EU OBIECTIVE OF 120g CO_2/km EMISSION FOR NEW CARS, A CHALLENGE FOR TRIBOLOGY

IVAN ILIUC
Tribology Department
Institute of Solid Mechanics
Constantin Mille 15, Bucharest
ROMANIA

Abstratct Passenger cars produce about 12 % of overall EU greenhouse gas –GHG- emissions (CO2) and transport sector with about 20 % is the second biggest emitter of GHG among all sources. Since 1990, EU has reduced transport emissions by 5 % but the contribution of road transport increased by 26 %. In order to accomplish the Kyoto requirements it is clear that transport emissions should also be reduced. A new decision of EU Commission from Feb 2007 specific the average emission in EU 27 should be 120 g/km by 2012. For several decades the most cost-effective method of reducing CO2 emissions from cars will be to improve fuel efficiency. There are many ways of further improving the fuel efficiency of conventional engines and cars, among them: ignition systems that ensure complete combustion of the fuel available, improved compression at low engine loads, engine and gear friction reduction, six-speed manual transmission, stop-go systems, cylinder deactivation and other. Tribology will help to realize the above improvement by using low friction lubricant, adequate additive and modifying the frictional surface. The paper presents the problems and research direction which could solve this challenge

Key-Words: GHG emissions, fuel efficiency, friction modifiers, structured surfaces, surface treatment

1 Introduction

Cars plays an important role in the everyday activities of a large number of Europeans, and the automotive industry is a significant source of employment and growth in many regions of the EU. In the same time car usage has significant impacts on climate change, with about 12% of the overall EU emissions of carbon dioxide (CO2), the main greenhouse gas (GHG) coming from the fuel consumed by passenger cars. The whole transport sector with about 20 % is the second biggest emitter of GHG among all sources. Since 1990, EU has reduced transport emissions by 5 % but the contribution of road transport increased by 26 %. In order to accomplish the Kyoto requirements it is clear that transport emissions should also be reduced. A new decision of EU Commission from Feb 2007 specific the average emission in EU 27 should be 120 g/km by 2012. The optimum solution to reduce CO2 emissions from cars and to safeguard jobs and investments in Europe is an integrated approach, which should combine further improvements in vehicle technology, an increased use of alternative fuels, improved infrastructure and traffic management, a more economic driving style and last but not least a stimulant CO2-related taxation.

Another non-technological way to reduce GHG emission caused by transport is the gradual, but accelerated renewal of aged car fleet. That is essential, as CO2 emissions from new cars have decreased significantly and the majority of emissions are caused mainly by an aging car fleet on Europe’s roads.

From all these measures, improvements in vehicle technology are most complicated and expensive operations. Developing improved engines and vehicles needs ample preparation, up to 5 years at minimum. New technologies often need even longer to enfold their full market potential.

2 The technical potential for reducing fuel consumption

For several decades the most cost-effective method of reducing CO2 emissions from cars will be to improve fuel efficiency. There are many ways of further improving the fuel efficiency of conventional engines and cars, among them:

- *Engine and transmission friction reduction*
- *Improved compression at low engine loads*
- *Continuously variable transmission (CVT) to improve gearing efficiency*
- *Stop-go systems*
- *Cylinder deactivation*
- *Six-speed manual transmission*

All above presented measures have directly or indirectly to do with tribology. Greater compression ratio, stop-go system and cylinder deactivation could, without adequate measure.
worsen lubrication and wear in cylinder-piston – piston rings ensemble.

- *Reduced air drag and rolling resistance*

Although also here intervene different kind of friction the tribology cannot help too much.

- *Computer controlled engine management*
- *High-powered ignition systems that ensure complete combustion of the fuel available*
- *Improved fuel injectors*
- *Variable valve timing*

The use of computer to control management of engine (ignition, fuel injection and valve timing) is compulsory for the improvement of fuel efficiency.

- *Reduced mass*

This very effective method to reduce CO2 emission depends on utilization of new light materials but also of acceptance of automobile customer.

3 Friction reductions without increasing of wear

3.1 Friction reduction and friction modifiers

All moving parts in the powertrain of the car are lubricated. Some of them work most of the time in full hydrodynamic conditions as for example journal bearings, which guide the crankshaft. They are so designed that most of the operation time the solid surfaces are completely separated by a continuous lubricant film (Fig 1a). In modern engine journal bearing the minimum oil film thickness is in order of few microns. If the speed or lubricant viscosity reduces the film become thinner and the opposite surfaces came into contact at the tips of surface asperities. The load is carried now both by oil film and solid contacts (Fig. 1b). This is the case when engine start and stop. At rest the full load is supported by solid-solid contacts. The coefficient of friction (COF) of journal bearing and various lubrication regimes can be seen on Stribeck curve as function of parameter ηU/W (viscosity, speed, load) (Fig. 2).

