evaporation. The steel ball was mounted on freely rotating supports (8) to minimize frictional resistance. These supports were fixed in a housing (2), which, together with the lubricant bath (9), was fabricated as a single structural element. This design allowed for near-ideal rolling conditions with minimal sliding, preventing excessive lubricant heating that could reduce viscosity in the contact zone. High sliding would cause additional energy dissipation due to viscous friction, adversely affecting experimental accuracy.

Disk rotation was driven by an electric motor (7) transmitting torque through a single-stage transmission (6). Contact load was controlled via a lever mechanism, where the primary pressure was applied through a movable bearing (3) mounted on shaft (4). Rotational speed was monitored with a non-contact electronic tachometer (5), recording the disk's revolutions. Lubricant temperature was measured using a thermocouple positioned close to the friction contact area.

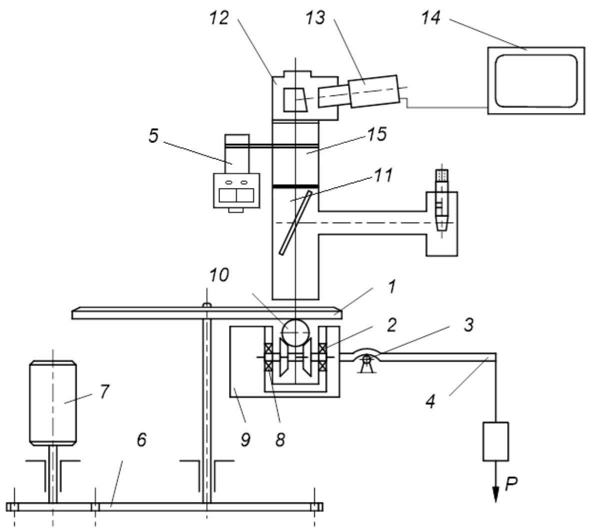

Fig. 3. Schematic of the friction unit

The contact zone (ball–plane) is observed using a microscope objective (11). To analyze the interference pattern in the friction area, a video recording system is employed, consisting of a transition tube (15), a microphotoadapter (12), a video camera (13), and a television monitor (14) on which the image is displayed.

Influence of lubricant components on the formation of lubricant film thickness under pure rolling conditions

An important factor determining the elastohydrodynamic (EHD) lubrication of a point contact is the dependence of the lubricant film thickness on the rolling speed [3]. Analyzing the variation of this thickness makes it possible to evaluate the influence of the rheological characteristics of different lubricants on the performance efficiency of mechanisms equipped with rolling bearings [4].

Maintaining pure rolling conditions is essential to prevent lubricant overheating, which can lead to a decrease in its viscosity at the inlet to the contact zone. This phenomenon results from slip and the dissipation of energy due to viscous friction. To ensure pure rolling in a ball–disk contact, the condition $V_1 = V_2$ must be satisfied in the following equation:

$$V_1 - V_2 = \frac{2\pi}{60} \cdot (\omega_1 \cdot r_1 - \omega_2 \cdot r_2), \quad (1)$$

Where V_1, V_2 are the linear velocities of the ball and the disk; r_1, r_2 are their radii; ω_1 i ω_2 – the angular velocities of the ball and the disk.

To ensure pure rolling, the condition $\omega_1 = 3\omega_2$ must be satisfied, meaning that the angular velocity of the ball should be three times greater than that of the disk. Under these conditions, equation (1) takes the following form:

$$r_2 = 3r_1 \quad (2)$$

To ensure the condition of pure rolling, the ball must be positioned at a distance from the center of disk rotation equal to three times its own radius.

The study focuses on evaluating the influence of rolling speed on the formation of the lubricant film in the central contact area. Five types of lubricants were analyzed experimentally: 1. transmission fluid Total SAE 85W90, 2. automatic transmission fluid Total SAE ATF, 3. engine oil Total SAE 15W40, 4. engine oil Total SAE 10W40, 5. universal motor–transmission oil Total SAE 25W. The experiments were carried out within a speed range from 0 to 1.8 m/s at a constant temperature of 20 °C. The contact stress reached 251.5 MPa. The lubricant film thickness was measured using optical interferometry.

To describe the lubrication process, a dimensionless parameter λ is used, which characterizes the lubrication regime and is calculated by the following expression:

$$\lambda = \frac{h}{\sqrt{R_{a1}^2 + R_{a2}^2}} \quad (3)$$

where h – the lubricant film thickness (μm),

R_{a1} – the arithmetic average surface roughness of the glass disk (μm),

R_{a2} – the arithmetic average surface roughness of the steel ball (or roller) (μm).

