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TEST RIG FOR MEASUREMENT OF FILM THICKNESS IN TRANSIENT POINT CONTACT USING INTERFEROMETRY

Ioan UNGUREANU, Ilie MUSCĂ, Delia Aurora CERLINCĂ

”Stefan cel Mare” University of Suceava, ROMANIA
ionut@fim.usv.ro

ABSTRACT

The film thickness computation in the lubricated contacts is very important in order to assess lubrication conditions. Although a great variety of experimental methods has been developed, an experimental determination of the film thickness distribution is generally difficult. The optical interferometry is often used to assess the parameters in the elastohydrodynamic (EHD) lubricated contacts, like the film thickness or the contact pressure. This paper presents an original design for a test rig capable of simulating the contact transient conditions. The entraining velocity and the loading are varied following sinusoidal or triangular laws, for three different frequencies.

Keywords: tribology, contact analysis, experimental stand, interferometry

1. INTERFEROMETRY PRINCIPLE IN EHL CONTACT ANALYSIS

The principle of interferometry consists in the evaluation of the interference fringes formed by beams reflected on the two surfaces limiting the contacting bodies, in the presence of the lubricant. The basic scheme for fringes formation in monochromatic or white light interferometers is shown in Fig. 1.

The model is based on the contact between a glass disc covered with a layer of translucent chrome and a ball made of steel, which are separated by a film of lubricant on the contact area [1, 2]. A beam of light, which crosses the glass, is partially reflected at the glass-chrome interface, while another one reflects at the lubricant-ball interface. The interference of these two yields the interference fringes.

The monochromatic interferometry uses the monochromatic light in order to obtain darker or brighter fringes related to film thickness, while the white light interferometry uses the white light and outputs a spectrum of coloured fringes. In the monochromatic interferometry, the film thickness can be determined if the wavelength of light and the refractive index of contacting layers are known. Usually, the resolution of the experimental data is limited because only the digitized film thicknesses values can be calculated from bright and dark fringes. Consequently, additional data can be obtained only by interpolation.

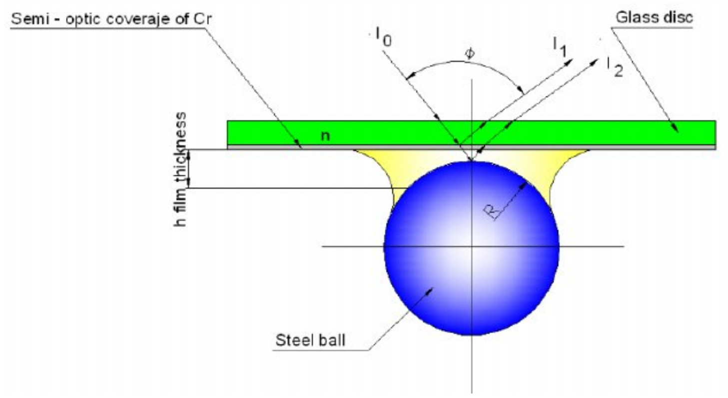


Fig. 1. The basic scheme of monochromatic interferometers

On the other hand, the transient conditions require a higher light intensity allowing for reduced exposures times in recording fast moving images. The white light interferometry is, therefore, used for these kinds of experiments. The difference between the wavelength and the refractive index of the lubricant is of the order of 90 nm. In the white light interferometry, each color corresponds to a certain film thickness and, therefore, the resolution is significantly increased. The correlation between the film thickness distribution and the color spectrum of the interference fringes is non-linear, due to rapid changes in speed and loading levels. Consequently, a calibration process must be performed under static loading conditions, using the fringes outside the contact area and comparing them to an analytically obtained distribution. However, the white light interferometry cannot be used to predict film thicknesses smaller than 0.1 μm. The corresponding regions of the interferograms tend to appear as grayscale. On the other hand, the fringes above 1 μm are not visible at all due to the low coherent nature of the white light. Although the measuring range is quite narrow, it is generally in the range of values normally obtained for the EHL film thicknesses [5].

