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Numerical Solution of Micro-Lubrication in Internal Combustion Engine Journal Bearing

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Abstract: All technological processes leading to the final surface visage of mechanical components create on its surface characteristic pattern. These surface patterns subsequently play a significant role in terms of their function and lubrication, particularly in the case of surface contact pairs. However, inclusion of the actual surface patterns of machine parts as one of the input parameters of the computational simulation of friction losses is still not common. This article describes a complex computational model for solving the frictional losses for directionally oriented and non-oriented sliding surfaces.

The first part of this article provides information regarding the description of surface roughness. Attention is paid to the two basic possibilities of obtaining the surface characteristics – namely those obtained by measurement (3D scanning surface) or those obtained using a specialized software generator. The software generator of surface characteristics is based on the relation:

$$z(x,y) = \frac{\sigma}{\sqrt{nm}} \sum_{k=1}^{n} \sum_{l=0}^{m} \eta_{x+k,y+l} \,. \tag{1}$$

The second part of this contribution describes the behaviour of thin lubricating layers depending on the lubricated surfaces topologies. The generally accepted simplification of similar tasks accepts the assumption of zero velocity near the lubricated surface. On the other hand, the computational approach described in this paper takes into account flow of the lubricant between each asperity, which is governed by the Reynolds equation. The described procedure provides a sort of loss coefficients of the oil flow (flow factors) that are specific for the technology of the resulting surface, the material, coating, or surface finishing method that gives its final form. The directional dependence of the analysed surface is determined by its autocorrelation function, which is given in Eq. 2.

$$R(\tau_i,\tau_j) = \frac{1}{(M-i)(N-j)} \sum_{l=1}^{N-j} \sum_{k=1}^{M-i} \eta(x_k,y_l)\eta(x_{k+i},y_{l+j}) \tag{2}$$

The resulting flow factors – form one of the inputs for the general solution of Reynolds equation (Eq. 3), which is the basic core of the hydrodynamics solver. Its numerical solution is generally known and is often used to describe the hydrodynamic lubrication regime.

$$\frac{\partial}{\partial x}\left(\phi_x \frac{\rho h^3}{12\eta}\frac{\partial p}{\partial x}\right) + \frac{\partial}{\partial y}\left(\phi_y \frac{\rho h^3}{12\eta}\frac{\partial p}{\partial y}\right) = \frac{U_1+U_2}{2}\frac{\partial(\rho h_T)}{\partial x} + \frac{U_1-U_2}{2}\sigma\frac{\partial(\rho\phi_s)}{\partial x} + \frac{\partial(\rho h_T)}{\partial t} \tag{3}$$

One of the outcomes of the computational sub-models mentioned above is number of pairs of surface protrusions in the contact (unique for the type of surface and ratio of height of the lubricating layer) and combined roughness of both surfaces. The full-length article gives examples of generated and scanned surfaces, examples of the surface roughness pattern impact on flow factors, and also examples of friction losses analysis. Regarding the automotive industry, the computational model can be applied, for example, to the piston ring pack, journal bearings, camshaft and others.

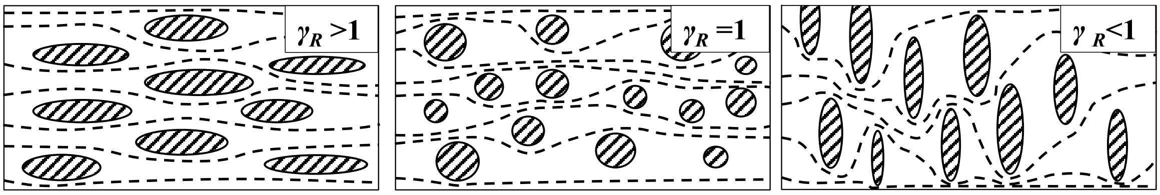

Fig. 1: Illustrative shapes of contact areas of longitudinally oriented (γ_R >1), isotropic (γ_R =1) and transversely oriented surfaces (γ_R <1)

The following tables list results of two sample analyses of crankshaft main bearing. The first table lists results for the case of naturally aspirated three cylinder internal combustion engine. In the second case the load was applied on the bearing from over-pressured internal combustion engine. Three different configurations of surface pattern of bearing shell (according to Fig. 1) were tested in both cases together with the case when the impact of flow factors was not considered.

Table 1: Results of analysis of naturally aspirated internal combustion engine slide bearing

γ_R	-	1	1/3	3	[-]
min h/σ	1.05	1.30	1.20	1.22	[-]
average h/σ	6.03	6.26	6.10	6.23	[-]
h/σ < 4	27.00	25.70	26.49	27.80	[%]
P_{ztr}	152.23	154.78	157.95	154.09	[W]

Table 2: Results of analysis of over-pressured internal combustion engine slide bearing

γ_R	-	1	1/3	3	[-]
min h/σ	0.77	1.01	0.94	0.91	[-]
average h/σ	5.22	5.47	5.31	5.43	[-]
h/σ < 4	30.00	28.70	29.90	29.31	[%]
P_{ztr}	169.70	174.26	178.94	173.24	[W]

When the results from both tables are compared, it is evident that the greatest differences are in case of transversally oriented surface pattern (γ_R <1) and when the flow factors were not considered. This difference reaches ones of percent. Wrong design of partial mechanical components can cause big mechanical losses of the final machine.

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