The classification of lubrication regimes according to the value of λ is as follows: λ= 0 – 1 – semi-dry; λ= 1– 1,5 – boundary; λ= 1,5 – 3 – mixed with boundary predominance; λ= 3 – 4 – elastohydrodynamic; λ≥ 4 – hydrodynamic.

Results of studying

When using Total SAE ATF, it was found that the lubricant film forms at a speed of $V_{\Sigma\kappa}$=0,24 m/s, and the actual film thickness reached h_d=0,128×10^{-6}m (**Fig. 4**), corresponding to a boundary lubrication regime with λ =1,28 (**Fig. 5**).

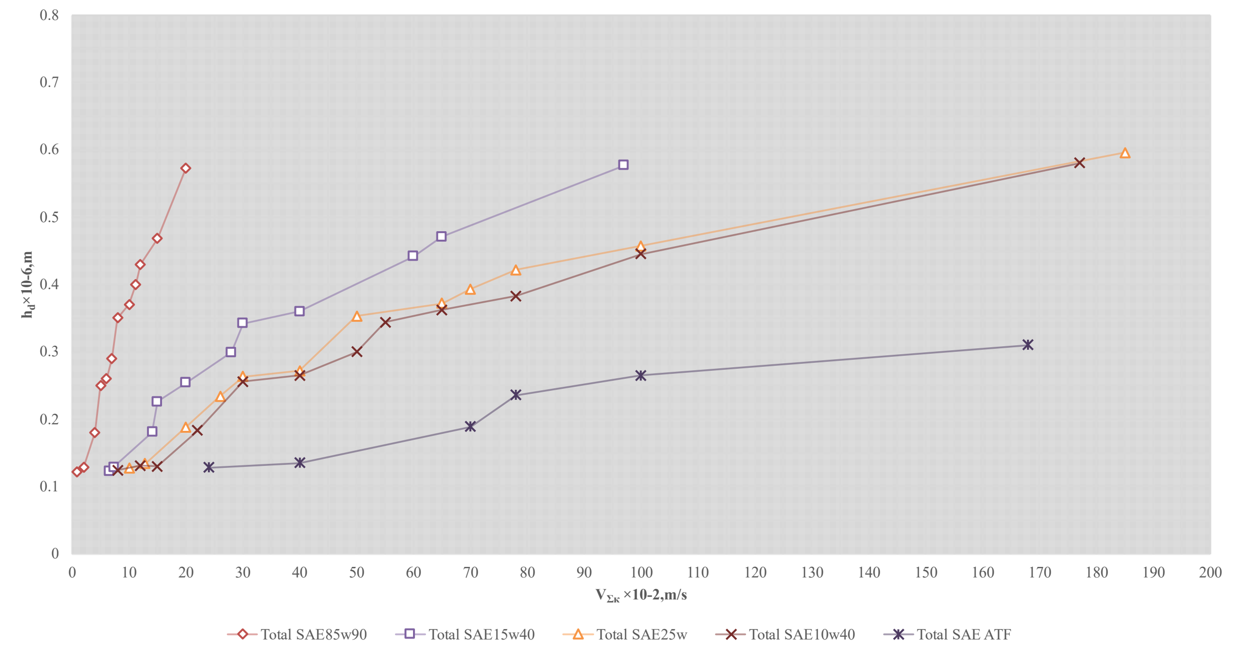

Fig. 4. Dependence of the actual lubricant film thickness h_d on the total rolling speed $V_{\Sigma\kappa}$

As the rolling speed increases, the lubricant film thickness also grows, reaching h_d=0,31×10^{-6}m at $V_{\Sigma\kappa}$=1,68 m/s, corresponding to a hydrodynamic lubrication regime with λ=3,10 (**Fig. 5**).

Experimental data show that when using the transmission oil Total SAE 85W90 at a total rolling speed of $V_{\Sigma\kappa}$=0,08 m/s a lubricant film with a thickness of h_d=0,122×10^{-6}m (**Fig. 4**), forms, corresponding to a boundary lubrication regime with λ=1,22 (**Fig. 5**). Upon reaching $V_{\Sigma\kappa}$=0,112 m/s, the film thickness increases to h_d=0,4×10^{-6}m (**Fig. 4**), establishing a hydrodynamic lubrication regime with λ=4 (**Fig. 5**) which persists for $V_{\Sigma\kappa}$ >0,2 m/s.

