Experimental test rig for oil film thickness study

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ABSTRACT

The paper presents some aspects regarding the conception and construction of an experimental test rig used for studies concerning friction phenomenon of threads immersed in oil, maintained in a state of motion with constant velocity. The structure of the experimental test rig, testing methodology, experimental results and the applicability of the experimental set-up were detailed. To validate the experimental equipment and method, the obtained values were correlated with those obtained analytically. A good correlation was found, which attests the applicability of the test rig and method.

Keywords:

friction, thread, lubricant, test rig, film thickness, optic fiber .

INTRODUCTION

One of the most important factors responsible for energy loss, wear and damages in machines is friction. Due to those reasons, friction must be controlled or reduced to an acceptable level in order to have a small influence in machine reliability. One of the multiple methods to reduce friction is lubrication [1, 2]. From the oldest times, humans used different substances to reduce friction such as: water, animal fat, mineral oil, vegetable oil etc. [3]. Nowadays, lubricants are used in multiple domains, such as: automotive, aerospace, cryogenic equipment etc., to reduce friction, to increase reliability, to reduce corrosion and energy loss, [4]. Having such a great applicability, the lubricants have to ensure a large spectrum of properties, impossible to be achieved by a single type of lubricant. Due to these reasons, a large variety of lubricants is available on the market. The best applicability for each lubricant can be found by knowing his properties.

The paper presents an experimental study conducted on an original test rig conceived to evaluate the deformations of an elastic thread immersed in a moving mineral oil layer by measuring the film thickness. Oil film thickness is directly dependent on lubricant viscosity, the geometry of the interstitial gap and relative velocity. The experimental test rig presented in this paper has the ability to maintain constant the velocity and lubricant viscosity, while the evaluation of lubricant quality can be made by analyzing the geometry of the interstitial gap generated by the lubricant flow. A practical application of the threads immersed in oil is met in turbine seals, [5].

Therefore, authors aim is to create experimental equipment that meets all the conditions required to obtain correct data sets with the highest possible accuracy.

THE EXPERIMENTAL TEST RIG

In order to study the friction between the thread and a fluid, the deformation of an elastic thread immersed in a moving oil layer was evaluated. For this purpose, an experimental test rig was conceived and built. The structure of the experimental test rig is presented in Figure 1.

The experimental test rig consists in two rotational wheels with a rubber belt wrapped on them which drives a constant amount of oil in a convergent interstitial gap formed between the thread and the belt. One of the wheels is directly connected to a DC electric motor which rotates with constant velocity while the second one is used to stretch the belt and to maintain a constant relative position between thread and belt. The motor speed can be modified to a desired value by voltage adjustment. The rotational wheels were conceived with a circumferential channel in order to prevent belt twisting. Also, the circumferential channel must drive a sufficient amount of oil in the interstitial gap formed between the thread and the upper surface of the belt in order to highlight the oil film thickness and thread bending due to oil moving. To achieve this goal the circumferential channel was conceived and built with 6 mm depth. The driving wheels were manufactured from poly-methyl-methacrylate (PMMA) due to good transparency properties and high friction pair with the rubber belt.