On the right side, slightly ascendant, lubrication regime is full film hydrodynamic (I). In the middle is mixed regime lubrication where the hydrodynamic film is so thin that asperities come in contact. The COF rise up as more and more solid contacts appear (II). At the left of diagram is boundary lubrication regime where almost the entire load is supported by surface asperities (III).

The power loss and minimum oil film thickness in full film hydrodynamic journal bearing depend on bearing parameters:

$$F_B \propto \frac{\eta^{0.75}\omega^{1.75}L^{0.25}W^{0.25}R^{2.75}}{c^{0.5}} \quad \text{(W)} \qquad (1)$$

$$h_{\min} \propto \sqrt{\frac{\eta\omega RL^3}{W}} \quad (\mu\text{m}) \qquad (2)$$

where η is viscosity, ω rotation speed, R radius, L bearing length, W load, R bearing radius, c radial clearance (R- shaft radius)

From the relation 1 and 2 and the Stribeck curve one can see the friction reduces (and power loss) when viscosity is lower. Simultaneously diminishes the minimum oil film and probability of solid- solid contacts raises. The mechanical wear of surfaces appears as consequence of such contacts i.e. in mixed lubrication regime. To reduce the wear amount (and COF) in this lubrication regime one uses chemical compounds, which are added to the basic lubricant. These substances consist of long alkyl chain to which a chemically active group is attached to ensure that the molecule has certain polarity. The most frequently used additive of this type are esters of fatty acids (ex. glycerol mono-oleate), the long chain aliphatic alcohols and amines.

Other class of additive is antiwear additive as for example compounds of sulfur, phosphor and zinc or molybdenum (ex zinc di-alkyl dithiophosphate ZnDTP and molybdenum di-thio carbamate MoDTC). These additives form on surfaces reaction layer with greater shear strength as adsorbed layer (Fig. 3). Both types of layers prevent direct contact between metallic surfaces and so the excessive wear. The layers formed from additives present in lubricant are permanently renewed by adsorption and reaction. Presence of

ISBN: 978-960-6766-75-6

ISSN 1790-5125

friction modifiers additives in lubricant reduce the COF in mixed regimes (Fig. 2 dotted line).
The formulation of new engine oil is a complex task. Modern motor oil contains also other additives (antioxidants, detergents, VI improvers and some other) and a new formulation should consider also the interaction between them.
Energy saving effect of lower viscosity oil come not only from reduced friction in lubricated moving machine parts but also reduced energy loss by pumping of oil in motor or splashing of crankcase oil and gear box oil.

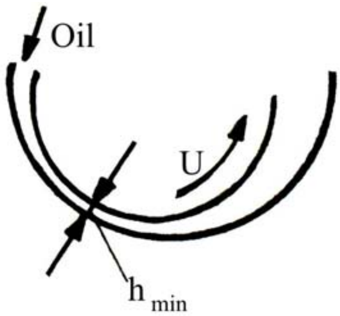


Fig.1a Full film hydrodynamic journal bearing

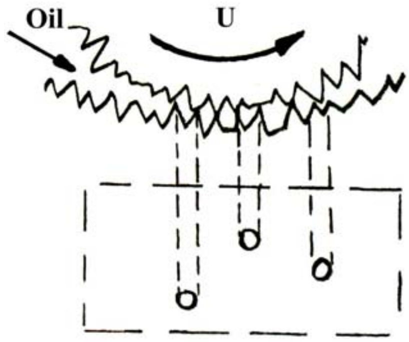


Fig.1(b) Journal bearing in mixed lubrication
The load is supported by oil film and solid contacts

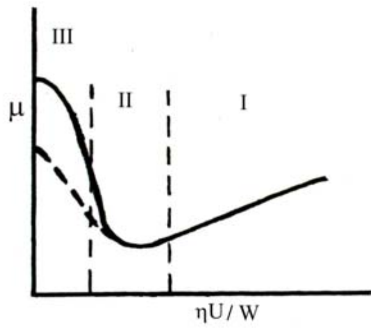


Fig. 2 Stribeck diagram
I – Hydrodynamic lubrication; II – Mixed lubrication regime; III – Boundary lubrication

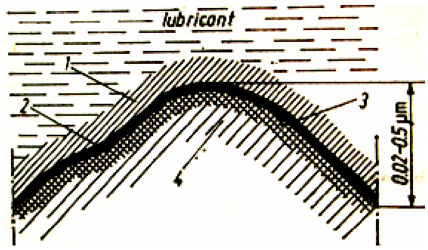


Fig. 3 Superficial layer on metallic surface
1- mono (poly) molecular adsorbed layer
2- reaction layer (oxide + other compound)
3- microcrystalline layer
4- deformed layer

Use of lower viscosity oil, well formulated, can save up to 40% of energy loss by fluid friction without diminishing the durability of engine or transmission. In the table 1 is shown the influence of lubricant viscosity grade on friction loss in a 2 liters European engine.

