

ENERGY STATE IMPACT ON FRICTION AND WEARING IN COMBUSTION ENGINES

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Abstract

Friction pairs are designed from elements, where is very difficult to define in unequivocal way all optimal parameters. Research on stability of friction pairs are focused on the surface and the top layer of surface in the parts. The main goal is find new solutions to design and material, thereby achieving one million kilometres of mileage to main repair in the case of internal combustion engines. The biggest structural difficulties are noticeable in friction pairs where we can observe sliding and returning motion, which is also connected with sealing function. Piston – ring – cylinder assembly of combustion engine has many friction pair's examples, also one of them, which decide about fastness to wear. A typical example of such a pair is first sealing ring – cylinder sleeve, called further in piston – rings – cylinder unit in combustion engine. Engineers are currently seeking an additional factor, which would be unable to gain the reduction of tangential force by reducing the friction coefficient in elements of friction pair during operations. Such a factor may be the surface free energy that results from molecular structure and nature of the bonds between the molecules present in the material. Components of surface free energy determine the tribological properties of the material, which is reflected in the stability of the units. The work aims to show the possibilities and benefits of the application of this new method in order to reduce wearing, which is consistent with the observed trend of technology development.

Keywords: *friction, energy state, combustion engines, wetting drop, tribology*

1. Introduction

Tribological processes in an internal combustion engine are one of the most complex phenomena's that describe engine operation, and consequently the consumption of individual components [1, 2]. The best object to describe this type of process is a wearing pair of piston – ring – cylinder [6, 7]. The operation of these components affects not only by the geometry or manufacturing technology, but also by the material and its properties. Going further on this track, each material has its own specific molecular structure and therefore has some surface energy that can also affect the wear process of the part.

However, there is a lack of a specific property, which with appropriate value would ensure optimum work of co-operating elements. Work on this issue has led to considerations over the free surface energy of materials that make up the parts.

When choosing surfaces and materials in wearing pairs, it is worthwhile to suggest also the additional factor, which is free surface energy and its constituents. By using this algorithm, there is

possibility to get better combinations in pairs by creating the corresponding shells or layers [12]. Each component of surface energy plays a concrete role in phenomena that occur at the interface of two closely co-operating materials. To achieve the value of the energy parameter, a wettability problem is very useful to construct a number of mathematical relationships based on material properties.

Defined free surface energy and hardness minimize friction and consequently wear of components. This parameter can also be used to describe the principle of material selection on pairs that perform reciprocating motion with a sealing function, and undoubtedly, an example of such a pair is the TPC (piston – ring – cylinder) on the internal combustion engine [3, 4].

This type of operation, where the temperature of the components presents in the result of combustion process, significantly diminishes the sealing function, which negatively affects the lubrication processes and speeds up the wear process by friction.

To properly fulfil sealing function material should be characterized by high:

- elastic boundary,
- fatigue strength,
- hardness,
- toughness ,
- bending strength and compression

This combination of requirements often results good anti-wear (tribological) properties and, as a result, parts easily blur and have a high coefficient of friction when working with the cylinder. The combination of good strength properties with tribological properties is possible thanks to the application of coatings to the cooperating elements, which minimize the loss of energy in friction pairs.

Wearing pair is subjected to varying mechanical and thermal loads during operation, and therefore piston-ring-cylinder elements are characterized by appropriate construction. Piston rings and cylinders feature a suitable shape to keep the lubricating oil on the work surface to minimize wear [8, 9]. In case of loss of oil film, this construction is intended to ensure continued operation of the unit without the danger of seizure. Here, the characteristic features of the lubricant – the so-called ability to create an oil film layer, which in turn is dictated by the properties of the material from which the cylinder is made and the piston rings [10, 11]. This article proposes an additional factor whose inclusion reduces the tangential force and also affects the tribology thereby reducing the coefficient of friction in the pair during operation. This parameter is the free surface energy, which is the effect of molecular structure and bonding in a given material whose components influence the tribological properties of the material of the pair. Confirmation of this theory has already been found in durability studies, which will minimize tangential force, improve overall durability, and reduce wear.

2. Free surface energy

All deliberations on free surface energy are initiated by phenomena that occur at the boundary of the elements of the cohesive pair that co-operate and which are the result of intermolecular interactions. Atoms located at the boundary (ex. solid – liquid) are attracted by both the atoms of their phase and the atoms of the adjacent phase, thus appearing in an asymmetric force field. Atoms migrate so far into the phase (hence the distance between the atoms changes) until they are in equilibrium. The emergence of diverse forces at the interface contributes to such phenomena as adhesion and wetting. To describe the phase state, we use thermodynamic functions as internal energy (U), free energy (F), and free enthalpy (G) are used. In pure systems we can distinguish the pure phase α and β and the transient surface phase between the limits σ . The total internal energy of each phase is the sum of each of the energy: heating (TS), volumetric (pV), surface energy γA , chemical energy $\sum \mu$ and others such as magnetic energy BM or electrical $Q\Psi$.