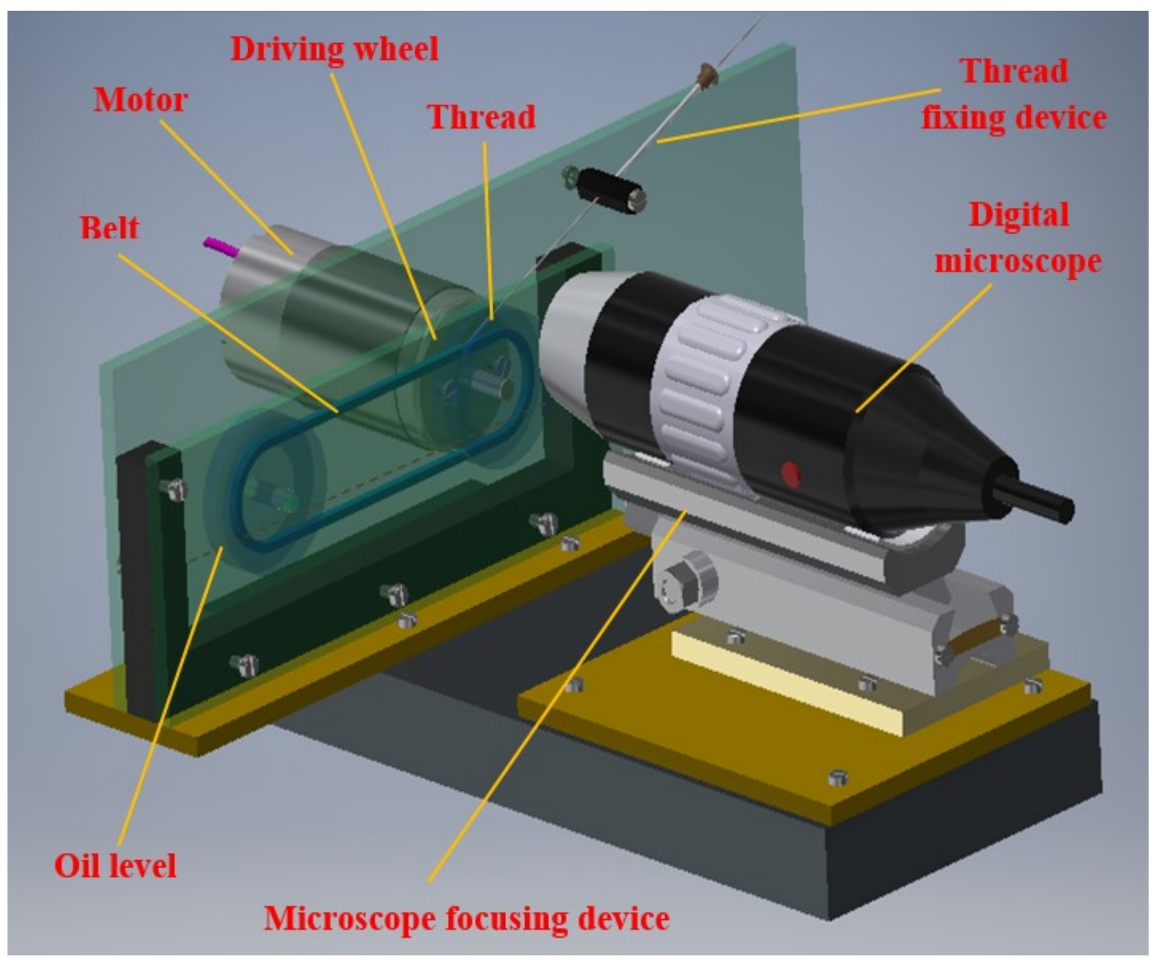


Figure 1. The experimental test rig

For tests, an optic fiber thread was used having 0.246 mm radius. One of the ends of the thread is fixed using a special device while the second one is placed so as to touch the upper surface of the belt in the initial state. The special device used to fix the optic fiber thread is placed in such a way to obtain a convergent interstitial gap between the thread and the upper surface of the belt. The thread length remains constant on the entire testing period.

A rubber belt having 1x1.5mm rectangular cross section and 196 mm length was also used. The rubber belt was wrapped on the rotational wheels and must drive oil in the interstitial gap.

The wheels-belt assembly is closed in a rectangular box having transparent walls to allow the visualization of the thread deviation. The assembly is partially immersed in oil, which attaches to the belt surface and to the circumferential channel walls due to intermolecular interactions and then, is driven into the interstitial gap. The attached oil layer, due to relative motion, acts upon the thread's free end and bends the thread from its initial position. The deviation of the thread is visualized and recorded using a digital microscope.

To obtain clear images of the thread's deviation, a focusing device was used to adjust the relative position between microscope and the testing device. The device is capable to adjust the distance between microscope and the testing device without changing the relative orientation.