Table 1 Effect of lubricant viscosity grade on friction loss (W) in a 2 l. European engine operating in urban condition [1].

Oil grade SAE	Valve train	Bearing	Piston assembly	Total
20W/50	588.5	610.1	743.9	1942.5
15W/40	599.8	567.5	677.6	1844.9
10W/30	625.4	467.5	554,2	1647.1
0W/20	410.2	380.0	492.2	1282.4

Further friction reduction via lower viscosity depends on research and development of new chemical active compounds (additives) materials or new phenomena discovered in the boundary lubrication.
In the last few years it has been shown experimentally that simple, Newtonian liquids, including paraffinic can slip against solid surfaces. The phenomenon seems to contradict the basic hypothesis of hydrodynamic lubrication of “no slip” at the wall. The slip occurs when solid surface is very smooth and the liquid is only weakly adsorbed to the solid, that is the liquid does not fully wet the solid [2]. One interesting application of this effect could be the development of a fluid film bearing in which the liquid lubricant is able to slip against one solid surface but not against the other. The friction in such bearings should have a lower friction as classical bearing. An attempt to reduce friction in boundary lubrication condition

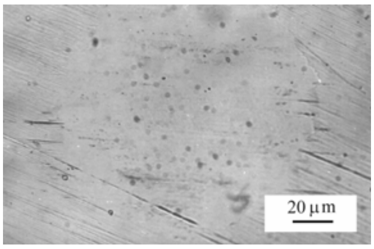
ISBN: 978-960-6766-75-6

ISSN 1790-5125

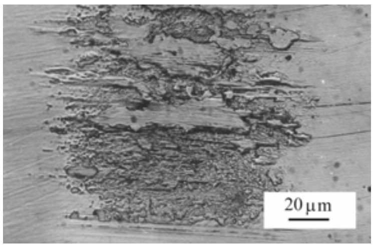
using fine polished TiN inserts was recently tried in lubrication of valve train [3]. The result was positive when oil without friction modifier has been used.

An "abnormal " wear behavior was recently found in thin film lubrication of steel ball on TiN plate, both very fine polished [4]. Glycerol, with a short molecule, assures "zero" wear in contrast with that obtained with paraffin oil with about 20 carbon atoms in molecule (Fig. 4).

Beside oil formulation further improvement in friction and wear (durability) of engines will bring the optimization of surface micro-geometry and new surface treatments.



a



b

Fig. 4 Wear scar on the steel ball [4].
Lubricant: glycerol (a), mineral oil (b)
Steel ball on TiN surface
Load: 10 N, Running time: 5 min
Umed = 175 mm/s
Alternate movement,

3.2 Surface micro-geometry optimization

Whatever is machining process uses to build the machine parts their surfaces have a typical micro-geometry. Grinding in various forms is main manufacturing process in motor industry. To characterize the micro-geometry of the surface on simply way is to consider the profile highs (z) as random variables. Then their statistical representation in term of the probability density function p (z) is high distribution and for a digitized profiles the histogram. The high distribution of ground surfaces can be considered almost gaussian. (Fig.5). Following numerical parameters can be computed for a given digitized profile with N sample of high z_i in measured interval L:

$$Ra = \frac{1}{N}\sum_{i=1}^{N}[z_i - m] \quad (3); \quad \sigma^2 = \frac{1}{N}\sum_{i=1}^{N}[z_i - m]^2 \quad (4)$$

$$S_k = \frac{1}{\sigma^3 N}\sum_{i=1}^{N}[z_i - m]^3 \quad (5); \quad m = \frac{1}{N}\sum_{i=1}^{N} z_i \quad (6)$$

Are also used the average (in five point) peak-to-valley height Rz and maximum height Rt. For a full film hydrodynamic designed machine part, as for example the journal bearing the considering of parameter Ra (or Rz) is sufficient. The minimum film thickness under load and at medium speed must be 2-3 times greater as Rz. When the minimum oil film thickness is reduced in domain of surface roughness, the surface micro-geometry became important for wear of surfaces. The correct running- in clear away from the profile highest part. The bearing area raises but the dipper zone of the profile remain almost unchanged. The performance of surfaces –load capability – raises. The new surface is characterized by negative skewness S_k (Fig. 5).

