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MEASUREMENT OF COEFFICIENTS OF FRICTION OF AUTOMOTIVE LUBRICANTS IN PIN AND VEE BLOCK TEST MACHINE

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Abstract : *The paper deals with experimental mechanics in the field of fluid lubricants, investigating frictional characteristics of automotive engine and gear oils using experimental tests on a pin and vee block test machine (Falex). The test is standardized according to ASTM D3233 and represents a relevant and rapid measurement of coefficients of friction in a tribometer. Three engine oils and three gear oils were tested on the same loading-time procedure being analyzed the coefficients of friction according to SAE class of viscosity, degree of use (fresh or aged) and manufacturer. The calculations at different speeds and loads proved that coefficients of friction comply with the Stribeck rule. The research work succeeded to set up a procedure for operation on Falex machine, both for research and educational purposes.*
Keywords: *automotive lubricants, friction coefficient, tribology, pin and vee block test machine, Stribeck curve*

1. INTRODUCTION

The road vehicles consume in average one-third of fuel energy to overcome friction which in case of passenger cars is divided four main contributors: engine (35%), transmissions (15%), tires (35%) and brakes (15%) [1].The identification of friction loss sources as well as the methods to reduce them has a tremendious effect on global primary resources, especially on fuels and lubricants. Friction reduction methods are difficult to apply as operation modes, speeds, loads and working temperatures are variable in broad ranges.
The potential activities to reduce friction in engines and transmissions are related to type of lubricants and lubrication regimes, the expected benefits being reducing fuel and lubricant consumptions and emissions, wear, costs of maintenace operations and increasing energy efficiency and reliability.
Besides the improvement of surface quality (advanced coatings and special surface texturing), an important friction loss source is linked to the tribological characteristics of the lubricants. The objective of this paper is to investigate friction coefficients of engine and transmission lubricants in a special purpose tester and to compare load-carrying and friction reduction capability, the effect of viscosity and aging.

2. TESTING METHODS

The accurate measurement of friction reduction in real life condition is very complicated, time consuming and expensive, so most of the tribological measurements use special purpose tribometers which evaluate coefficients of friction within specific regimes of lubrication.
As a general rule, the lubrication should keep two surfaces in relative motion apart, for a minimum wear. A regime of lubrication depends on specific parameters of the application (load, speed, temperature, geometry of the bearing surfaces), but also on fluid lubricant viscosity and lubricity.
If it is considered as a parameter of the lubrication regime the lubrication oil film thickness, four different regimes of lubrication can be defined on Stribeck curve which impose different demands on lubricants: hydrodynamic lubrication (HL) is the one in which the relative motion of the sliding surfaces keeps a continuous fluid film separating the surfaces, elasto-hydrodynamic lubrication (EHL) in which there is a separation oil film, but elastic deformation of surface and oil viscosity are important, boundary lubrication (BL) when surfaces are in contact and chemical and physical properties of the film are dominant and finally, mixed lubrication (ML) is the lubrication characterised partly by direct contact of asperities and partly by EHL and BL.

The chosen tribometer and method should determine lubricant performance in the same lubrication regime as in real life and to measure the load-carrying properties and ability to protect against scuffing.

2.1. Tribometer

The Falex pin and vee block method is used to evaluate lubricant behavior in metal to metal applications, in standardized tests for measurement of extreme pressure [2] and wear properties of fluid lubricants [3], wear and load carrying capacity of solid film lubricants [4].
The equipment is described in figure 1. A test pin (journal) rotates at a constant speed against two vee blocks, all immersed in 60 ml of lubricant.

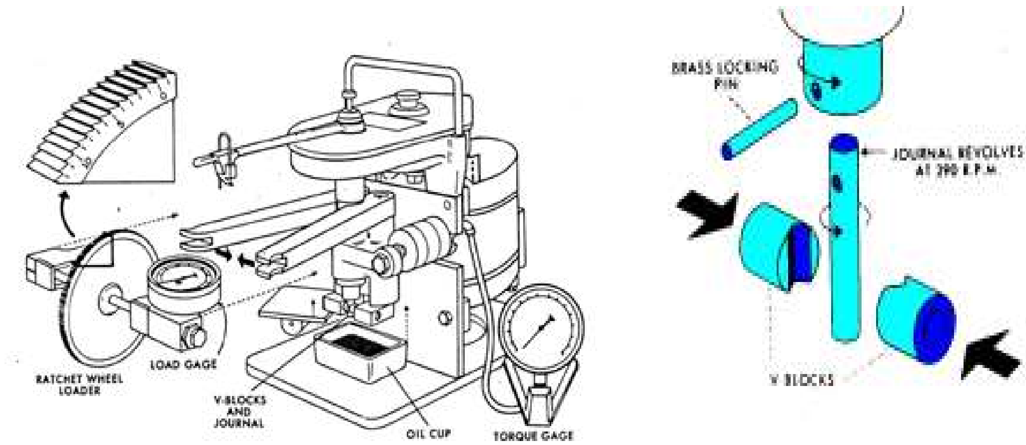

Figure 1: Falex pin and vee block test machine [2]

There are four contact lines between the pin diameter and the vee blocks when a load is applied through a mechanical gauge by means of a ratchet wheel and eccentric arm.

