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Friction in Low Speed Lubricated Rolling and Sliding Contacts for Alumina

Friction experiments were conducted on alumina Al_2O_3 *. 97.8% against themselves in oil under different contact pressures and sliding velocities. The term low speed is of course a relative one. In the following surface velocities less than 0.1 m/s will be considered as low speeds. A survey of the present knowledge of the different fundamental mechanisms of friction and lubrication which is some way might be included in the complex mechanism of lubrication governing frictional properties in low speed lubricated rolling and sliding contacts, was present in this paper.*

Keywords: alumina, low speed, centre disc, outer disc, contact pressure

1. INTRODUCTION

In low speed lubricated rolling and sliding contacts the mechanism of boundary lubrication is cating. However, other mechanisms of lubrication might simultanously also be involved.

Large industrial gear units, low speed roller bearings and wheel-on-rail contacts can be mentioned as typical examples of application. At low speed in the regime of boundary lubriction the Striebeckcurve is often presented somewhat indefinitely because of lack of knowledge of the frictional behaviour.

2. AIMS OF THE WORK

The main aim of this study was to increase the knowledge of the mechanism of lubrication and the parameters that influence the frictional properties in low speed lubricated rolling and sliding contacts. Because the typical engineering applications of the work are multistep industrial gear units or low speed roller bearings the choice of lubricants is limited to liquid oils and the choice of solids to some engineering materials. The specific aims of this study were:

(i) to experimentally evaluate the level of the coefficient of friction,

(ii) to determine the main parameters influencing frictional behaviour and to find out the way in which they influence and

(iii) to describe the mechanism of lubrication in the conditions of low speed lubricated rolling and sliding contacts.

3. LUBRICATION AT LOW SPEEDS

The term low speed is of course a relative one. In the following treatment surface velocities less than 0.1 m/s will be considered as low speeds. Naturally no wider conclusions about the frictional behaviour and the parameters influencing it can be made from this.

A few reports of wear studies at low speeds have been published. LADEN (1968) found in his low speed disc machine tests carried out at velocities of 0.015.1.8 m/s that wear of rolling and sliding carburized rollers can be expressed as a distance rate of wear, which depends on the oil film thickness separating the surfaces.

A survey of the present knowledge of the different fundamental mechanisms of friction and lubrication which in some way might be included in the complex mechanism of lubrication governing frictional properties in low speed lubricated rolling and sliding contacts, was presented in this paper. Two mechanisms of lubrication were omitted, namely hydrostatic and

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solid film lubrication, the former because no external pressure is brought into the contacts under consideration and the latter because only liquid lubricants and additives are considered in this work.

4. EXPERIMENTAL DEVICE AND PROCEDURE

To overcome these problems four-disc machines, with three outer discs loaded symmetrically around a centre disc (Fig. 1), have been used for friction measurements.

The whole construction is made rigid to allow high loads so that high pressure conditions can be studied with contact belts wide enough to avoid disturbing edge effects.

The construction is symmetric in such a way that increased load causes only symmetric deformations on the rig and does not influence the symmetricity of the contact conditions.

The four discs are self aligned, so that the centre disc shaft is floating around a supporting spherical ball bearing. When loaded this shaft first sets to its position and then the floating outer discs align themselves in.the same axial direction as the centre disc.

Because the spherical ball bearing supporting the shaft of the centre disc is loaded only by the weight of the shaft, the disc and a part of the torquemeter, which together comprise only about 1 % of the load applied to the discs, its influence on the torque measurement is negligible and the coefficient of friction in the three disc contacts can be measured with good accuracy.

The centre disc has two contact belts to increase the torque needed for the self alignment of the discs.

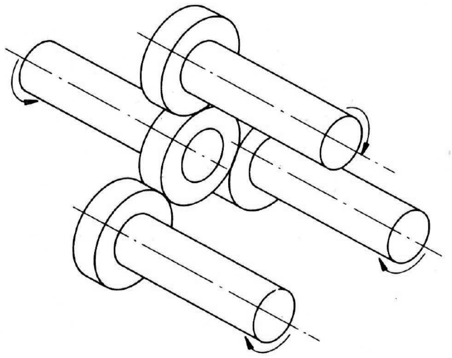

Fig.1. Four disc machine . the center disc is supported by the three outerdiscs

Technical data of the four-disc machine are given in table 1.

Table1

Maximum load on discs	F=30kN
Maximum torque at centre disc	T=700Nm
Rotational speed range of centre and outer discs in both directions and separately	n=0.03 - 50 rot/s
Centre distance of discs	c=0.1m
Variation range of disc diameter	D=0.09 -0.11m
Minimum surface speed of disc	v=0.01m/s
Volume of lubricant tank	V=50 or 10dm^3
Power of the electrical DC motors	P=130kW
Speed reducers on both sides	2.232 :1 and 31.73:1

Photographs of the device and its details are shown in fig. 2.

