COMPARISON 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 with isolated pockets. These surfaces were measured by stylus profilometer. In reference method, oil capacity was calculated by summation of volume contained in all the separate dimples from measured surface. Oil capacity was calculated also on the basis of material ratio curve using the Svk and Sr2 parameters from the Sk group (areal extension of ISO 13565-2 standard). The second procedure was developed on the basis of Sq parameter group (areal extension of ISO 13565-3 standard). The third method is bases on determination of point of maximum curvature of the normalized material ratio curve. It was found that in most cases it is possible to obtain correct values of oil capacity using the Sk family parameters. However when the slope of material ratio curve in its middle part is small or high, the errors of oil capacity estimation using this approach may be large. In this case the other methods gave better results.

Keywords: surface topography, oil capacity, surface texturing

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, involving micropits (holes, dimples, cavities, oil pockets) is an approach to improve tribological properties of sliding elements. Those micropits may reduce friction by acting as a reservoir for lubricant, improving seizure resistance. Holes can also serve as a micro-trap for wear debris in lubricated or dry sliding. Various techniques can be employed for surface texturing including machining, etching and laser techniques. 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 is reported that oil consumption is also influenced by cylinder liner finish. Oil capacity of cylinder liner is parameter functionally important. It described the volume of lubricant reservoir under defined roughness height. Too small oil capacity results in larger oil consumption by internal combustion engine, however two big – high inclination to seizure. Therefore optimal value of oil capacity is needed. Oil capacity can be arbitrary determined, on the basis of defined material ratio like 60% [1] or 70%. However it should depend on transition point between base (core) part and deep valleys part of material ratio curve. There are problems in defining this point. According to Trautwein [2,3] this point resulted 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 [4]. The following parameters can be determined: the reduced peak heights Rpk, the reduced valleys 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 (Rmr2). However the other method 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 [5, 6, 7]. 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 between plateau and base parts. This method can be only used for two-process random surfaces (however it can be modified for description of two-process random-deterministic surfaces [8]), contrary to method from ISO 13565-3 standard. Augustyn [9] determined the point of the passage from the core roughness to the deep valleys region as the point of maximum curvature of the normalised bearing ratio curve. Michalski and Pawlus [10] defined the limits of the characteristic profile regions in similar manner, however they used different formula for approximation of the normalised material ratio curve.

However method contained in ISO 13565-2 standard is now the most commonly used. Improper calculation of oil capacity may results in false estimation of functional properties of assemblies. The present authors tried to find cases when it gives improper results along with proposal of other methods.

2. MATERIALS AND METHODS

Several surface topographies contained oil pockets were studied. Dimples were created on the bronze surface after precise turning by burnishing technique. Surface roughness in areas free of oil pockets were characterised by the Ra parameter of about 0.5 μm. These samples were selected, because they contained isolated oil pockets, therefore it was possible to obtain precise value 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 were measured by stylus measuring equipment Hommel Etammic T8000. Initial measuring area was 4 mm x 4 mm, sampling interval was 5 µm in two orthogonal directions. Measuring speed was 0.5 mm/s. For measured surfaces, form was approximated and removed using a polynomial of the second degree. Digital filtration was not used.

For reference results, the volumes of all the holes were calculated using procedure of TalyMap Gold software and summed. Oil capacity was also achieved in different ways. The normalised oil capacity was obtained by half of product of parameters: Svk and 0.01 (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 values should be magnified by measuring area. However the passage point of material ratio curve between base and valley parts was also determined by different ways. The first method bases on modification of procedure of Spq and Smq parameters (areal extensions of Rpq and Rmq parameters from ISO 13565-2 standard) estimation for random-deterministic two-process surface. The main problem is determination of transition point between random and deterministic regions. This point was determined by rotation of material probability plot of ψ angle anticlockwise. ψ angle is the slope of straight line passing by the first and the finishing point of the material ratio curve. 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 is equal to transition Smq parameter. Details are given in [8]. This method was changed for rotation of conventional material ratio curve by ψ angle. The transition point was called Smr.

In the second method height of material ratio curve was normalized (between 0 and 1) and for all points of this curve, its radius of curvature was calculated. Then point of minimum radius was determined. It was called Smc. It can be treated as passage point between base and valley parts of surface topography. The special procedure was elaborated in order to proper determination of minimum radius of curvature. It was calculated on the basis of material ratio curve without approximation, which is the main difference between the present method and that reported in [10].

When the passage points were determined, surface was truncated eliminating parts lying above this point; only valley part was left. For this valley part the Sp parameter (maximum pit height) was determined. Because this parameter describes surface void volume, it should be magnified by measuring area, in this way the real oil capacity can be calculated.