$$U^\alpha = TS^\alpha - pV^\alpha + \sum \mu_i^\alpha n^\alpha + \text{other} , \quad (1)$$

$$U^\beta = TS^\beta - pV^\beta + \sum \mu_i^\beta n^\beta + \text{other} , \quad (2)$$

$$U^\sigma = TS^\sigma - pV^\sigma + \Upsilon A + \sum \mu_i^\sigma n^\sigma + \text{other} , \quad (3)$$

where:

α, β, σ – phases,

T – temperature [K],

S – entropy,

P – pressure,

V – volume,

Υ – interphase tension,

A – interphase surface,

μ_i – chemical potention,

n – number of particles,

B – magnetic induction,

M – magnetic moment,

Q – electric charge,

Ψ – electrical potential,

Σ – chemical energy as the sum of the energy of chemical individuals.

Based on the calculations using the basic thermodynamic functions it was assumed that the surface processes take place in constant volume and constant pressure, so it is true that:

$$\Upsilon = \frac{dF^s}{dA} = \frac{dG^s}{dA} , \quad (4)$$

where:

Υ – interphase tension,

F – free energy,

G – free entalpy,

A – surface dimension,

s – parameter describing the surplus of a given feature.

Interphase tension is also called free phase energy (so-called free surface energy). For solids, is used the free surface energy Υ , while for liquid the surface tension. Free surface energy can be determined by several parameters:

– based on the surface tension of the molten solid in function of temperature

$$\Upsilon_s = \Upsilon_m + \frac{d\Upsilon}{dt}(T - T_m) , \quad (5)$$

where:

Υ_s – surface tension of liquid metal at temperature T,

Υ_m – surface tension of liquid metal at melting point T_m ,

– based on Young's modulus and known intermolecular distance (equivalence of interaction and absence of lattice defects)

$$E = r_0 \left(\frac{dF_r}{dr} \right) , \quad (6)$$

$$E = \frac{32\Upsilon_s}{r_0} , \text{ so } \Upsilon_s = \frac{E r_0}{32} \text{ [J/m}^2\text{]}, \text{ [N/m]} , \quad (7)$$

where:

E – Young module [Pa],
 r_0 – particle distance [m],

– based on its components

$$\gamma = \gamma^d + \gamma^m + \gamma^h + \gamma^o, \quad (8)$$

where:

γ^d – dispersion component (London forces, momentary elementary dipoles),

γ^m – metallic bonding component (associated with free electrons circulating in a solid body),

γ^h – hydrogen bonding components (solids and liquids),

γ^o – other binding (ionic, covalent).

– based on the Hamaker constant (since dispersion effects are essential)

$$\gamma^d = \frac{A_{11}}{24\pi r^2}, \quad (9)$$

where:

γ^d – dispersion portion of free surface energy,

A_{11} – Hamaker constant,

r – intermolecular distance of affected bodies.

– based on the wetting angle, which will be described in more detail below.

3. Wetting drop

Wetting is the dissipation of liquid droplets (total or partial) on the surface of a solid or other liquid. There is also the concept of wetting angle Θ . When it is set to 0° , there is full wetting. When its value equals 180° , it is absolutely not wetting. This angle depends on factors such as the cohesive attraction between molecules, the attraction of molecules by the surface of the solid surface at the point of contact, the attraction of liquid molecules that are not in contact with the body surface, but are within the range of gravitational interactions and forces.

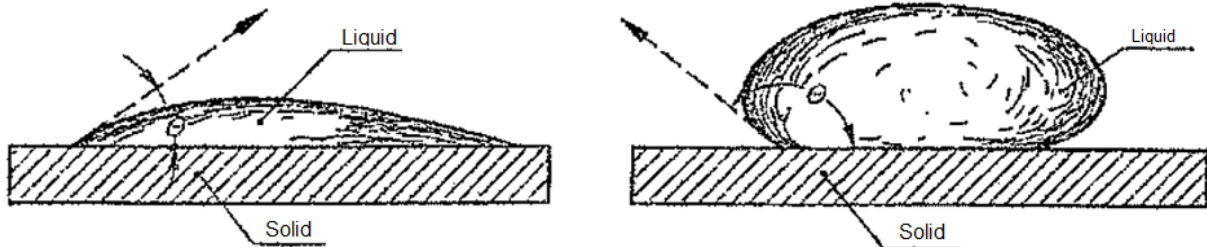


Fig. 1. Wetting angles for wetting and non-wetting liquids

The microscope observes the droplet lying on the surface of the solid. Of course, the droplet dimensions depend on the temperature and purity of the surface of the solid. With geometric measurements, we can get the following relation:

$$\operatorname{tg} \frac{\Theta}{2} = \frac{h}{r} = \frac{2h}{d}. \quad (10)$$

The liquid wetting process of the solid is in the form of the equation:

$$\gamma_{SV} = \gamma_{SL} + \gamma_{LV} \cos \Theta_Y, \quad (11)$$

where:

γ_{SV} – free surface energy of a solid in equilibrium with a saturated steam,

γ_{SL} – free interfacial energy of solids and liquids,

γ_{LV} – free surface energy of liquid in equilibrium with saturated steam,

Θ – the angle that forms the tangent to the surface of the measured drop deposited on the surface of the solid at the point of contact of the three phases.