2. EXPERIMENTAL STAND

The newly proposed experimental stand is composed of three distinct parts, namely, the mechanical parts; the electronics and the optical devices. This paper presents only the mechanical part, while the other two are addressed in a companion paper. Following an original design, an experimental stand for assessing the lubricated contacts under transitory conditions was executed in the Contact Mechanics Laboratory of Suceava University [3, 4]. The mechanical part (Fig. 2) consists of the following main elements: the glass disc made of polished glass and having a thickness of 5 mm, was designed by the authors and produced by SC IOR S.A. Bucharest. One of its sides is covered with a chromium thin layer of approximately 10 nm, and the other with an antireflexive coating of MgF2 optical material. The glass disc roughness and the deviations are shown in Fig. 3. A typical bearing ball, having a diameter of 12.4 mm, is positioned on three small rolling bearings. Two of them are oriented at 45 degrees with respect to the horizontal plane and the third is aligned with the rolling direction of the ball. The rolling bearings are mounted in a sealed cage which holds a small quantity of transmission oil, in which the ball is submersed up to its half.

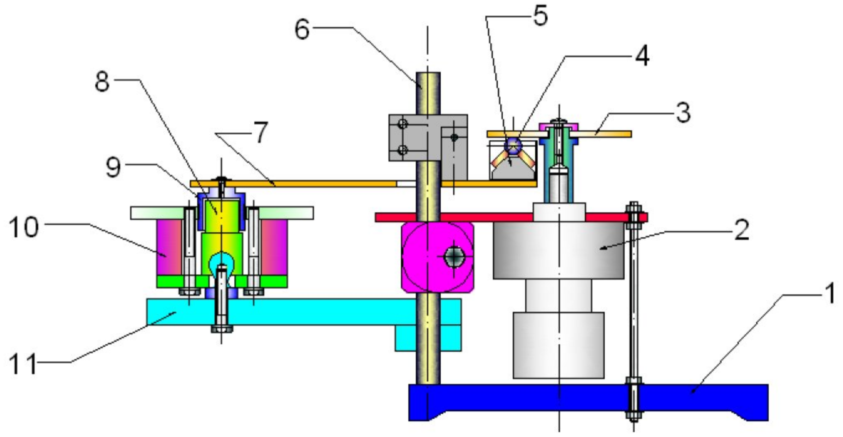


Fig. 2. Stand scheme: 1. stand support; 2. motor (DC), 3. semireflective glass disc; 4. steel ball; 5. support for three rolling bearings; 6. support rod; 7. loading plate; 8. core; 9. coil; 10. permanent magnet; 11. coil support

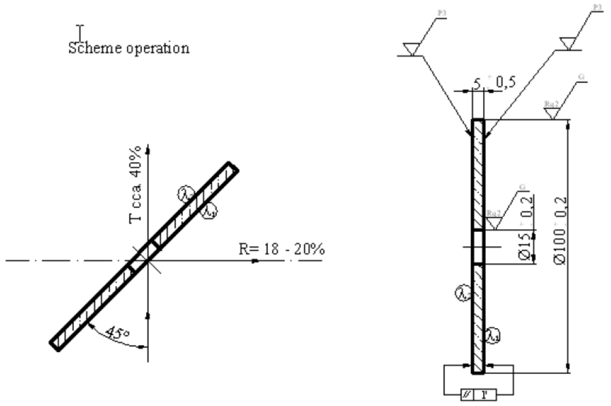


Fig. 3. Glass disc

3. ELECTRICAL PARTS

The mechanical part of the stand was presented in detail in a companion paper, which should be read for a better understanding of the experimental principles involved. This paper only addresses the subject of describing the electrical components and presents some new and encouraging results [3, 4]. The coil receives a signal from the generator via a power amplifier. A light emitting diode (LED) sets a signal every two seconds, thus, marking the beginning of a new period of the functions, which describes speed or load modification. The current experimental simulations are restricted to the triangular or sinusoidal variation. The contact load is measured with the help of two tensometric marks and a tensometric bridge. The power block consists of a step-down voltage transformer and three rectifiers. A view of the electrical parts involved is presented in Fig. 4.

4. OPTICAL SYSTEM

The optical system is composed of a binocular microscope modified to adjust the distance to the focusing surface, namely, the coated side of the glass disc. A digital camera takes pictures through the microscope objective, with a 25 frame rate, which are later transmitted and inputted to a numerical program. An overall picture of the stand is presented in Fig. 5.