3. RESULTS AND DISCUSSION

Figure 1a presents contour plot of surface S1 with separated oil pockets. Volume of dimple 1 is 0.01943 mm^3, dimple 2 is 0.01658 mm^3. Real oil capacity OC_r is equal to sum of these volumes: 0.036 mm^3. Figure 1b presents material ratio curve of surface S1. Measured area is 12.25 mm^2. Oil capacity OC_{Sk} obtained according to this method should be:

$$0.005*(100-90)*0.054[mm]*12.25[mm^2]= 0.03307[mm^3] \quad (1)$$

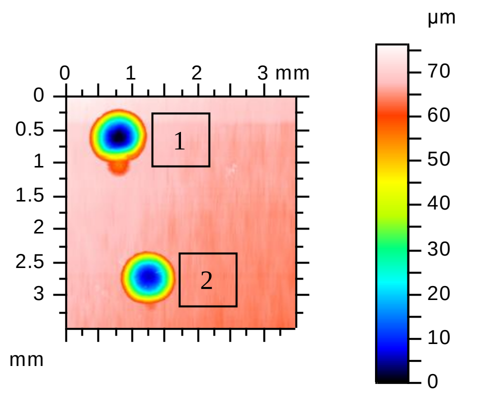
The relative error is:

$$\Delta OC_{sk} = \frac{OC_{SK} - OC_r}{OC_r} \quad (2)$$

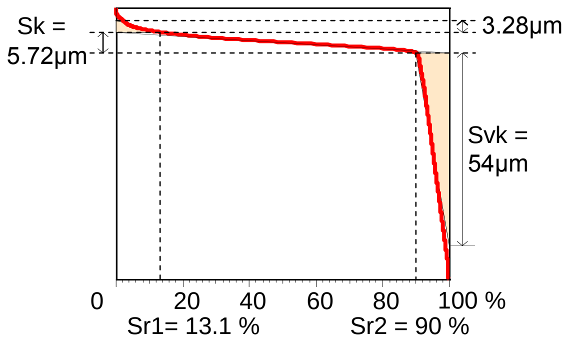
It is equal to -8.14%.

The passage point between base and valley parts was calculated based on rotation of material ratio curve. Figure 1c presents this curve with straight line passing by the first and the finishing point and ψ angle. Material ratio curve is shown in Fig. 1d. The Smr material ratio was found to be 90.43%. Surface S1 was then truncated removing ordinates higher than this corresponding to this material ratio. It contained only valley part. The Sp parameter of this truncated texture is 2.69 µm. The oil capacity OC_{mr} is 0.00269 x 12.25 = 0.03295mm^3. The relative error ΔOC_{mr} is -8.48%. Similarly, passage point obtained as point of a maximum curvature of normalized material ratio curve is found for material ratio of 90.79%. Similar to procedure described previously, surface was truncated and Sp parameter of only valley part was found to be 2.67 µm. Therefore the relative error of the method based on maximum curvature of normalized material ratio is ΔOC_{mc} is -9.16%. Figure 1e shows material ratio curve with transition points of abscissas: Smr and Smc. Three methods gave oil capacity similar to correct (real) value.

a)



b)



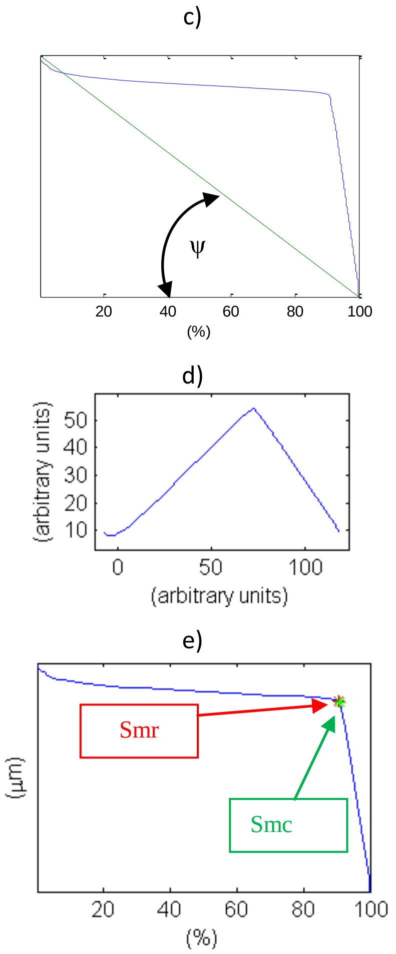


Figure 1. Contour plot of surface S1 (a), its material ratio curve (b), material probability plot with straight line passing by the first and the finishing point and ψ angle (c), material probability plot rotated by ψ angle (d), material ratio curve with transition points between base and valley regions of material ratios Smr of 90.43% and Smc of 90.79% (e)