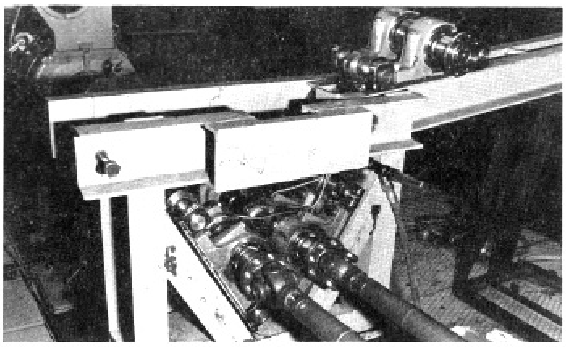

Fig.2 Experimental device

5. SPECIMENS

The centre disc is provided with two contact belts to ensure good shaft alignment and high maximum contact pressure at the same time. The diameter of the centre disc is 0.1 m and the width of each contact belt is about 5 mm as shown in Fig. 3. The surface roughness of the contact belts was varied in the experiments.

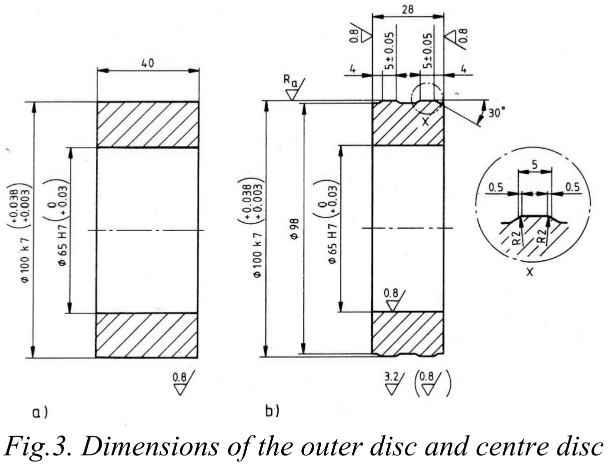

Fig.3. Dimensions of the outer disc and centre disc

6. LUBRICANTS

The lubricant is supplied through three separate oilpipes to each disc contact by a hydraulic pump from an oil tank. The filtration grade of the lubricants in the experiments was 3 μm.

7. TEST PROCEDURE

Before starting the friction tests the following measures were taken:

1. The hardness of the discs was measured.
2. The surface roughness (Ra-value) of the contacting areas in the circumferential direction on the discs was measured. A curve of the surface profile in the circumferential direction was recorded and a replica of the topography was taken.
3. The viscosity of the lubricant was measured according to standards and its additive content was analyzed. The running-in was necessary for two reasons:

(i) possible sharp edges in the surface profile were flattened out and thus bigger changes in the surface topography during the friction measurements were avoided and

(ii) adequate time was made available for chemical reactions within the contact to build up boundary lubrication films on the disc surfaces.

The measurements described in up section were carried out first with low pressure (PHZ = 600 MPa) at six fixed speeds for the outer disc (u0 = 65, 45, 30, 20, 15 and 10 mm/s) and a variable speed of the centre disc in the slide-roll ratio range of (- 0.15... +0.15). The same measurements were then carried out at the same speeds at high pressure (PHZ = 1300 MPa).

After the friction test the surface roughness (Ra-value) was measured, the surface profile was recorded and a surface replica was taken, all from the same places on the are the disc as before the test.

8. EXPERIMENTAL RESULTS

The friction measurement experiments were carried out in a surface velocity range of u0 = 10.70 mm/s and at slide-roll ratios of .0.10... +0.10. The theoretical value for elastohydrodynamic film thickness calculated by equation under the experimental conditions described would thus be hmin = 0.02 . 0.45 μm. The value for the specific film thickness calculated by equation will not exceed 0.5 at loads corresponding to PHz = 1300 MPa when low viscosity oils with v = 120 rrim2/s at the experimental temperatures are used.

8.1 Friction at pure rolling

In a rolling two disc contact the frictional traction torque, T, can be expressed by

$$T=T_R + T_S$$

where T_R is the traction due to rolling and T_S is that due to sliding (Crook, 1963).

Accordingly the coefficient of friction can be expressed by

$$\mu = \mu_R + \mu_S$$

where μ_R is the part of the coefficient of friction due to pure rolling and μ_S is the part due to sliding.

The coefficient of friction in pure rolling conditions, that is in conditions in which the four discs rotate with equal speeds, will first be considered.

