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Short Communication

Proposals of methods of oil capacity calculation

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ABSTRACT

The aim of this work is to compare various methods of oil capacity calculation for surfaces containing cavities. In reference method, oil capacity was computed by summation of volumes contained in all the holes of measured surface using TalyMap software. Oil retention volume was calculated also on the basis of material ratio curve using the Svk and Sr2 parameters from Sk parameters group (areal extension of ISO 13565-2 standard). The second and third procedures were developed on the basis of rotation of material ratio curve axes. The fourth method is based on determination of point of maximum curvature of the normalized material ratio curve. It was found that in the most cases it was possible to obtain correct values of oil capacity using the Sk parameter family. However when the slope of material ratio curve in its middle part (core roughness) is small or high, the errors of oil capacity estimation may be large; up to 80%. In those cases the other methods gave better results–usually errors of oil capacity estimation were not higher than 10%; average deviations were about 5%. Determination of transition point between valleys and plateau regions as the point of maximum curvature of the normalized material ratio is recommended. The new proposals of oil capacity calculation can be used also for surfaces with cross-hatched pattern.

1. Introduction

Some properties of assemblies, such as material contact, friction, lubricant retention and wear resistance are related to surface topography of the components. The introduction of specific textures on a surface by surface texturing, involving micropits (holes, dimples, cavities or oil pockets) is an approach to improve tribological properties of sliding elements. Those micropits may reduce friction by acting as reservoirs for lubricant, improving seizure resistance. Holes can also serve as micro-traps for wear debris in lubricated or dry sliding [1,2].

Plateau honing is one of the first examples of surface texturing. Cylinder liners have a plateau-like surface topography with a cross-hatch pattern generated in finishing process known as honing. It is believed that proper honing improves lubrication and reduces friction and wear. In a number of recent studies it was reported that oil consumption was also influenced by cylinder liner finish [3–5]. Oil capacity (oil retention volume) of cylinder liner is parameter functionally important. It described the volume of lubricant reservoir under defined roughness height. Too high oil capacity results in large oil consumption by internal combustion engine, however too small – high inclination of cylinder liner to seizure. Oil retention volume is often included in requirements of internal combustion engine builders. This parameter is also important in other lubricated elements contained dimples or grooves, like sleeve or journal [6]. The volume of lubricating oil, saved in dimples or valleys influences the tribological characteristics of sliding elements. Introduction of dimples on honed cylinder surface caused increase of oil capacity about 50%, which resulted in decrease of the coefficient of friction almost twice comparing to plateau honed cylinder liner surfaces [7]. The large cavities might aid lubrication when the lubricant could escape from the pockets into the contact area. The textured samples with increased oil retention volume compared to smooth surfaces exhibited a clearly longer lifetime [8–12]. In starved lubrication regime minimum amount of lubricant required is related to surface oil retention volume. When the amount of lubricant is too low, the profitable effect of oil pockets disappeared compared to untextured specimens and tribological properties of sliding pairs can be even deteriorated (increase of the friction force). Decrease of oil capacity can be solution of this problem. In starved lubrication conditions oil capacity of textured surfaces should be specified.

Oil retention volume can be arbitrarily determined on the basis of defined material ratio like 60% [13] or 70%. However it should depend on transition point between core (base) and deep valleys portions of the material ratio curve. There are problems in defining that point. According to Trautwein [14,15] transition point resulted

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Nomenclature

Methods of oil capacity calculation

AFR based on rotation of the material ratio curve
MP based on rotation of probabilistic plot of the material ratio curve
MRC based on finding the point of minimum radius of curvature of the material ratio curve
Sk based on calculation of the Svk and Sr2 parameters
VH reference method based on summation of volumes of all the holes