However not always application of the Sk method gave correct results of oil capacity calculation. Figure 2 shows example of its underestimation, but Figure 3 overestimation. Material ratios Smr and Smc of passage points are also shown. Real oil capacity OC_r is 0.5212 mm^3. Oil capacity OC_{Sk} is 0.3874 mm^3. The relative error ΔOC_{sk} is -25.7%. The oil capacity OC_{mq} of surface S2, shown in Figure 2c is 0.471 mm^3. It was obtained on the basis of the Smq parameter of 58.5%. The relative error ΔOC_{mr} is -9.6%. Passage point obtained as point of a maximum curvature of normalized material ratio curve was found for material ratio of 59.2%. In this case, the relative error of oil capacity estimation using the method based on maximum curvature of normalized material ratio ΔOC_{mc} is -10.32%.

Figure 3a presents contour plot of surface S3 with separated oil pockets. Volume of dimple is 0.00315 mm^3. Real oil capacity OC_r is equal to this volume. Figure 3b presents material ratio curve of surface S3. Oil capacity OC_{Sk} is: 0.004418 mm^3. The relative error ΔOC_{sk} is 40 %. One can see that oil capacity is overestimated. The Smq parameter is found to be 94.34%. The oil capacity OC_{mq} is 0.002978mm^3. The relative error ΔOC_{mr} is smaller -5.59%. Passage point obtained as point of a maximum curvature of normalized material ratio curve is found for material ratio of 93.8%. The relative error of the method based on maximum curvature of normalized material ratio is ΔOC_{mc} is 0.59%. It is minimum from all the analysed values.

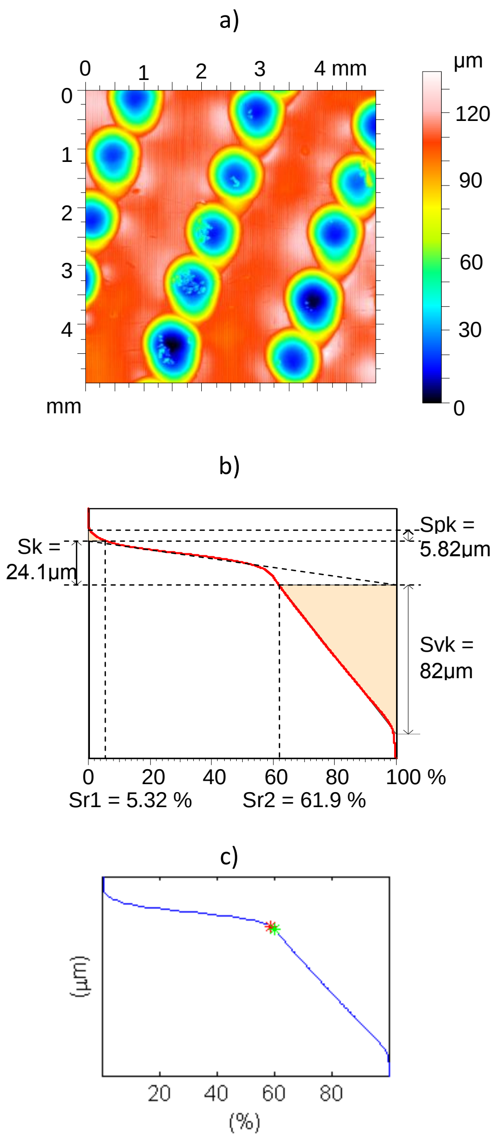


Figure 2. Contour plot of surface S2 (a), its material ratio curve (b), material ratio curve with transition points between base and valley regions of material ratios Smr of 58.5% and Smc of 59.8% (c)

It is evident that all three methods of material ratio curve analysis gave similar values of oil capacity estimation of surface S1. This value is a little smaller than that obtained after analysis of volumes of separated dimples. In this case the application of method based on the Sk family parameters is easier than usage of two other methods. It was found that generally the errors obtained using this approach are acceptable, which was confirmed in other investigations for different surfaces containing cavities [11].

However sometimes application of this method lead to non-correct calculation of oil capacity. It may cause false estimation of functional properties of elements. Of course one can obtain real oil capacity by summation of dimple volumes, but it can be difficult or impossible for connected valleys of cross-hatched cylinder texture after plateau honing.