The recorded images of the thread's deviation were analyzed using specialized Autodesk CAD software

TESTING PROCEDURE

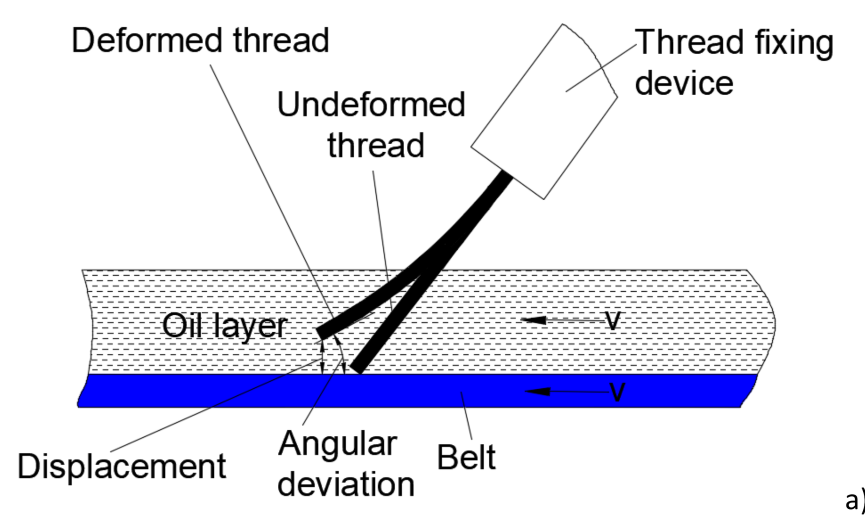
The transparent rectangular box containing the wheel-belt assembly was filed with the tested mineral oil. The oil level from the transparent box was adjusted in such a way to allow wheels and belt to be partially immersed and to attach oil to the immersed surfaces. M25W/HOS3 oil was used for tests, having the viscosity between 8.5 and 9.5ºE. The tests were conducted at 20 ºC.

The DC voltage was adjusted from the power supply to a desired value in order control the motor speed. Tests were conducted at: 4V, 6V, 9V and 12V. The motor speed levels corresponding to those voltages were: 20rpm, 28rpm, 44rpm and 57rpm.

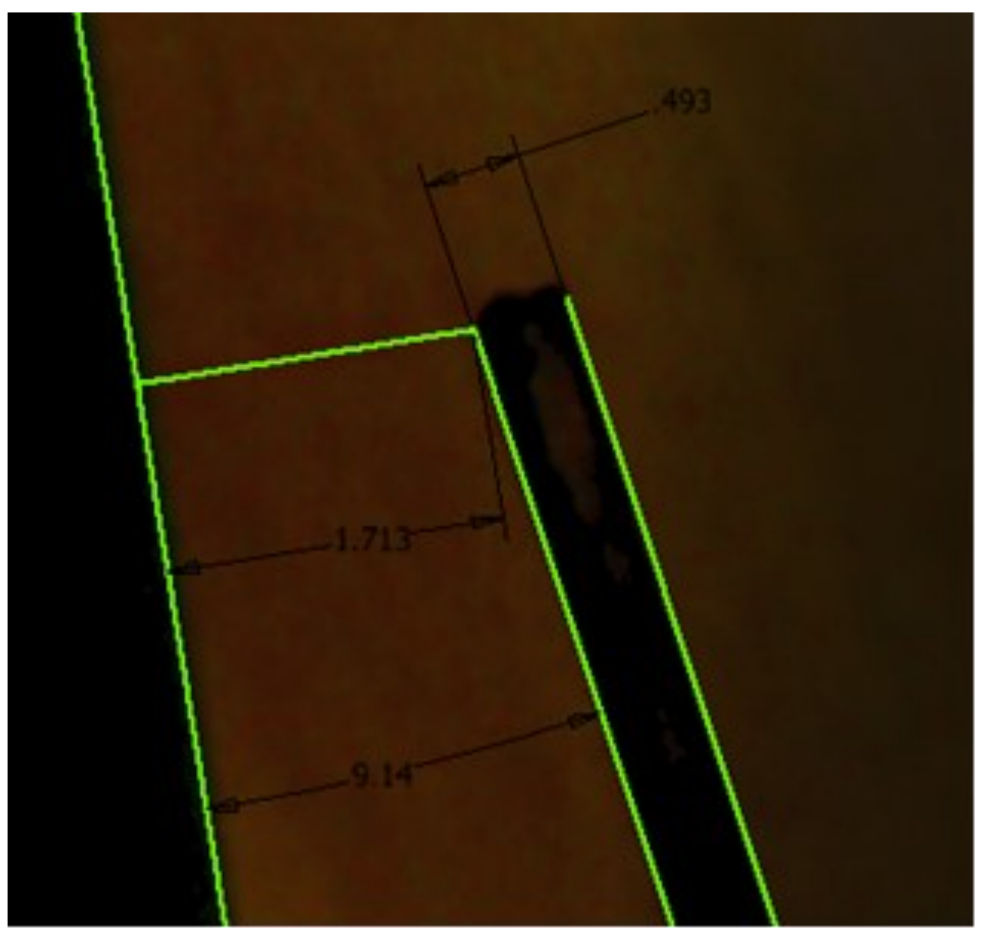
The relative position between microscope and the testing device was adjusted in order to obtain the maximum image accuracy. The position of the threads towards belt upper surface was adjusted. The free end of the thread must be close to belt surface. When this condition is achieved, the test can be initiated. The electric motor is turned on and the image with the thread bending is recorded. For each speed level, images of the deformed thread were captured. The obtained images were analyzed using CAD software. The displacement and the angular deviation of the free end of the thread were evaluated. These parameters were quantified by comparing their magnitude with the thread radius

