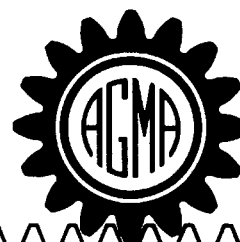


Systematic Investigations on the Influence of Viscosity Index Improvers on EHL-Film Thickness

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American Gear Manufacturers Association



TECHNICAL PAPER

Systematic Investigations on the Influence of Viscosity Index Improvers on EHL-Film Thickness

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

The lubricant film thickness of more than 20 well defined polymer-containing oils was systematically measured in a twin disk machine and compared with film thickness calculations. The permanent and temporary viscosity loss due to shearing were determined separately from each other by means of KRL-shear tests and high temperature - high shear (HTHS) viscosity measurements.

It is shown that the use of the standard kinematic viscosity, as derived from measurements using a glass capillary at standard conditions, for EHL calculation does not lead to a proper prediction of lubricant film thickness for polymer-containing oils. A polymer-correction factor P is derived from the test results, by which the accuracy of film thickness calculation is improved considerably for polymer containing oils.

The applicability of the polymer-correction-factor P is discussed and exemplified by calculating the film thickness along the path of contact of a gear pair.

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SYSTEMATIC INVESTIGATIONS ON THE INFLUENCE OF VISCOSITY-INDEX-IMPROVERS ON EHL FILM THICKNESS

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Nomenclature

A	deformed area of disk capacitor
C	capacitance of disk capacitor
C	thermal correction factor acc. Murch/Wilson [13]
E_1, E_2	Young's modulus of contact bodies
E'	reduced Young's modulus
F_N	normal force
G	EHL-parameter of elasticity
L	thermal load factor acc. Murch/Wilson [13]
M_w	weight average molecular weight
P	polymer-correction-factor
R	reduced radius of curvature
SSI	shear-stability-index
U	EHL-parameter of velocity
VI	viscosity-index
W	EHL-parameter of load
b	deformed Hertzian contact width
d_a	tip circle
d_b	base circle
d_w	pitch circle
f	frequency of resonance circuit
h_{meas}	measured lubricant film thickness
h_{min}	minimum film thickness calculated acc. Dowson/Higginson [6]
h_0	film thickness in the parallel gap calculated acc. Ertel/Grubin [7,9]
l_{eff}	disk width
p_H	Hertzian contact pressure
r_1, r_2	radius of curvature of contact bodies
s	slip ratio ($s = 1 - v_2/v_1$)
v_1, v_2	surface velocity of contact bodies ($v_2 < v_1$)
v_x	hydrodynamic velocity ($v_x = v_1 + v_2$)
α	pressure-viscosity coefficient
α_t	temperature coefficient of dynamic viscosity
$\dot{\gamma}$	shear rate
ϵ_{oil}	relative dielectric coefficient of the oil
ϵ_0	electric field constant ($\epsilon_0 = 8,8542 \cdot 10^{-12} \text{ C/(Vm)}$)
η	dynamic viscosity
η_M	dynamic viscosity at bulk temperature
ϑ	temperature
ϑ_M	average bulk temperature

$$(\vartheta_M = (\vartheta_1 + \vartheta_2)/2)$$

ϑ_1, ϑ_2	bulk temperature of contact bodies
ϑ_{oil}	oil inlet temperature
λ	heat conductivity of lubricant (mineral oil: $\lambda \approx 0,133 \text{ W/(m}\cdot\text{K)}$)
ν	kinematic viscosity
ω	angle velocity

1 Introduction

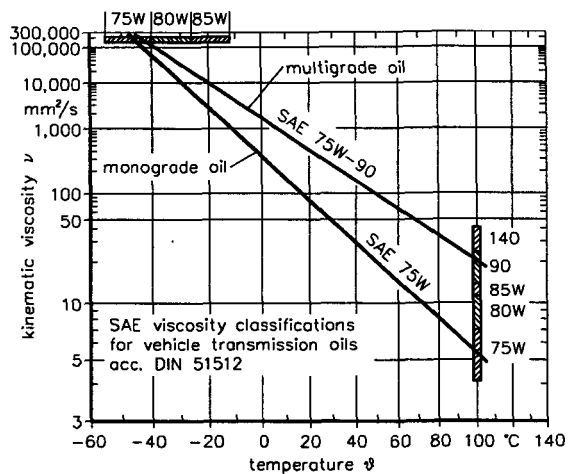


Fig. 1. Difference between monograde and multigrade gear oils for vehicles.

