Experimental results of a hydrodynamic friction behaviour of a linear contact at low sliding velocity

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Abstract: We propose in this work the experimental results of the lubricated friction behavior of linear contact (finite length) in isoviscous hydrodynamic regime. This study was made on a tribometer Plint - Cameron TE77, using a pure mineral oil lubricant (N175) without additives for three loads 20, 40 and 80 Newton. and a velocity, range varying from 0.05 to 0.4 ms⁻¹, trials are held in pure sliding mode for a total distance of displacement L = 15mm. The studied contact is a cylinder/cylinder. The geometry of test pieces is part of a piston ring and a liner of a real engine. The first cylinder represents the male part with material of MKJet nuance having undergone a surface coating by thermal projection (HVOF). the second cylinder represents the female part whose material is cast iron of nuance FGL, without surface treatment, and whose dimensions were adapted to minimize the computational error on the speed of sliding and the force of friction which is lower than 5%. Processing the results recorded for ten cycles with four hundred points per cycle to the extraction of average curves, enables us to plot the curves of friction according to velocity and thereafter the curve of Stibbeck. The results show that we can get a total isoviscous regime for loads 20 and 40N, however for load 80N, this regime is partial, as it comes off the final curve from a speed value 0.1 m/s. the values of the friction coefficient varies for the three loads used between 0.004 and 0.017. These results show the possibility of obtaining a hydrodynamic regime with high load and low speed, with treatments suitable surfaces and are made to reduce wear and increase the lifetime of the mechanism.

Keywords: linear contact, hydrodynamic lubrication, friction, tribometer Plint-Cameron

1. Introduction

The linear contacts such as gears, roller bearings, cams, are generally classified in the category of hertzian contacts[1], considering that they work under strong loads and, in this fact, the birth of strong deformations. In lubricated mode, that elements work in mixed lubrication or elastohydrodynamic mode[2]. On the other hand when it is a question of working under weak load (case of micro or nano mechanisms), the phenomenon of hertzian elasticity is null, we find the hydrodynamic regime [2,3].

We propose in this work the experimental results of the lubricated friction behavior of linear contact (finite length) in isoviscous hydrodynamic regime. This study was made on a tribometer Plint - Cameron TE77[4]. The geometry of test pieces is part of a piston ring and a liner of a real engine. Processing the results recorded for ten cycles with four hundred points per cycle to the extraction of average curves, enables us to plot the curves of friction according to velocity and thereafter the curve
of Strubeck [5,6] This curve can be divided into three areas that are the lubrication boundary lubrication area (BL), hydrodynamic lubrication (HL) or elastohydrodynamic (EHD) and mixed lubrication (ML) which is the transition between the limit and hydrodynamic lubrication [6]. Figure 1 indicates the position of these various regimes on the Strubeck curve. This curve gives the total friction coefficient ($f$) as a function of the parameter Somerfield ($S$) [1,5], who originally written.

$$S = \eta_0 \frac{V}{p}$$  \hspace{1cm} (1)

**Figure 1.** Strubeck curve

2. **Experimental study**

This study is to make lubricated friction tests of a linear contact on a tribometer Plint - Cameron TE77(Fig.2a), using a pure mineral oil lubricant (N175), without additives for three loads 20, 40 and 80 Newton and a velocity, range varying from 0.05 to 0.4 m/s trials are held in pure sliding mode for a total distance of displacement $L = 15$mm. This tribometer allows using samples of real parts, and its kinematic can be adaptable to be close to the operating conditions of the majority of contact types [5]. The figure2a shows the principle of the tribometer and the image of figure 2b the arrangement of test specimens and their characteristics. The possible test configurations in this version of the tribometer are planes contacts, cylinder on plane surface contact and Contact cylinder to cylinder.