RESULTS

The deformations obtained for four speed regimes were evaluated, corresponding to: 20rpm, 28rpm, 44rpm, 56rpm. For each speed level, the angular deviation of the thread and the free end displacements were recorded using the video microscope and then, the obtained images were processed in Autodesk Inventor software. In Figure 2.a is represented the principle for thread deformation measurement, while in Figure 2.b are presented the obtained result for 0.042m/s relative velocity



a)



b)

Figure 2. a) Principle for thread deformation measurement; b) Results for 0.042m/s

The deformation of the elastic thread generated by a moving oil layer was measured and represented graphically. The obtained results are presented in Figure 3.

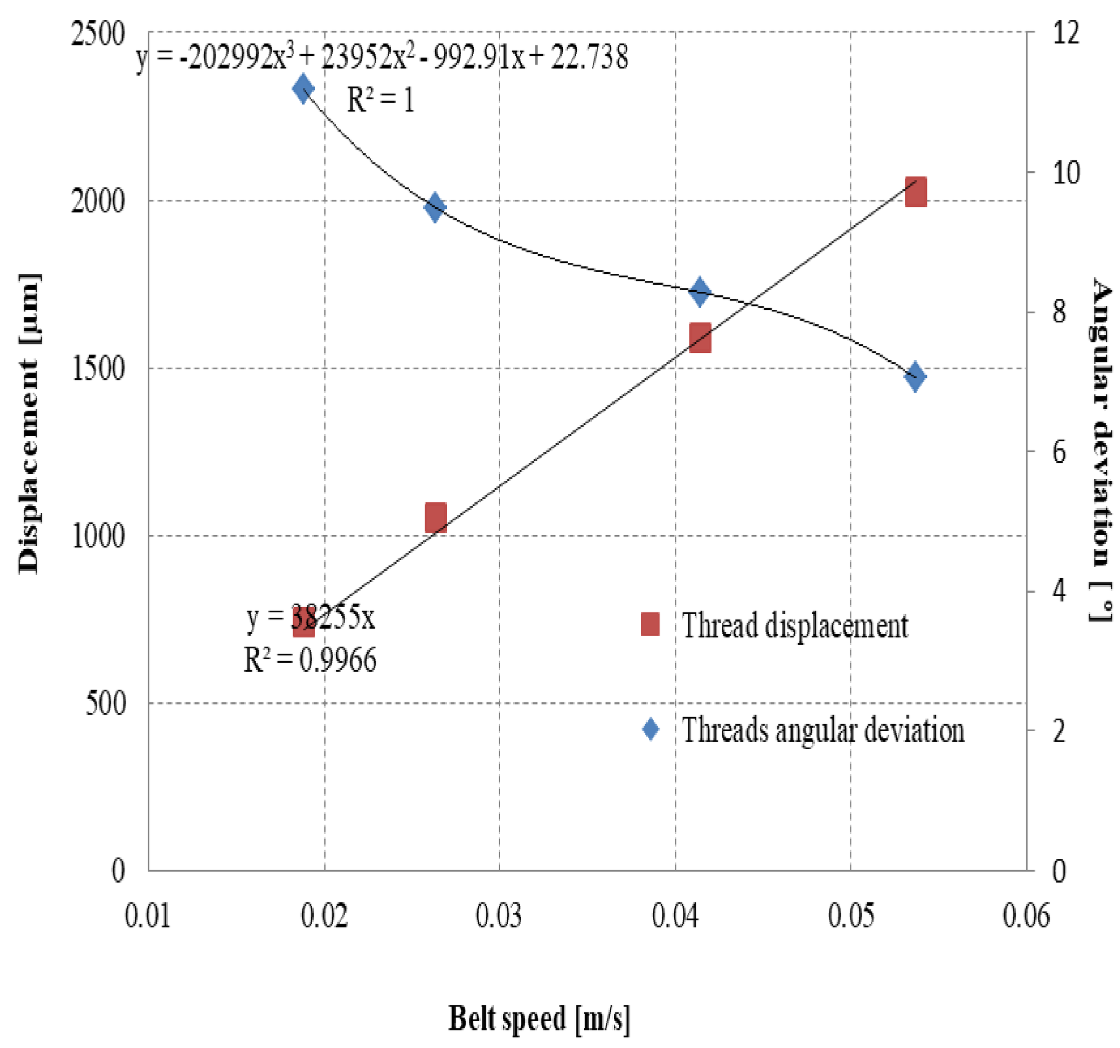


Figure 3. Experimental results obtained for thread dispacement – belt speed correlation and angular deviation-belt speed

In order to validate the experimental results and the experimental test rig, an analytical calculus of the oil film thickness was made. The material used for optic fiber threads is presented in literature as being nonlinear elastic, [6]. For this type of materials, Young's modulus is expressed by an equation having the following form:

$$E = E_0\left(1+\alpha\cdot\varepsilon+\beta\cdot\varepsilon^2\right), \tag{1}$$

where, according to Glaesemann [6]: $\alpha = 3.2$, $\beta = 8.48$, $\varepsilon = r/R$ and $E_0 = 70.2GPa$.

The generated load by the oil flow against the optic fiber threads can be equated to a beam, fixed to one end and subjected to an equivalent concentrated force to the second one. The equation for the generated oil pressure against the optic fiber thread can be written as:

$$p = \frac{F}{A} = \frac{3\cdot h\cdot E_0\cdot\left(1+\alpha\cdot\varepsilon+\beta\cdot\varepsilon^2\right)\cdot I_z}{l^3\cdot\left(2\cdot\pi\cdot r\cdot l+\pi\cdot r^2\right)}, \tag{2}$$

where, F is the equivalent concentrated force expressed by $F = \frac{3\cdot h\cdot E\cdot I_z}{l^3}$, $l = 36mm$ is the thread length, $r = 0.246mm$ is the threads radius, h is the thread's displacement along vertical direction, I_z is the cross section momentum of inertia.

Also, literature presents for hydrodynamic journal bearings an equation for pressure distribution having the following form, [7]:

$$p(x,y) = \frac{3\cdot\eta\cdot v\cdot\alpha_p\cdot y^3}{h^3} - \frac{3}{4}\cdot\frac{\eta\cdot v\cdot L^2}{x^3\cdot\alpha_p^{\,2}}, \tag{3}$$

where, η is cinematic viscosity, v oil velocity, α_p interstitial gap angle, L interstitial gap length.

Customizing equation (3) for infinite short hydrodynamic journal bearings case and equating the two relations for pressure, the lubricant film height was obtained for each speed regime.

$$h = \frac{12^{1/3}\cdot\eta^{1/3}\cdot v^{1/3}\cdot\alpha_p\cdot y^{2/3}\cdot x}{\left(3\cdot\eta\cdot v\cdot L^2+4\cdot p\cdot\alpha_p^{\,2}\cdot x^3\right)^{1/3}}. \tag{4}$$

The experimental values were correlated with those obtained from calculus. A relative error of approximately 3% was obtained between values. The comparison of the experimental results with the analytical ones was graphically represented in Figure 4.