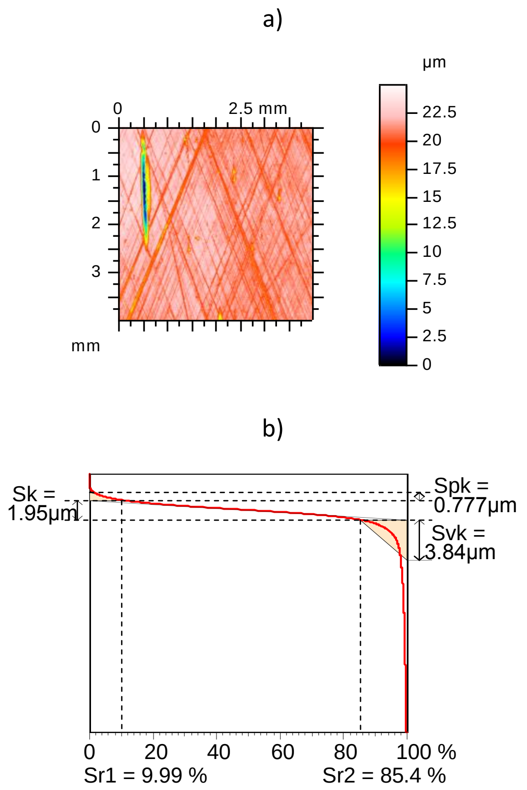


Figure 3. Contour plot of surface S3 (a), its material ratio curve (b), material ratio curve with transition points between base and valley regions of material ratios Smr of 94.34% and Smc of 93.8% (c)

False estimation of oil capacity by Sk group is caused by slope of middle part (core) of material ratio curve. For surface S2 this slope is comparatively high, so relative error of oil capacity estimation was higher than 25% (underestimation of oil capacity occurred). Application of two other methods resulted in considerable decrease of dispersions.

Different situation takes place with regard to surface S3. Because of rather small slope of material ratio curve in its middle part (core height) the oil capacity was overestimated by more than 40%. Application of the other methods caused also decrease of errors.

Several surfaces containing separate oil pockets were tested. In each cases errors of oil capacity calculations using methods based on material curve rotation or determination of points of its minimum radius of curvature were not higher than 10% (average deviations about 5%).

However methods of oil capacity calculation different to procedure based on the Sk family were tested on surface with separated dimples, they can be used for surfaces with connected valleys, like cross-hatched cylinder structure. It seems that from among these two methods, approach based on finding points of minimum radius of curvature of normalized material ratio curve has sounder theoretical basis and is more elegant. It is important that its application doesn't require approximation of material ratio curve, which can be additional source of errors. Therefore more in-depth research on this procedure is required in future work.

CONCLUSIONS

Oil capacity is important tribological parameter, Therefore oil efforts aimed increase of accuracy of its estimation have practical importance. Three procedures of oil capacity estimation were compared with reference method based on summation of volumes of separated dimples. It was found that method based on Sk parameters group is the easiest, but substantial errors caused by slope of its middle part are possible. Errors due to application of the other methods are smaller. Method using rotation of material ratio curve is simpler, but approach of determining point of minimum radius of curvature of normalized material ratio curve has sounder theoretical basis.

REFERENCES

[1] E. Willis, "Surface finish in relation to cylinder liners", *Wear*, vol. 109 (1-4), pp. 351-366, 1986.

[2] R. Trautwein, „Bewertung der Oberflache von Zylinderlaufbahnen", *MTZ*, vol. 35 (10), pp. 339-340, 1974.

[3] R. Trautwein, "Kenwerte zur Erfassung und Bewertung der Oberflache von Zylinderlaufbahnen", *MTZ*, vol. 38 (12), pp. 565-566, 1977.

[4] H.S. Nielsen, "New approaches to surface roughness evaluation of special surfaces", *Precision Engineering*, vol. 10, pp. 209-213, 1988.

[5] H. Sanna Reddy, J. Raja , K. Chen, "Characterization of surface texture generated by multi-process manufacture". *International Journal of Machine Tools & Manufacture*, vol. 38 (5-6), pp. 529-536, 1998.

[6] M.C. Malburg, J. Raja, "Characterization of surface texture generated by plateau-honing process", *CIRP Ann*., vol. 42 (1), pp. 637–640, 1993.

[7] C. Anderberg, P. Pawlus, B. G. Rosén, T. R. Thomas, "Alternative descriptions of roughness for cylinder liner production", *Journal of Materials Processing Technology*, vol. 209 (4), pp. 1936-1942, 2009.

[8] W. Grabon, P. Pawlus, L. Galda, A. Dzierwa, P. Podulka, "Problems of surface topography with oil pockets analysis". *Journal of Physics, Conference Series*, vol. 311 (012023), 2011.

[9] W. Augustyn, "Elaboration of the method describing surface topography of cylinder liners", *PhD Dissertation*, Wroclaw University of Technology, 1985.

[10] J. Michalski, P. Pawlus, "Characterization of the shape of the roughness profile ordinate distribution", *Wear*, vol. 161(1-2), pp. 135-143, 1993.

[11] K. Fejkiel, "Difference between various methods of determination of oil capacity estimation", *Diploma thesis*, Rzeszów University of Technology, 2013.