Analysis of Total SAE 85W90 characteristics compared to Total SAE ATF shows that the former provides a lubricant film thickness that is 79% greater than that of Total SAE ATF.

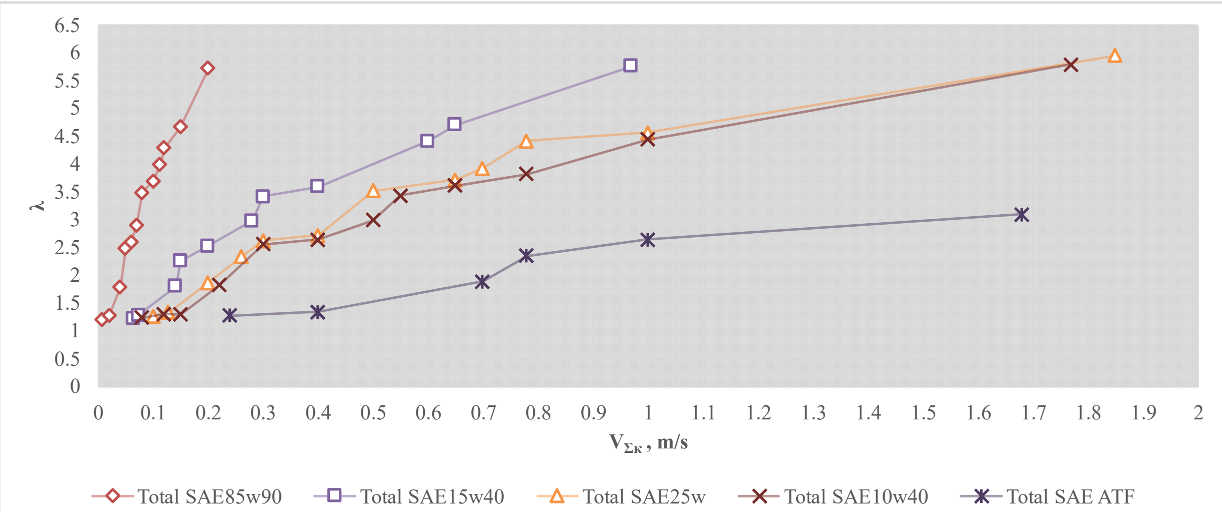

Fig. 5. Dependence of the lubrication regime λ on the total rolling speed $V_{\Sigma\kappa}$

The study using the engine oil Total SAE 15W40 showed that at a rolling speed of $V_{\Sigma к}$=0,065 m/s, a lubricant film with a thickness of h_d=0,123×10^{-6}m (**Fig. 4**) is formed, corresponding to a boundary lubrication regime with λ=1,23 (**Fig. 5**). When the rolling speed reaches $V_{\Sigma к}$=0,60 m/s, the lubricant film thickness increases to h_d=0,442×10^{-6}m (**Fig. 4**), establishing a hydrodynamic lubrication regime with λ=4,22 (**Fig. 5**), which remains dominant up to $V_{\Sigma к}$ = 1,05 m/s.

When using the engine oil Total SAE 10W40 as a lubricant, it was found that the film begins to form at a total rolling speed of $V_{\Sigma к}$=0,08m/s, with a film thickness of h_d=0,124×10^{-6}m (**Fig. 4**), corresponding to a boundary lubrication regime with λ=1,24 (**Fig. 5**). Upon reaching $V_{\Sigma к}$=1m/s, the film thickness increases to h_d=0,445×10^{-6}m (**Fig. 4**), resulting in a hydrodynamic lubrication regime with λ=4,45 (**Fig. 5**), which persists up to $V_{\Sigma к}$=1,96m/s.

Comparing the properties of this oil with those described above, it can be noted that Total SAE 10W40 produces nearly the same lubricant film thickness (according to the interferometric method) as Total SAE 15W40, with a difference of only 1–2%. However, film formation occurs at higher rolling speeds (by about 67%), indicating the use of a different base oil. Total SAE 15W40 employs mineral base oil I-40, while Total SAE 10W40 is formulated with synthetic base oil PAO-8.