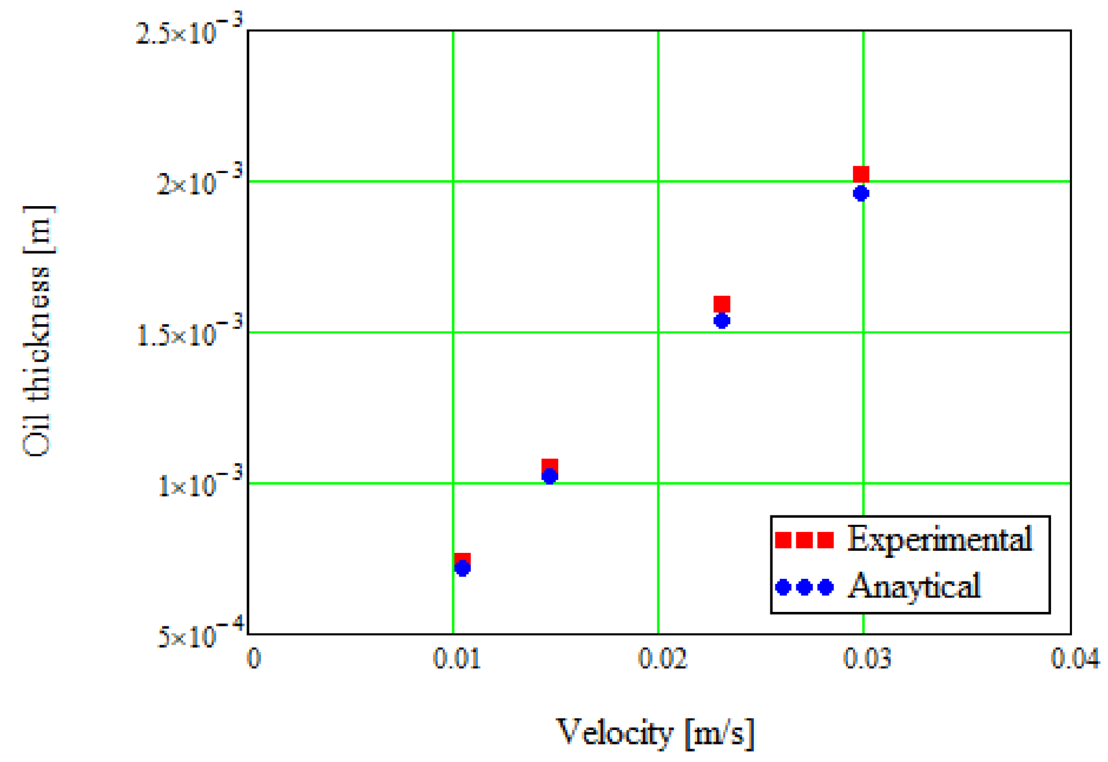


Figure 4. Experimental vs analytical comparison of oil film hight

CONCLUSIONS AND DISCUSSIONS

The film thickness is one of the most important parameters in tribology to determine the friction regime. Using a fiber optic thread, a microscope with video camera and an original oil drive system, the thickness of oil film can be evaluated for different speed regimes. The experimental test rig can be used to evaluate the capability of film generation for different categories of oils.

The principle of the experimental test rig consists in measuring the displacement of an optic fiber thread due to oil fluid flow. An optic fiber thread was used because all mechanical properties are precisely controlled in its manufacturing process and are known.

An original oil drive system was conceived and built. The system consists of two driving wheels with a wrapped rubber belt around them. One of the wheels is connected to an electric motor while the second is used to stretch and to avoid the twisting of the belt. The oil drive system velocity is constant during testing and allows different speed regimes by adjusting the DC motor voltage.

Images of the optic fiber displacement were recorded and analyzed by using a microscope with camera. The magnitude of the displacement was evaluated by comparing it with the optic fiber thread radius.

To validate the method and the test rig, the experimental values were compared with those obtained analytically. A good correlation was found between results (aprox.3% relative error).

The main advantage of the experimental test rig is the small dimensions of the equipment and the small quantity of oil needed for tests. The short period of testing is also another advantage of the experimental test rig. Due to short testing period, the variation of oil temperature is negligible. This experimental test rig can also be used to estimate with fairly good precision the kinematic viscosity of the oils.

Above presented aspects highlight the idea that the experimental test rig can be used for tests outside the laboratory. The limitation of the method consists in tests for oils with low transparency due to the principle of the method used for measuring thread deviation .

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