2.2. Lubricants

The lubricants supposed to be tested belong to commercial well-known manufacturers and are marked with M1, M2 and M3. Six lubricants were tested, three engine lubricants and three transmission lubricants, four were fresh, not used at all, and two were changed according to vehicle manufacturer recommendations.
For further discussions there were measured their densities and viscosities, which are presented in table 1, along with manufacturer code, class of viscosity and condition.

Table 1: Lubricants characteristics

Lubricant type	Class SAE viscosity	Density [kg/m^3]	Viscosity (20ºC)[mm^2/s]	State
Engine	5W40M1	852	215.3	fresh
Engine	5W40M2	850	207.6	fresh
Engine	5W30M2	860	-*	aged, 10 000 km
Transmission	75W80M1	884	116.2	fresh
Transmission	75W80M1	888	-*	aged 30 000 km
Transmission	80W90M3	899	463.3	fresh

*The viscosity could not be measured with Gibson Jacobs method because the aged lubricant was opaque.

The density was measured by weighting a given volume of lubricant in a graduated cylinder, and then by dividing mass to volume. The viscosity was measured [5] on the hydrostatic test bench Cussons using the falling ball viscosimeter Gibson Jacobs, which measures the time in which a falling standardized ball travels a given distance in a graduated cylinder containing the tested lubricant.
The test was performed at the same temperature of the lubricants, at 20°C and kinematic viscosity υ was calculated using equation (1) :

$$\upsilon = \frac{d^2 g(\delta - \rho)F}{18 v \rho} \tag{1}$$

with d - ball diameter [mm], g - gravitational acceleration [m/s^2], δ-sphere density [g/cm^3], ρ- lubricant density [g/cm^3], F- dimensionless correction factor, v- falling speed of the ball [mm/s].

2.3. Testing procedure and calculations

During the operation of the tribometer an external load is applied on the vee blocks upon the journal, all these parts being immersed in a lubricant bath. Mechanically, the direct load P_d , expressed in pounds or Newtons is decomposed in a normal force F_n and a tangential friction force F_f .
As the pin is driven at constant speed, a friction torque M_f is produced and the coefficient of friction between pin and vee blocks can be calculated based on equations of force and torque conservation, as illustrated in figure 2.
Applying the torque conservation upon the pin, it yields the following equations (2):

$$\sum M_O = 0 \ , \ M_f - 4F_f \cdot \frac{d}{2} = 0 \text{ and } F_f = \frac{M_f}{2d} \qquad (2)$$

Applying the force conservation on x direction upon the vee block , it yields the following equations (3):

$$\sum F_x = 0 \, , \ -P_d + 2F_n \cdot \cos 45° = 0 \, , \text{ and } F_n = \frac{P_d}{2\cos 45°} \qquad (3)$$

Finally, the friction coefficient, μ, is calculated with formula (4):

$$\mu = \frac{F_f}{F_n} = \frac{\frac{M_f}{2d}}{\frac{P_d}{2\cos 45^\circ}} = \frac{M_f \cdot 2\cos 45^\circ}{2d \cdot P_d} = 2.9724 \frac{M_f}{P_d} \qquad (4)$$

with M_f expressed in inch-pounds and P_d expressed in pounds.

