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Apparatus for measuring the lubricating properties with limiting friction

Summary: An apparatus is described which with a low degree of dispersion of results enables the frictional coefficient to be measured with limiting lubrication. In construction it is very simple, easy to operate and therefore particularly suitable for short tests. The apparatus makes it possible to differentiate easily between the individual lubricants and affords the possibility of investigating the effect of additives of different kinds.

Purpose of the experiments:

An apparatus was developed at the Technical Experimental Station enabling the frictional coefficient to be measured with limiting friction. With this apparatus a number of lubricants were to be tested in order to form an opinion as to its practical use.

Experimental installation.

The fundamental construction of the apparatus will be seen from Figures 1, 2 and 3 (The suggestion that prompted the development of this apparatus was the grease meter described by Charron - Publications Scientifiques et Techniques du Ministère de l'Air). It consists in the main of a ground and polished steel roller with a diameter of 40 mm and a width of 20 mm. This steel roller can be caused to rotate slowly by means of an electric motor through a worm gear.

On the lower side of this roller is a brass chain, which can be loaded at the end by a weight, while the other end is connected by a lever transmission system (1 : 2) with a balance. The chain used here is a simple link chain 12 cm long, which according to a spectroscopic analysis consists of an alloy of copper with about 20% zinc. With an angle of contact of 180°, the 26-link chain is in contact with the roller throughout its length of 63 mm.

Both chain and roller are immersed in the test-oil, which can be warmed by an electric heater. A thermometer is used for measuring the temperature of the oil in the container. It is however, more important to ascertain the temperature on the surface of the roller, as the thin film of lubricant between the chain and the roller will approximate to this temperature. This measurement is effected by means of a thermo-element, which passes from the inside to the surface of the roller. The temperature read off on the millivoltmeter is used as a basis for the measurements shown in Figs. 7 to 13 and is there called the "oil temperature". This temperature is about 10°C below the oil bath in the maximum case.

The apparatus works in the following way: The weightedchain is pressed against the roller from below. When the latter is rotated, according to the lubricating effect of the oil, the chain is carried along to a greater or less extent in the direction of rotation and thereby brings about a corresponding deflection of the balance. Since in the experiment the peripheral speed is very low and only punctiform contact takes place between chain and roller, the apparatus works with limiting friction. It is interesting to examine more closely the distribution of the pressure along the chain. For a load of 400 gr the pressure of the individual links was calculated, and this is shown diagrammatically in Figures 4 and 5. As basis for the calculation, a coefficient of friction of $\mu = 0.1$ or 0.2 was used. It will be seen that the pressure distribution along the chain rises slowly against the direction of rotation, and the pressure increase with a higher frictional coefficient occurs more rapidly than with a low frictional coefficient. Oils with good lubricating properties are therefore tested with somewhat lower mean pressures, as for those with poor lubricating properties. This phenomenon and the uneven distribution of the load is not, however, a fundamental fault of the apparatus. Measurements with limiting friction follow the law of Coulomb, i.e. the coefficient of friction is independent of the load ($\mu = \frac{R1}{N1} = \frac{R_2}{N_2} = \frac{R_3}{N_3} \ldots$).

As long as measurements remain within the domain of limiting friction, the difference in load that occurs is of no consequence.

One drawback of the apparatus is however that no accurate information can be obtained about the specific surface pressures. Attempts have been made, by calculation, to obtain the specific surface pressures at least approximately. This was done as the result of the following considerations: Each link touches the roller at two points. At these points the radii of curvature are, on an average, approximately equal to that of a sphere with a diameter of 1 mm. If we imagine the link to be replaced by two such spheres, the specific load can be calculated for each sphere according to Hertz. On the supposition that a weight of 30 gr is brought to bear on one sphere, we may calculate from this a specific load of 6500 kg/sq cm. In this way some indication is obtained as to the order of magnitude in which the specific surface pressures can be expected.

Experimental method.

Before each experiment the roller was cleansed of the old oil attaching to it. This was done by washing with gasoline and treating with polishing rod. For each type of oil a new chain was used. In a normal oil test the experiment commenced with measurement at room temperature. Here the frictional power at the moment of starting (i.e. the static friction) was not determined, as with Charron, but measurement took place when the roller was turning uniformly, i.e. with sliding friction. The roller had a speed of n = 2.4 r.p.m. which corresponds to a peripheral speed of V = 0.16 cm/cc. When the measurement was completed, the oil was slowly warmed with a heat input that remained constant for all the experiments. After raising the temperature by about 8-10°C, a measurement was carried out and so on. In between the individual measurements, the motor driving the roller was stopped in order to avoid unncessary wear and tear on the chain. The process was continued until the oil had reached a temperature of 100°C, when the experiment was broken off. When the experiment was repeated, the oil was renewed, the chain was turned and the experiment started once more at room temperature. Each chain was only used twice, once on each side, and only for one the same oil. It was not therefore necessary to clean the chain.