The interferograms obtained with this stand allow for measuring the lubricant film thickness under nonstationary conditions with a high degree of accuracy. The various transient regimes were inputted. For three fixed loading levels, namely 5.4 N, 12.55 N and 18 N, the nominal speed was varied between 33.32 rev/min and 100 rev/min, following the sinusoidal or triangular laws. On the other hand, for three fixed nominal speeds, namely 33.32 rev/min, 66.66 rev/min and 100 rev/min, the loading level was varied between 5.4 N and 18 N, following the sinusoidal or triangular laws.

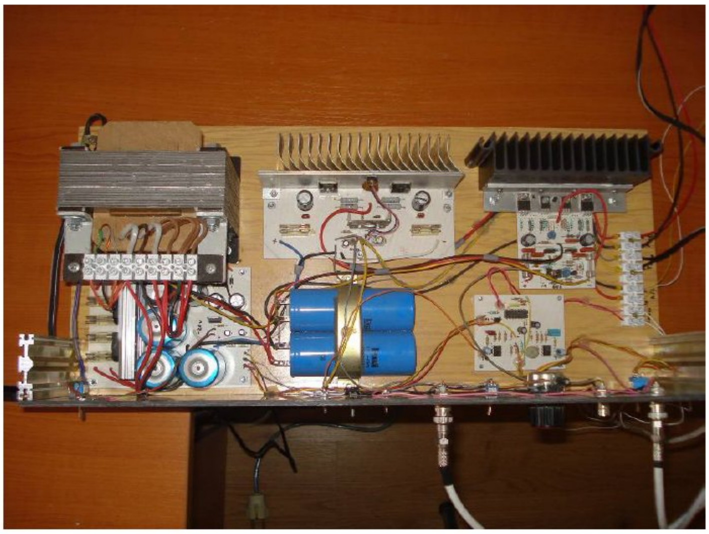


Fig. 4. The electrical parts of the stand

Fig. 5. Experimental stand

The film thickness distribution obtained under transient conditions is presented and analyzed. However, the colors' perception may vary from person to person and, thus, a "manual" analysis of white light interferograms should be taken with care. In order to bypass this limitation, the process was automated by means of a computer program.