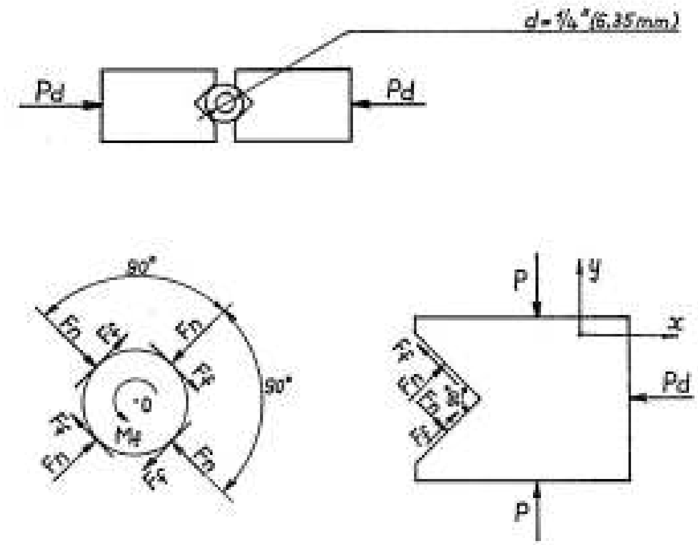

Figure 2: Scheme for the calculation of friction coefficient

Previous to load measurements, as the vee blocks are not perfecty flat, a run –in test was performed adapted from standard [2] ; the duration was of 15 minutes at the direct load applied of 300 lbs.The assessment of tribological properties is detailed in a program load–time considering similar tests performed in [6] for commercial engine oils,with the configuration of direct load P_d applied in time, according to figure 3.The test was repeated three times for each lubricant.

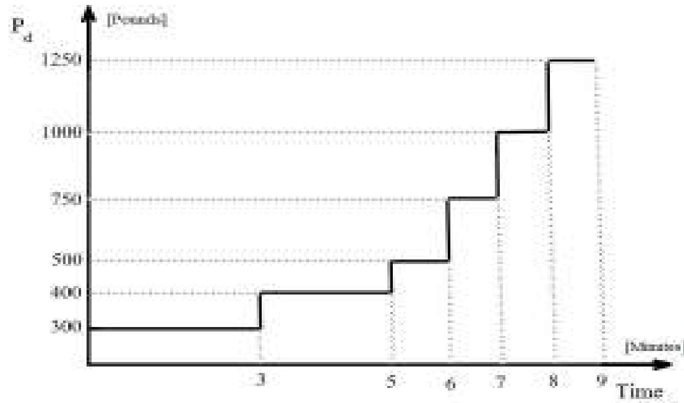

Figure 3: Load versus time - testing program

3. RESULTS AND DISCUSSIONS

3.1 Engine lubricants

The calculations of the coefficients of friction for engine lubricants were performed for the same loads and are illustrated in figure 4, having load expressed in pound-force and coefficient of friction being dimensionless. The measured points were lined using third order polynomial regression. The variation of coefficients of friction with load is similar for two fresh oils, the tribological behavior being better for manufacturer M1 than M2. Having a lower viscosity at ambient temperature, the lubricant 5W30, due to aging and contaminants has an increased coefficient of friction at higher loads.

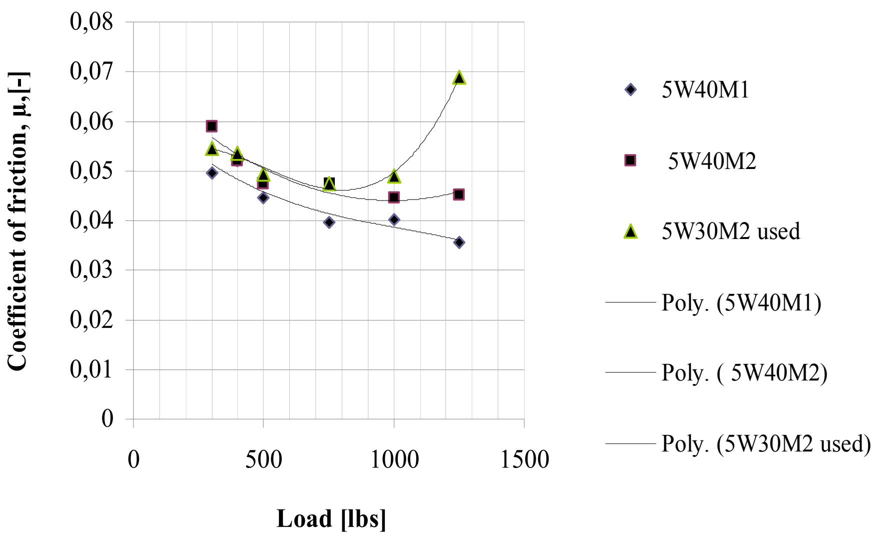

Figure 4: Coefficient of friction versus load for engine lubricants

3.2 Transmission lubricants

The coefficients of friction for transmission lubricants were calculated for the same loads as in previous case being illustrated in figure 5. The values are close to those of engine lubricants, in the same range (0.035 - 0.07). The coefficients of friction have a small increase with the class of viscosity, the increase of friction being higher for used lubricants, having the same behavior as that of engine lubricants.