From the measured deflection of the balance the coefficient of friction was calculated as follows:

Calculating the coefficient of friction:

S_1 = pull of chain in direction of rotation in gr

S_2 = " " " against " " " " gr

G = load in gr

A = deflection on the balance in gr

α = angle of contact

μ = coefficient of friction.

According to the well-known formula for friction with rotation ("Hutte" 27th Ed. Vol. 1., p.403.)

$$S_2/S_1 = \mu\, 2$$

Furthermore

$$S_1 = G$$

$$S_2 = 2\,A$$

$$\alpha = \pi$$

From this we have

$$\frac{2\,A}{G} = \mu\,\pi$$

$$= \frac{1}{\pi}\ln\frac{2\,A}{G} \qquad \mu = \frac{{}^{10}\log\frac{2\,A}{G}}{1.386}$$

The following oils were tested with and without additive

Description of oil	Remarks	Viscosity °T 38°C	99°C
Shell A B 11	Mineral Oil	14.9	3.19
Rotring reference Oil	Aviation oil	275	20.46
T2 900/2	Synth.lub. oil	197	15.8
Essolube Running-in oil	-	62.8	8.9
Wehrmacht-Unit oil	Mineral oil	101.9	10.4
HB	Synth. hydro-carbon oil	60	8,55
H 32	do.	247.3	23.2
H. 140	do.	1104.5	57.3
H 426	Synth. Ester	50.7	6.57
Bone oil	-	45.7	9.02
Rape oil	-	44.8	10.0
Castor oil	-	296.4	20.0
Elaol 4	Synth. ester	27.05	4.92
IK 2200	Water-soluble synth.lub.	116.8	13.9

Results of the experiments.

The first thing to be examined was whether the apparatus functions in the domain of limiting lubrication. As will be found from all the measurements (see Fig.6-B) the friction indices are more than 0.1, so that we have a case of limiting lubrication. (Philippovich VDI Zeitschrift Vo. 86 No.25/26, 27th June 1942). In this condition of lubrication, Coulomb's law must apply, according to which the coefficient of friction is independent of the load. As can be seen in fig. 6, this condition is very appro imately satisfied. This is therefore further proof of the presence of limiting lubrication.

Of special interest is the variation of the coefficient of friction with temperature. Since an influence of variable load, as described above, is not present, it is sufficient to select one load only. In all the other experiments this was 400 gr.

As Fig. 7 shows, the coefficient of friction increases, with rising temperature, to a different extent with the various oils. Particularly sensitive are the hydrocarbon oils, e.g. Wehrmacht unit oil, as opposed to products of a different composition, e.g. IK 2200 which is soluble in water.

Fig. 8 shows the course of the coefficient of friction of three synthetic hydrocarbon oils of similar composition. The products differ mainly in their viscosity and the size of their molecules. These three oils can be classified according to their viscosity, the most thinly flowing compound giving the highest coefficient of friction. The question now arises as to whether this is indeed the effect of viscosity or that of the different size of the molecules. Fig. 6 also shows the result with a synthetic ester H 426. The course of the coefficient of friction coincides almost exactly with that of the H 8.

Fig. 9 shows animal and vegetable oils together with a synthetic ester "Elaol 4". In these lubricants, not only the low coefficient of friction is remarkable, but also the more or less falling course of the curves with rising temperature. Whether we are confronted here with a chemical change in the oil as a result of the high temperature is a matter for future investigation.

Of particular interest is the behaviour of the different additions to the lubricating oil, e.g. oleic acid in the proportion of 2% with Rotring reference oil brings about a very considerable improvement in the friction coefficient, especially in the high temperature range (Fig.10.).

With Wehrmacht unit oil the action of the oleic acid is rather similar. The coefficients of friction are rather higher than those of the pure oil (Fig.11). It is well known that sulphur products also have an anti-friction effect. An instance of this is afforded by Wehrmacht unit oil with 2% of a sulphur compound. The effect of graphite is likewise remarkable. The mixture tested here of mineral oil with 2% autokollag produces very much lower friction coefficients.

Fig. 12 shows results with oil mixtures, such as are used in a similar composition as cutting oils for machining operations. In practice, for reasons of economy, the mineral oil is supplemented for this purpose with a few per cent of an animal or vegetable oil.

That such a mixture brings about a very great improvement in the lubricating action may be seen from Fig. 12. Practical experience is thus fully borne out by experiment. A test method of this type is therefore of particular value for investigating substitutes for animal and vegetable oils.

Fig. 13 shows the friction-promoting, i.e. unfavourable effect of adding water of the lubricant IK 2200 which is soluble in water.

On the basis of these examples it may be said that the apparatus in this form and in accordance with these experimental processes gives excellent measurement values which can be repeated, and enables the lubricants to be classified unambiguously. Its simplicity and ease of operation make it specially suited for short tests on small samples of oil.