The use of the universal motor–transmission oil Total 25W made it possible to determine that the lubricant film formation begins at a rolling speed of $V_{\Sigma к}$ = 0.1, m/s corresponding to a boundary lubrication regime with λ = 1.27 (**Fig. 5**), and an actual film thickness of h_d=0,127×10^{-6}m (**Fig. 4**). When the rolling speed reaches $V_{\Sigma к}$= 0.78m/s, the film thickness increases to h_d=0,422×10^{-6}m , establishing a hydrodynamic lubrication regime with λ = 4.2 (**Fig. 5**), which remains dominant up to $V_{\Sigma к}$ = 1.39 m/s.The experimental results indicate that this lubricant provides a film thickness 47% greater than that of Total SAE ATF, while its film formation rate exceeds that of Total SAE 10W40 by 14%. At the same time, it is inferior to oils such as Total SAE 85W90 (by 92%) and Total SAE 15W40 (by 31%).

The conducted studies show that the process of lubricant film formation during start-up is directly related to the rolling speed. As this speed increases, the film thickness in the center of the contact grows, allowing a transition from boundary to hydrodynamic lubrication. In this process, the kinematic viscosity of the oil, which largely depends on its base composition, plays an important role. The additive content in such oils typically ranges from 10–15%. Total SAE 85W90, containing high-molecular-weight petroleum fractions (up to 80%), forms the lubricant film thickness optimally.

Compared to other lubricants, Total SAE 25W accelerates the process due to a viscosity modifier of up to 8%, which increases the time required for film formation. It acts effectively at temperatures above 50 °C, promoting a significant increase in film thickness.

A comparison of the mineral oil Total SAE 15W40 with semi-synthetic oils Total SAE 10W40 and Total SAE 25W is also of interest. The lower efficiency of synthetic oils in film formation may be associated with the adhesion properties between polyalphaolefins and glass surfaces, where the interaction force is weaker than between petroleum components and glass. Total SAE ATF exhibits the fastest lubricant film formation among all tested samples, ensuring the quickest transition to the boundary lubrication regime. This is likely explained by its low kinematic viscosity, which is on average 60% lower than that of the other oils.

Conclusions

From this, it follows that when selecting a lubricant for a specific component, it is important to consider not only the kinematic viscosity but also the chemical composition of the oil and the properties of the interacting surface materials. This approach allows achieving optimal conditions for the rapid formation of the lubricant film during start-up and for maintaining a stable lubrication regime during operation, which ultimately ensures the durability and reliability of the friction system.

References

1. Milanenko A.A. The lubricating effect of oils under point contact friction conditions: abundant lubrication and lubricant starvation: Ph.D. thesis: 05.02.04 / A.A. Milanenko; National Aviation University. – Kyiv, 2000. – 214 p.

2. Savchuk A.N. Kinetics of changes in lubricating properties of transmission and motor oils under conditions of abundant and limited lubrication: Ph.D. thesis: 05.02.04 / A.N. Savchuk; National Transport University. – Kyiv, 2010. – 210 p.

3. Dmytrychenko M.F., Milanenko O.A. Lubricating action of oils under elastohydrodynamic lubrication conditions / M.F. Dmytrychenko, O.A. Milanenko // Monograph. – Kyiv: Ukravtodor, 2009. – 184 p.

4. Dmytrychenko M.F. Elastohydrodynamics: theory and practice / M.F. Dmytrychenko // Monograph. – Lviv: Publishing House of Lviv Polytechnic National University, 2000. – 224 p.

Ахматов В., Стецький Д. Оптична інтерферометрія як засіб оцінки характеристик мастильного шару.

У роботі досліджено вплив швидкості кочення та властивостей мастильного матеріалу на утворення мастильного шару в точковому контакті. Для вимірювання товщини мастильної плівки застосовано метод оптичної інтерферометрії, що забезпечує високу точність у реальному часі. Експериментальні дослідження проводилися на спеціально розробленому стенді, який моделює умови кочення в підшипникових вузлах. Аналіз різних типів мастильних матеріалів показав, що кінематична в'язкість, базова основа та хімічний склад олив істотно впливають на характер змащення та режим утворення плівки. Встановлено, що зі збільшенням швидкості кочення відбувається перехід від граничного до гідродинамічного режиму змащення, а мастильна плівка значно змінює свою товщину. Отримані результати можуть бути використані для оптимізації вибору мастильних матеріалів у підшипникових вузлах точних механізмів.

Key words: триботехнічна система, точковий контакт, вузол тертя, мастильний шар, оптична інтерферометрія, ЕГД мащення