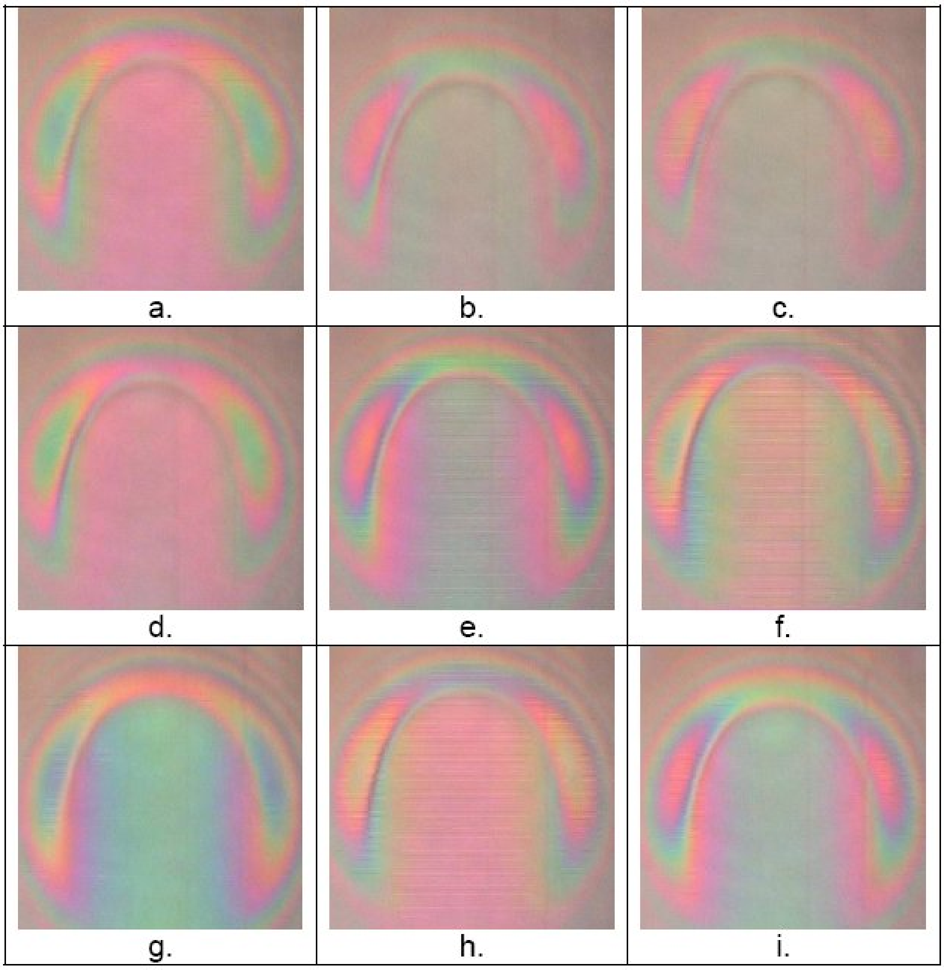


Fig. 6. Interferograms obtained using a normal load of F=12.55 N, a triangular signal of 2 Hz frequency and the following speeds [rev/min]: a. 66.66; b. 81.47; c. 96.29; d. 88.88; e. 74.05; f. 59.25; g. 44.43; h. 37.02 i.66.66.

5. RESULTS

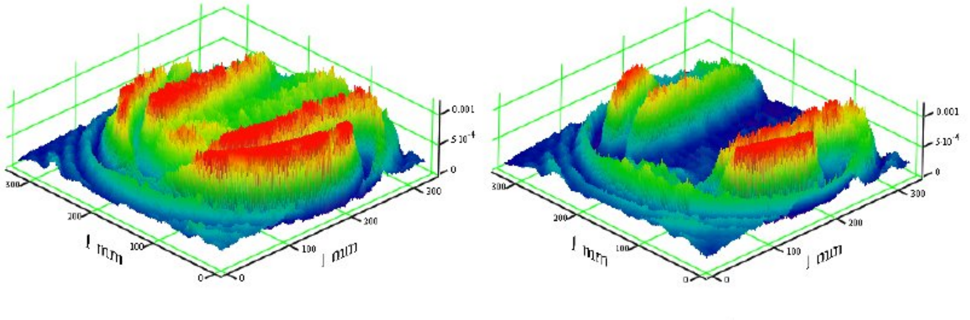
In order to correlate the color information from the recorded frames to the film thickness in an automatic way, a calibration procedure is necessary. With this approach, the calibration is performed using the area outside Hertz contact [5], whereas for image analysis, the contact zone itself is considered. An interferogram image of a Hertz point contact is required for the calibration procedure. The mapped data are linked to a two-dimensional array containing the analytically computed gap distribution. This way, a one-to-one relationship between the pixel color and the height is established.

Additionally, filtering and interpolation can be added to reduce the interferogram inherent noise and DCFFT technique is efficient for the computation of the resulting convolution type products, [6, 7]. Some results are depicted below. Fig. 6 shows the interferograms in the case of a fixed normal load and a variable speed following a triangular law. For two values of the nominal speed, the film thickness, the distributions returned by the numerical program are presented in Fig. 7. Another simulation (Fig. 8) uses a fixed loading level of 18 N, a 0.5 Hz frequency and a nominal speed following a sinusoidal law. Typical film thickness values are depicted in Fig. 9.