**Figure 2.**

a: Tribometer Cameron – Plint TE77 [4]

b: Characteristics of the test ($\vec{U}$ : sliding velocity)
2.1. Test pieces
The studied contact is a cylinder-cylinder in pure sliding. The geometry of test pieces is part of a piston ring and a liner of a real engine (fig2b). The first represents the male part with material of MKJET nuance having undergone a surface coating by thermal projection (HVOF), the second represents the female part whose material is cast iron of nuance FGL, without surface treatment and whose dimensions were adapted to minimize the computational error on the speed of sliding and the force of friction which is lower than 5%, whose characteristics are those of table I.

| Geometry  | Young Modulus | Lubricant (N175) |
|-----------|----------------|------------------|
| l (m)     | R₁(m)          | R₂(m)            | L(m) | E₁ (GPa) | E₂ (GPa) | η (Pas) |
| 4.5 × 10⁻³ | 42.5 × 10⁻³    | 42.9 × 10⁻³      | 15 × 10⁻³ | 590      | 160      | 0.085   |

2.2. Experimental procedure
The tests were prepared, carried out and exploited by developing a procedure that consists in the following stages:
- After a preliminary scanning of a certain number of loads and speeds combinations, we opted for loads of 20, 40 and 80N.
- The total distance of displacements of contact is 15mm with an instantaneous displacement of 4.5 mm and a hold time of ten cycles for frequencies of seven and nine Hertz (7HZ and 9HZ).

3. Results and discussion
The Figure 3, indicate the variation of friction for loads of 20N, 40N and 80N according to velocity variation. The Figure4, indicate the variation of friction according to the parameter of Somerfield (S).

Concerning figure 3, shows a growth of friction whatever the load used. This growth, is inversely proportional to the load. The value limits accounts for 0.017. What shows that we summons in hydrodynamic mode. What enables us to plot the curve of Strubeck for these various loads indicated by the figure 4, that shows two distinct curves: the curve (3) represents the combination of loads 20 and 40N and the curve (4) represents the values for load of 80N. It is noticed that the curve (4) is
detached from the curve (3) at the value of SL ∼ 510^{-9}, for a friction coefficient of 0.0042. This curve shows that we have two modes. The First is rigid isoviscous whose SL represents the limit and the second is viscoelastic or rigid piezoviscous.

we think this is a viscoelastic field, because the experimental conditions used, the viscosity piezo has not had time to form, among other our model [6] confirms this situation. The experiment shows that, for the load of 80N this mode starts from a sliding speed of about 0.1ms^{-1}

Concerning the curve (3) the isoviscous mode is observed and we recover continuity of the curve for loads of 20N and 40N. We deduce the final curve of Striebeck given by figure 5, which represents the final curve of variation of the friction coefficient according to the parameter S. For the rigid hydrodynamic mode, in the case of lubricated linear contact, we notice the increase of friction (f), with the increase of S which varies between the values 10^{-8}<S<1.2 \times 10^{-7}, for values of friction 0.004<f<0.017.

![Figure 5. Final experimental curve of friction according to the Somerfield Parameter (S)](image)

4. Confrontation

Confrontation of the Striebeck curves, regarding the results obtained by models[6] and experimental, is indicated by the figure 6, in which we notice convergence of the two curves up to the S value of S=4 \times 10^{-8} for a friction coefficient f = 0.01, subsequently the two curves are detached from one another, but remain converging on average for an error of about 5%.

![Figure 6. Confrontation Model[6]/Experimental results](image)
5. Conclusion

The results show that we can get a total isoviscous regime for loads 20 and 40N, however for load 80N, this regime is partial, as it comes off the final curve from a speed value 0.1 ms\(^{-1}\). The values of the friction coefficient varies for the three loads used between 0.004 and 0.017. The confrontation of the experimental Stribeck curve with model curve, shows same shape as the model. Comparison shows a total convergence for very low speeds below 0.15 ms\(^{-1}\), after that we have a separation of the two curves but within an average convergence for an error of 5%. It is noted that the combination of material with an adequate surface treatment or surface coating, enables us to increase the values of loads and to stay in an isoviscous hydrodynamic mode. These results implies the possibility of obtaining a hydrodynamic regime with high load and low speed, with treatments suitable surfaces and are made to reduce wear and increase the lifetime of the mechanism.

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