of the cross-cut of a tangent to the curve in its middle part with the regression straight line describing the deep valleys region. The method described in German standard DIN 4776 (and then in ISO 13565-2) was more synonymous than Trautwein's method [16]. The following parameters can be determined: the reduced peak heights Rpk, the reduced valley depth Rvk, the core roughness depth Rk, and material ratios determined by the straight line separating the core roughness from the material side (Rmr1) and free from material side (Rmr1). However different methods of material ratio curve description can be used, on the basis of its probability plot, presenting material ratio on Laplace-normal system (ISO 13565-3). This method has the sounder theoretical basis [17–19] than ISO 13565-2. Rpq (plateau root-mean square roughness) parameter is the slope of a linear regression performed through the plateau region, but Rvq (valley root-mean square roughness) through the valley region. The intersection point on normal probability graph of abscissa Rmq (material ratio of plateau-to-valley transition) defines the separation of plateau and valley portions. This method can be only used for two-process random surfaces (however it can be modified for description of two-process random-deterministic textures [20,21]). Augustyn [22] determined the point of the passage from the core roughness to the deep valleys region as the point of maximum curvature of the normalized material ratio curve. Michalski and Pawlus [23,24] defined the limits of the characteristic profile regions in similar manner, however they used different formula for approximation of the normalized material ratio curve than Augustyn. However method contained in ISO 13565-2 standard is now the most commonly used.

Improper calculation of surface oil retention volume may results in false estimation of tribological properties of lubricated sliding assemblies, which may be connected with risk of seizure. This problem is very important nowadays when the role of surface texturing considerably increases. Therefore finding a method which would allow to proper determination of surface oil capacity is a task of a great functional importance.

2. Materials and methods

Several surface topographies contained holes were studied. They were made from the following materials: bronze CuSn10P of 138 HB hardness, steel 42CrMo4 of 35 HRC hardness and gray cast iron of 218 HB hardness. These samples were selected, because it was possible to obtain estimated values of oil capacity by calculation and summation of volume of all holes existed on surfaces, contrary to plateau honed cylinder liners with connected valleys. Surface topographies analyzed were measured by various instruments; stylus measuring equipment Hommel Etammic T8000 and white light interferometer Talysurf CCI Lite. For measured surfaces, form was approximated and removed using a polynomial of the second degree. Digital filtration was not used, because of risk of distortion of measurement results.

For reference results, the volumes of all the holes were calculated using procedure from TalyMap software and summed. Contours of the holes were evaluated using the mouse. Each hole was covered by parallel lines in two orthogonal directions and higher values of obtained volumes were chosen. This method is called VH.

Oil capacity was also achieved by four other methods: Sk, AFR, MP and MRC. The normalized oil retention volume was obtained by

$$OC_{Sk} = 0.005\ Svk(100 - Sr2)$$

where Svk and Sr2 are areal extensions of the 2D parameters Rvk and Rmr2 from ISO 13565-2 standard (unit of Sr2 is %). The obtained value should be magnified by measuring area. This method is called Sk.

The three other methods defined passage point between the base region and the valley region in different ways. The first of them depends on rotation of material ratio curve of ψ_1 angle anticlockwise. This angle is the slope of the straight line connecting the first and the last point of the material ratio curve. In rotated diagram the point of the highest ordinate is estimation of the passage point. This method is called AFR.

The next method is based on modification of procedure of Spq and Smq parameters (areal extensions of Rpq and Rmq parameters from ISO 13565-3 standard) estimation for random-deterministic two-process surface. The main problem is determination of transition point between random and deterministic regions which are plateau and valley surface parts, respectively. This point was determined by rotation of material probability plot of ψ_2 angle anticlockwise. ψ_2 angle is the slope of straight line passing by the first and the finishing point of probabilistic plot of the material ratio curve. Similar to AFR method, in rotated diagram point of the highest ordinate was determined. This point is treated as transition between deterministic and random regions and abscissa of this point after repeated rotation of the probabilistic plot of the material ratio curve is equal to transition Smq parameter. Details are given in Reference [20]. This method is called MP. It is similar to the AFR procedure, the main difference is that in MP method the material probability plot of the material ratio curve was used.

In the last method height of material ratio curve was normalized (between 0 and 1) and for all points of this curve, their radii of curvature were calculated. Then point of minimum radius was determined. It can be treated as passage point between plateau (base) and valley parts of surface topography. The point of minimum radius of curvature was calculated on the basis of material ratio curve without approximation, which is the main difference between the present method and those reported in [22–24]. This method is called MRC.

When the passage point was determined, surface was truncated eliminating portion lying above this point; only the valley part was left. For that valley portion the Sp parameter (maximum pit height) was determined. Because this parameter describes surface void volume, its magnification by measuring area is estimation of the real oil capacity.

3. Results and discussion

Fig. 1a presents contour plot of exemplary surface S1 with separated oil pockets and material ratio curve with the parameters