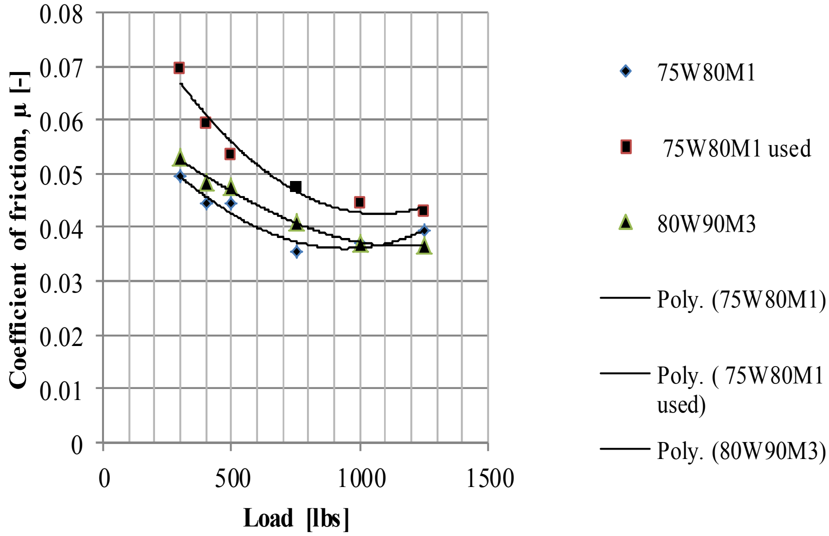

Figure 5: Coefficient of friction versus load for transmission lubricants

3.3 Failure load test

It is important to measure the failure load in the test, which is defined as the minimum load at which occurs a welding within test components. As a result the coefficient of friction and friction torque increase sharply. At that moment the pins and vee blocks are broken or damaged, as seen in figure 6. The lower value of the load at which the lubricant withstood represents the limit load carrying.

Figure 6: Scuffed pins and vee-blocks

The values of the failure loads for engine lubricants 5W40M1, 5W40M2 and 5W30M2 were 1500 lbs at a torque of 26 in.lbf.

3.4 Discussion on Stribeck curve

The tribological properties of fluids are widely represented in form of a graphical dependence known as Stribeck curve [7,8]. The variables are dimensionless, coefficient of friction μ and Stribeck parameter S, the latter being defined according to formula :

$$S = \frac{\eta \cdot v}{P_d} \tag{5}$$

with η - dynamic viscosity of the tested lubricant, v - relative speed of the pin and vee blocks, P_d - direct applied load reported to unit length of contact lines between pin and vee blocks.

For one of the tested lubricants, namely 75W80M1 transmission oil, there were calculated the position of the measurement points on Stribeck curve.The dynamic viscosity was calculated considering the lubricant density and its kinematic viscosity at temperature of the oil in testing cup , the constant rotational speed of the tribometer was turned into tangential speed, by multiplication with the radius of the pin, r. Finally, the Stribeck parameter becomes inverse proportional to direct load P_d and the correlation with coefficient of friction is illustrated in figure 7.

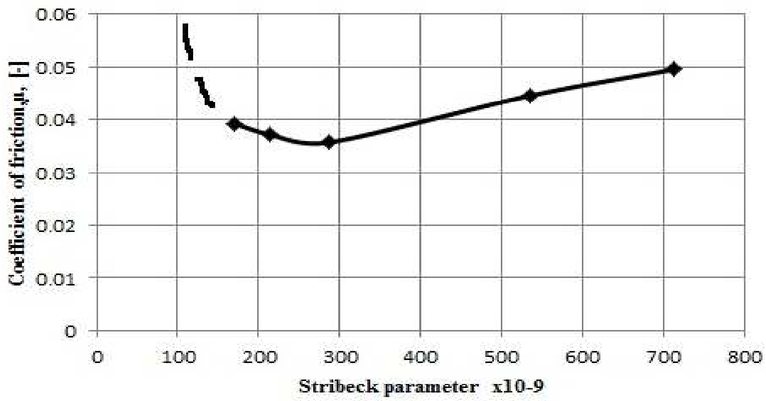

Figure 7: Stribeck curve profile for transmission lubricant

That curve expresses the friction variation within all types of lubrication areas, aforementioned described (BL, ML, EDL and HL).The left dotted line represents the area of BL and ML and the right continuous line represents the area of EDL and HL. For the transmission lubricant, the hydrodynamic lubrication begins in the point of the lowest friction coefficient when the oil film supports completely the carrying load.

CONCLUSIONS

The investigation of engine and transmission lubricants revealed that the values of coefficients of friction are close and for both types, the higher the viscosity class, the higher are the coefficients of friction. More important than the effect of the viscosity is the effect of aging and contamination which increased considerably the coefficients of friction of both lubricants. The coefficients of friction met the profile of Stribeck curve, being identified the areas of mixed lubrication and hydrodynamic lubrication.
The work has also an educational gain, succeeding to implement a procedure for laboratory work in tribology of automotive lubricants, at Transilvania University.

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