Mineral oil base lubricants show a significant decrease of the kinematic viscosity with rising temperature, as exemplified in Fig. 1 by lubricants for vehicle gears. An important attribute of lubricants is their viscosity index (VI) acc. DIN/ISO 2909 [5]. This is a calculated coefficient, which characterizes the change of viscosity of lubricants as a function of temperature. A high viscosity index represents a low variation of viscosity due to temperature and vice versa. A low viscosity-temperature-dependence is required for lubricants, which are operated at significantly varying temperature conditions, such as vehicle engine and gear lubricants in summer and winter time. This way, the oils remain flowing and pumpable at low temperatures on the one hand, and on the other hand sufficiently thick lubricant films

can be formed at higher temperatures for a safe separation of the surfaces.

A deliberate improvement of the viscosity-temperature-behaviour can be achieved by blending an oil with polymer additives as viscosity-index-improvers, such as polyalkylmethacrylate (PMA), olefin-copolymer (OCP), styrene-butadiene-copolymer (SBC) or polyisobutylene (PIB). This way, polymer-free monograde oils can be converted into multigrade oils, which are used in large quantities as engine oils in vehicles (e.g. SAE 15W-40), as gear oils in manual transmissions in vehicles (e.g. SAE 75W-90, see Fig. 1) or in automatic transmissions (e.g. ATF DEXRON® type oils). Universal oils for tractors and earth-movers (e.g. UTTO), which can be used for hydraulics and gears, are multigrade oils as well.

The viscosity-increasing effect of polymer additives at laboratory conditions is known and can be proved. However, their efficiency at EHL-conditions of high pressure, high shear rate and high temperature, such as in gear or roller bearing contacts, is questionable. Investigations by other authors, e.g. Spikes [12, 15, 16], show that the film thicknesses formed by polymer-containing oils are usually less than those predicted from EHL-theory. Spikes's investigations are based on optical film thickness measurements, where a steel ball is pressed against a glass disk with a maximum Hertzian contact pressure of 520 N/mm² in the point contact. The film thickness measurements described in this paper, however, were carried out using a capacitance test method with two steel disks pressed against each other. The maximum Hertzian contact pressure in this line contact is about 1,200 N/mm², which is significantly closer to the loads in actual gear applications.

The lubricant film thickness significantly influences the micro pitting and wear performance of gear applications and to a smaller extent it also affects the pitting and scuffing performance. Knowledge of the actual lubricant film thickness in a gear contact is therefore essential for a reliable estimation of the failure risks of wear and micro pitting, which are recently more and more in the focus of interest.

For this reason, the efficiency of VI-improvers in EHL-contacts was investigated by systematic measurements of the lubricant film thickness of more than 20 well defined polymer-containing oils. Various types of polymers with various molecular

weights and concentrations in the base oil were included in the test program in order to determine the influence of each parameter on the formation of lubricant films separately from each other.

2 Test Lubricants

The investigations were carried out with more than 20 test lubricants, which were blended especially for this research project. The base oils were two straight, paraffin base mineral oils M32 and M100 of the viscosity grades ISO VG 32 and ISO VG 100. The polymers, which were used, comprised PMA (polyalkylmethacrylate), PIB (polyisobutylene), OCP (olefin-copolymer), SBC (styrene-butadiene-copolymer) and STAR (star-shaped styrene-isoprene-copolymer). For each type of these polymers, a set of five different blends was investigated, which is shown in Table 1 for the polymer PMA as an example. Each polymer type was available with low molecular weight (PMA1, OCP1, etc.) and high molecular weight (PMA2, OCP2, etc.). The polymers with low molecular weight were added in low concentration (PMA1L, OCP1L, etc.) and high concentration (PMA1H, OCP1H, etc.) to the base oil M100 and in very high concentration to the base oil M32 (PMA1VH, OCP1VH, etc.). The polymers with high molecular weight were added in low concentration to base oil M100 (PMA2L, OCP2L, etc.) and in high concentration to base oil M32 (PMA2H, OCP2H, etc.).

Code of test oil	molecular weight		concentration			base oil		viscosity v_{100} in mm ² /s	
	low	high	low	high	very high	M32	M100	12.6	20
PMA1L	X		X				X	X	
PMA1H	X			X			X		X
PMA2L		X	X				X		X
PMA2H		X		X		X			X
PMA1VH	X				X	X			X

Table 1. Systematics of test lubricants for PMA-containing oils as an example.

The polymer concentration in each blend was chosen with respect to equal kinematic viscosities v_{100} of all test lubricants at 100°C, so that the lubricant film thicknesses of all oils could directly be compared at high temperature. Emphasis was put