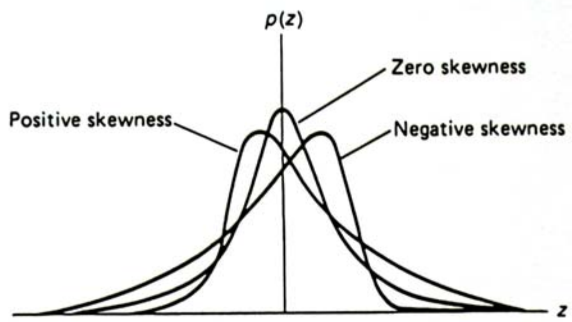


Fig. 5 Probability density function for random distribution with different skewness Sk

To reduce or eliminate the running-in process, some of machine parts, as for example the cylinder surface is obtained in two step machining process. After preliminary grinding, the surface is subjected to honing procedure. The honing process removes the upper part of the profile in so called plateau-honing procedure. The obtained surface, that have large bearing area, has also enough crosshatch depth to retain oil and provide good ring lubrication. The above mentioned statistical parameters (3-6) are not sufficient to characterize such complex procedure as plateau honing.

In was proposed and adopted, in automobile industry a semi-empirical way to described such surfaces. This measurement procedure start from bearing (Abbott) curve of profile. On this curve on calculate such parameters as: R_K,R_{PK}, R_{VK} and some other (Fig. 6)[5].

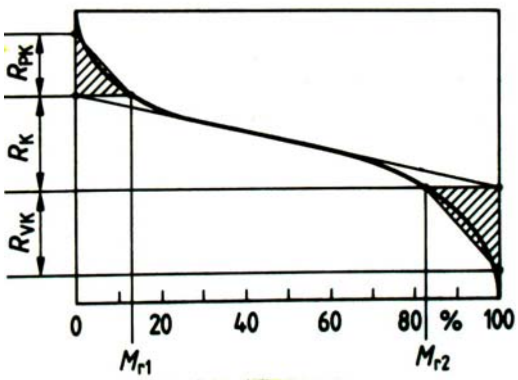


Fig. 6 Bearing curve and determination of surface roughness parameters: Rk, Rvk and Rpk.

Using these parameters the difference between grounded and honed surface became more evident. For example the same surface first grounded has (in micron): Rz = 3.52, R_K = 1.33, R_{PK} = 0.44, and R_{VK} = 1.97 and after honing the same parameters became: 4.08, 0.62, 0.13, 1.97 respectively. One can see that these parameters show better that upper part of the profile was cut off.

The researches for better surfaces are continuing. Because parameter of honing process is inevitable limited on try to improve the surface lubrication by additional procedures.

One of this is "laser structuring" or "laser honing", in which a computer guided laser spot burn out in surface small hole or line (about 5 μm deep) with various design. Finally the cylinder is subjected to final honing [6]. The tests on lab engine and on field have shown a reduction of wear of cylinder and piston rings and also reduction of oil consumption and particle emission.

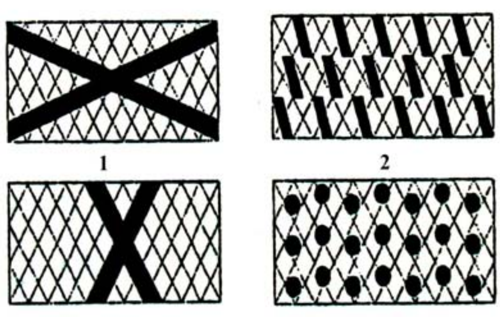


Fig. 7 Honed and laser structured surfaces.

1- line-interconnected system
2- micro-pressure (closed) system

The laser structuring of surfaces has found many other application. One of them, successfully applied, is improving of seal durability [7], [8]..

The research for better micro-geometry is continuously and yield news machining procedures. In one of them a performing surface micro-geometry of cylinder wall (in what concern oil consumption and wear- friction loss) is obtained when the plateau honing procedure is preceded by sanding of surfaces with fine grid diamond suspension. The procedure remove the TiN formation from surface, the remaining cavities will act as closed oil pocket in the finished cylinder surface [9]. In searching for better cylinder-piston-ring assembly, the improvement of micro-geometry should be completed with material study as in former example, when to the cast-iron is added small amount of titan in order to generate TiN formation in the material structure.

3.3 Surface treatments

Because sometime the bulk properties of materials do not fulfilled the tribolgical needs of machined parts, the modification of the surfaces is the solution. In the tribological application where the main interaction process take place in the upper layer of the piece the surface treatment can dramatically improve friction and wear. In the same time surface treatments leave unchanged the mechanical properties of the material core. The surface treatment is in tribological application a first chose technological procedure.