6. CONCLUSIONS

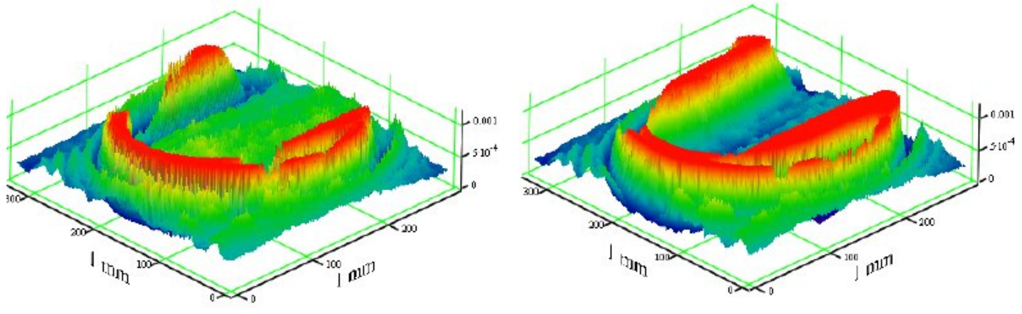
The white light interferometry, producing full spectrum colored images of interference fringes, is preferable to the monochromatic interferometry when transient lubrication conditions are to be experimentally investigated, as it provides a better resolution. Although the measuring range is quite narrow, it is generally in the range of the values normally obtained for the EHL film thicknesses.

The microscope and the illuminating system are very important in order to obtain good quality images, however, some factors, independent of the optical set-up, like the cavitation outside contact area, cannot be easily reduced. A numerical program has been developed in order to obtain the film thickness distribution from the interferograms [8]. To this end, the gap distribution outside a Hertz point contact area was matched to a steady-state interferogram, thus, obtaining the color-height correspondence.



a. b.

Fig. 7. Lubricant film thickness distribution predicted by the numerical program, F=12.55 N;
a. u= 37.02 rpm; b. u= 66.66 rev/min



a. b.

Fig. 9. Film thickness values outputted by the numerical program, F=18N;
a. u= 47.06 rpm; b. u= 34.95 rev/min

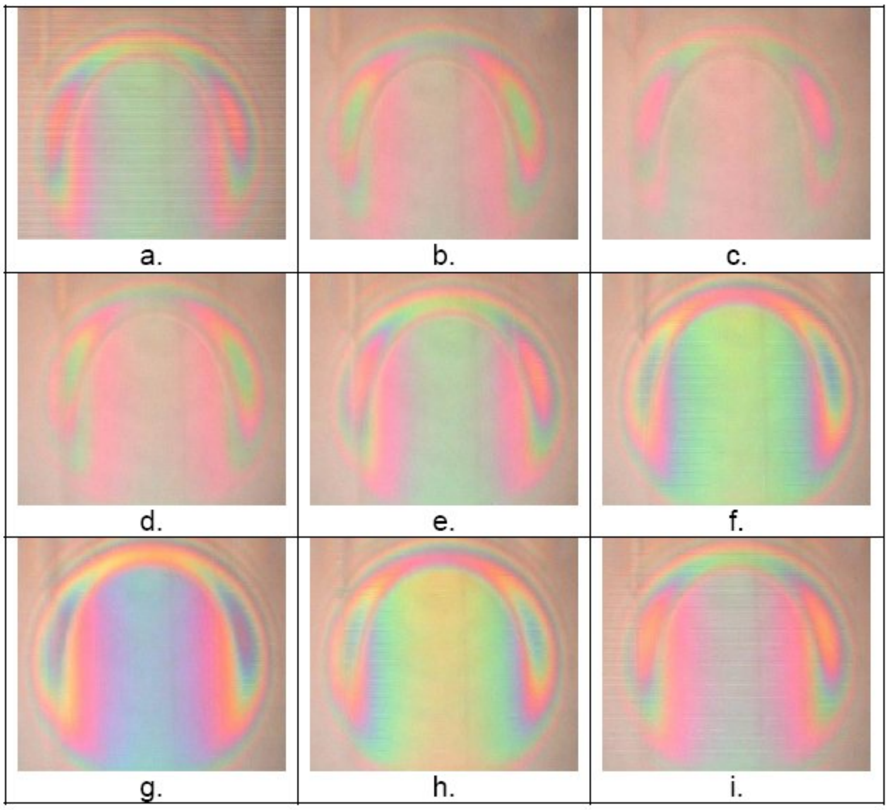


Fig. 8. Interferograms obtained using a normal load of F=18 N, a sinusoidal signal of 0.5 Hz frequency and the following speeds [rpm]: a. 66.66; b. 86.25; c. 98.36; d. 86.25; e. 66.66; f. 47.06; g. 34.95; h. i.66.66.

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