The value for the traction torque, TR due to rolling was calculated from the measured maximum and minimum values for the total traction torque. The coefficient of rolling friction, μR was then calculated from the known values of traction torque, load and radius of the centre disc.

8.2 Influence of velocity

A very clear influence of velocity on rolling traction torque (Fig. 4) and thus on the coefficient of rolling friction was measured (Fig. 5). The coefficient of rolling friction increased with decreasing values of surface velocity.

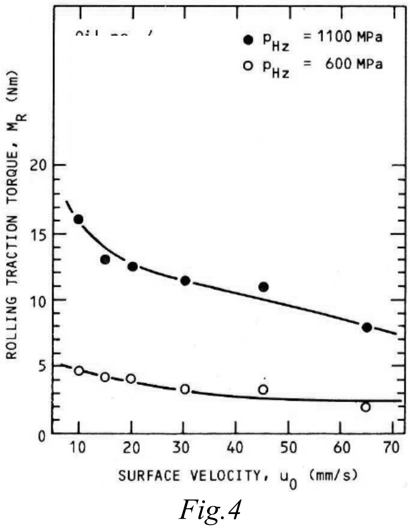

Fig.4

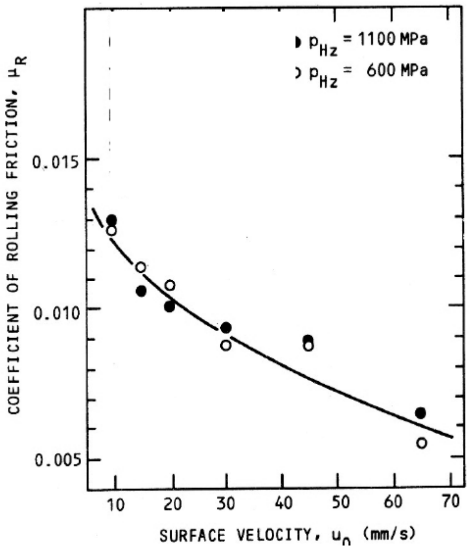

Fig.5

8.3 Influence of load

According to friction measurements at three different loads, 2.46 kN, 8.66 kN and 11.54 kN, with corresponding values for the maximum Hertzian contact pressure of about 600 MPa, 1100 MPa and 1300 MPa, no appreciable load influence on the coefficient of rolling friction could be discerned (Fig. 6).

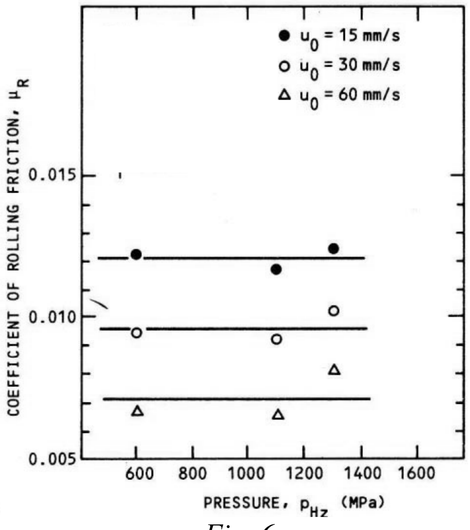

Fig. 6

8.4 Friction at combined rolling and sliding

The total coefficient of friction, including both the rolling and sliding component, was studied because of its practical importance. In all conditions except for pure rolling a sliding component will be present in the coefficient of friction. The sliding component will not be studied separately because in the conditions under consideration it does not appear as such.

8.5 Influence of load

The influence of load on the coefficient of friction was small within the load range used in the friction tests. Very commonly no load dependence was observed at slow surface velocities as low as an average surface velocity of 10 mm/s. At higher velocity values up to u'= 50 mm/s or 70 mm/s, loads corresponding to a maximum Hertzian pressure of 1100 MPa gave friction coefficient values that were about 20 % higher than loads corresponding to pHz = 600 MPa, as shown in Fig. 7. This load behaviour was typical in friction tests carried'out with different lubricants, lubricant viscosities and surface roughnesses.