The surface treatments (surface modification) before the part is utilized are classified as follow:

- without any material addition only by structural change (ex. superficial hardening)

-with material addition, material which is solved in superficial layer of machine part and eventually reacted with some element of the alloy (ex. nitriding).

-the new material is deposited on the surface and form a coherent layer. The main problem in this case is the adherence of deposited layer to support surfaces, problem manly solved using intermediate layers. This layer make a gradual change from base material properties to layer properties The domain is extremely vast and intense studied; it belong to the new domain of "surface engineering". In many cases it can be obtained layer with desired properties, i.e. the layer can be "designed". The physical-chemical procedures allow obtaining layer with extreme hardness and low COF as for example mono crystalline diamond layer or diamond-like –

ISBN: 978-960-6766-75-6

ISSN 1790-5125

DLC- layer well boded to the substrate. The DLC layer with COF of about o.o1 to 0.05 for boundary and dry friction respectively, and hardness of HV 2000 seems to be the ideal tribological layer. At the present time the piston ring are used only after surface treatment, for example chroming, nitriding or mixed chrome-ceramic spraying, which enhance considerably its durability [10]. The great durability of the newest piston ring treatment could make possible reducing of cylinder roughness even toward Ra ="0" [11]. Now the surface treatment is an inseparable part of tribology. For industrial application only impediment are the supplementary costs.

An important role in tribological processes play also the layers category which are formed by physical and chemical interaction between surface and additives presents in lubricant. The anti-wear and friction improver act via such layers. In this domain one needs more researches because of increased restriction in utilization of compound containing phosphor and sulfur in motor industry. A future solution could be utilization as additives for lubricant of metals nanopowder, diamond nanopowder, carbon nanotubes or fullerene. These new materials should generated on the bearing area thin renewable very effective protection layer [12].

4 Conclusions

Tribology can contribute to lower fuel consumption in motorcars. The first measure is to reduce the oil viscosity. The solution has been already successfully used. But the further reducing of the viscosity could increase the wear of the machine part. The future tribological research should find new materials, surface effects and treatments and oil additives, which can protect the surfaces against wear with ever more thinly becoming oil.

References

[1] R.I. Taylor, Lubrication, Tribology & Motorsport, *Motorsports Engineering Conference & Exhibition, December 2002*, Indianapolis, IN, USA, Paper 2002-01-3355

[2] HA Spikes**,** Slip at the wall—evidence and tribological implications, *Tribology and Interface Engineering Series*, Volume 41, 2003, Pages 525-535

[3] Amp Gangopadhyay, Douglas Mc Watt, et all**,** Effects of Composition and Surface Finish of Silicon Nitride Tappet Inserts on Valvetrain Friction, *Tribology Series*, Volume 36, 1999, Pages 635-644

[4] I. Iliuc, Wear and micropitting of steel ball sliding against TiN coated steel plate in dry and lubricated conditions, *Tribology International*, Volume 39, Issue 7, July 2006, Pages 607-615

[5] DIN 4776 (1990)

[6] U. Klink, Laser-Honing für Zylinderlaufbanen, *MTZ Motortechnische Zeitschrift,* Volume 58, Issue 9,1997, Pages 36-47

[7] H. Haefke, Y. Gerbig et all, Mikrostrukturierung von funktionellen Oberflächen zur Verbesserung der tribologischen Eigenschaften, *GfT TribologieFachtagung 1999 Reibung,Schmierung und Verschleiß, 27-29 September 1999, Göttingen,* 10/1-10/6

[8] Pettersson, U., and Jacobson, S. "Influence of surface texture on boundary lubricated sliding contacts" *Tribology International*, 36 (2003) 857-864

[9]E. Seck, J. Strobel, Diamant-Fluidstrhl-Glätthonung, MTZ Motortechnische Zeitschrift 62 {2001} 2, Pages 184-188

[10] U Buran, Chrom-Keramik-Kombinationschichten für Kolbenringe, *ATZ-MTZ Sonderausgabe: Werkstoffe im Automobilbau,* 1966, Pages 71-73

[11] A. Robota, F. Zwein, Einfluß der Zylinderlaufflächantopografie auf den Olverbrauch und die Partikelemissionen eines Dieselmotors, *MTZ Motortechnische Zeitschrift,* Volume 60 (1999) 4 Pages 246-255

[12] V.A. Leonidovich, P.E.Anatolievich et all, Diamond-carbon material and method for producing it, US Patent 5,916,955, June 29,1999