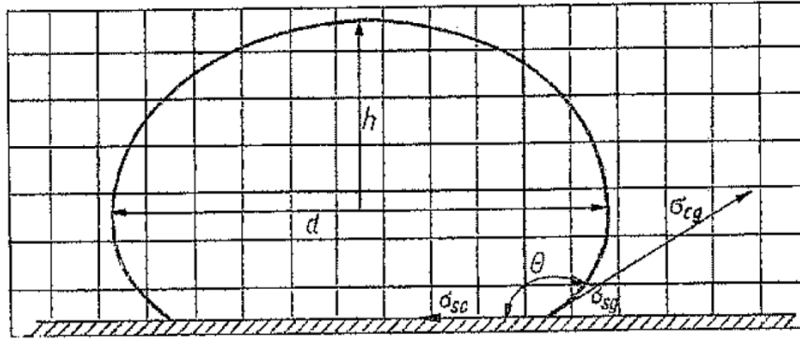


Fig. 2. Determination of wetting angle by droplet measurement

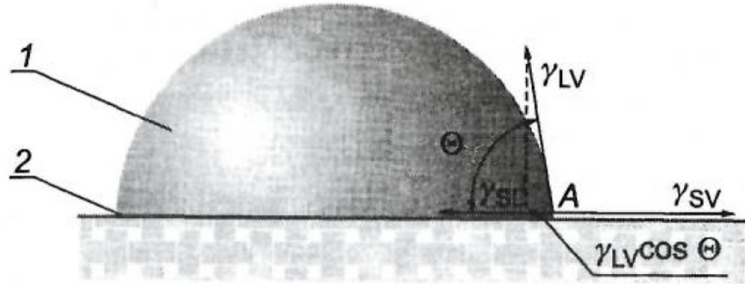


Fig. 3. Graphic interpretation of wetting drop: 1 – measured drop, 2 – solid body

The value of the wetting angle is measured with reference liquids and thus the free surface energy components of the solids can be calculated.

$$W_a = \gamma_s + \gamma_L - \gamma_{SL}, \quad (12)$$

where:

W_a – the work of adhesion necessary to create a liquid and solid surface,

γ_s – free surface energy of a solid in a vacuum (simplification),

γ_L – free surface energy of the measuring fluid (simplification),

γ_{SL} – interphase free surface energy of solids and liquids.

The adhesion work is very closely linked to the concept of wettability and free interfacial energy. The condition of dissipation is determined by the energy conditions of the interfacial boundaries.

In turn, cohesion work quite simply can be determined. In general, it is understood as the amount of energy needed to break: $W_k = 2\gamma_L$, that is, it is equal to the double free surface energy value of the fluid at the interfacial boundary. For lubricating oil, it is determined by measuring the surface tension of the lubricating oil. For most apolar liquid hydrocarbon liquids, it is equal to 24-25 mJ/m².

By using the free surface energy component based on the wetting phenomenon of the solid, 2-3 standard fluids with known free surface energy components are used. For simplicity it is assumed that free energy has only two components – dispersion and polar. Polar is Keesom interactions (durable dipoles), Debye (induction dipoles), affirmative, multipolar, and hydrogen. The whole can be saved using general patterns:

$$\gamma_L = \gamma_L^d + \gamma_L^p, \quad (13)$$

$$\gamma_s = \gamma_s^d + \gamma_s^p, \quad (14)$$

where:

γ_L – free surface energy as the sum of dispersion and polar liquid effects,

γ_L^d – dispersion part of the free surface energy of the liquid,

γ_L^p – the polar part of the free surface energy of the liquid,

γ_S – free surface energy as the sum of dispersion and polar solids interaction,

γ_S^d – dispersion portion of the free surface energy of the solid body,

γ_S^p – polar part of the free surface energy of a solid.

4. Summary

After the above considerations, it can be stated that the free surface energy depends on the Young module, the K module or the hardness of the substance. The dispersion element of free surface energy (apolar liquid, ex. lubricating oil) is a measure of wettability. Boldly it can be stated that the wetting angle Θ depends on the value of the dispersion component. The $\cos \Theta$ values may be indicator of material selection for friction pairs to ensure high wear resistance and, with adequate lubrication of lubricating oils, low losses for friction. Knowing the angle of wetting is a very important parameter because of the tribology because it affects the lubrication process. Based on the linear relationship between the angle and the surface tension, several methods have been developed to determine the surface tension, including the method by measuring the droplets.

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