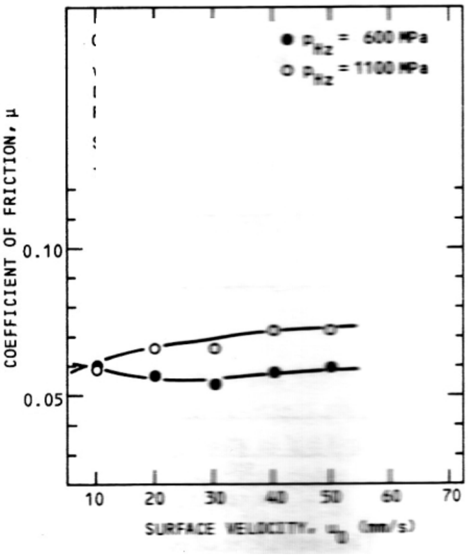

Fig.7

9. DISCUSSION

In the present study those parameters that are considered to have the most dominant influence on friction in low speed rolling and sliding conditions close to conditions of typical engineering applications were examined. These parameters are: load, surface velocity, slide-roll ratio, lubricant viscosity, type of lubricant including different additives, material of solids, surface roughness and surface topography. Because of the practical necessity of limiting the number of test runs, those parameters that were considered less important were kept constant in the experiments. These parameters, which in some applications might have an effect on friction, were: radius of disc, width of contact belt, elasticity of discs on a larger scale, temperature, presence of oxygen, surrounding atmosphere as well as different kinds of transient conditions.

10. PARAMETERS INFLUENCING ROLLING FRICTION

The experimental results of parameters influencing the coefficient of friction at pure rolling presented in this paper can be summarized as follows:

1. No appreciable influence of load,

2. The coefficient of rolling friction increased as the rolling speed decreased.

3 The values measured for the coefficient of rolling friction were in the range of μR = 0.005 . 0.018.

11. PARAMETERS INFLUENCING FRICTION AT COMBINED ROLLING AND SLIDING

The experimental results of parameters influencing the coefficient of friction at combined rolling and sliding conditions presented in this paper can be summarized as follows:

1. The influence of slide-roll ratio on the coefficient of friction is similar to typical traction curves measured in elastohydrodynamic conditions but no decrease of the coefficient of friction at high values of the slide-roll ratio was detected.
2. At low speeds of about u'= 10 mm/s no influence of load on the coefficient of friction could be measured but at speeds of about u' = 30 . 70 mm/s the coefficient of friction slightly increased with increasing load.
3. The values measured for the coefficient of friction were in the range of μ = 0,03 . 0,11.

11.1 Velocity

In the speed range of the present experiments, i.e. u = 10 . 70 mm/s, a common behaviour was that the coefficient of friction was almost independent of speed. A general similarity seems to exist in the frictional behaviour with velocity at low speed rolling and sliding conditions and pure sliding conditions.

11.2. Load

The experimental results showed a slight increase in the coefficient of friction with load at higher speeds while no load influence was measured at low speeds (Fig. 28). A possible explanation for this is that at low speeds the contacts are more dominant and the conditions closer to dry friction, where Amontons' law, which gives a linear relationship between friction force and load, is obeyed. At higher speeds a larger part of the load is carried by the lubricant film. An increase in shear strength of the lubricant film with pressure might be the explanation for the slight increase in the coefficient of friction with load. The results are in agreement with the frictional behaviour measured in pure sliding / conditions.

12. CONCLUSION

The four-disc machine turned out to be a very suitable tool for friction measurements at high load and low speed in lubricated rolling and sliding contacts. Friction measurements for conditions of pure rolling could also be made with satisfactory accuracy.

The friction measurements were carried out in low speed conditions with surface velocities of 10 . 70 mm/s, with slide-roll ratios in the range of .0.10... +0.10, with loads corresponding to maximum Hertzian pressure in the contact of 600 . 1300 MPa, with surface roughnesses in the range of Ra = 0.1 . 2.0 µm and with nine different lubricants, three disc material combinations and four different surface topographies. The coefficient of friction varied in the range of 0.03 . 0.11. The part of the coefficient of friction due to pure rolling varied in the range of 0.005 . 0.018.

The most importat parameters influencing the frictional behaviour at rolling and sliding conditions are the sliding speed, the lubricant and its additive content, the disc material combination, the lubricant viscosity and the topography of the surfaces. The load and the rolling speed as well as the surface roughness in the range of Ra < 1.5 µm have only a slight effect on friction.

The mechanism of lubrication is governed by a combination of the following three lubricating effects:

1. The formation of boundary films by chemical adsorption or chemical reaction on the solid surfaces.
2. The creation of a hydrostatic pressure in lubricant trapped in dents or corners formed by the topography of the surfaces.
3. The creation of a pressure in the lubricant as it is squeezed out in grooves or channels formed by the topography of the surfaces.

In conditions of pure rolling the lubricant and its additive content has a considerable influence on friction. The physical properties and the thickness of the boundary lubricant film influence the resistance to rolling motion because of a deforming or mangling effect of the surface film in the inlet region which dominates the rolling friction at low speeds. The coefficient of rolling friction is increased by decreasing rolling speed but only slightly influenced by the material combination of the solids. The load, lubricant viscosity and surface roughness have no appreciable influence on the coefficient of rolling friction.

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