Problem of selection of reference plane with deep and wide valleys analysis

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Abstract. Areal form removal of cylindrical surfaces containing deep and wide valleys was often analysed; the influence of selection of filtering techniques was taken into consideration in many original researches. However, the errors of reference plane selection on surface topography parameters of cylindrical elements containing deep and wide dimples (oil pockets, scratches) were not fully recognized. In this paper, the improper selection of reference plane in surface topography analysis of cylindrical elements with deep or wide oil pockets were taken into consideration. The errors of surface topography parameters (from ISO 25178 standard) caused by improper areal form removal were presented; some parameters were specified according to its the biggest distortions. It was proposed to select the reference plane with particular attention to the specified parameters. It was assumed that proposal of bandwidth (cut-off) values in digital filtering depends on both size and distance between dimples.

1. Introduction
Usually the surface texture parameters are calculated after form removal; there were many algorithms proposed for form extraction [1-6]. The unwanted elements of the surface texture are broadly defined to the waviness, as a results of inaccuracy in the machining process. Separation of form from the surface texture can be applied by positioning a mean reference plane. Areal form removal was often proposed by: least-square fitting algorithms [7], polynomials [8], digital filtering with its modifications [9, 10] and other methods [11]. However, selection of reference plane with particular emphasis on the deep and wide valley analysis was not fully recognized. Furthermore, the errors of surface topography parameters according to improper reference plane selection was not clearly presented; the amount of parameter errors was not precisely observed and defined.

Surface topography of car engine parts is functionally important so it is often analysed. Surfaces containing oil pockets have advantage over one-process surfaces [12]. However, this is exceedingly difficult to analyse the results of measurement of stratified textures. Surface topography of cylindrical elements containing oil pockets was analysed in [13, 14]. However, the distortion of dimples was not identified in accordance with improper selection of reference plane.

2. Materials and methods
Cylinder liners with dimples created by burnishing techniques were taken into consideration. They were measured by stylus instrument Talyscan 150 or white light interferometer Talysurf CCI Lite. Diameter (V_d) and depth (V_a) of oil pockets were around 1 mm and 100 µm respectively. More than 20 measured and 20 modelled surfaces were analysed but only three of them were showed in details. The maximum size of analysed surfaces was 5 x 5 mm; the spacing was 5 µm. Textures from cylindrical parts were thoroughly analysed. The examples of extracted details from measured (a, b) and modelled (c, d) surfaces were presented in figure 1. For separation of form and waviness directly from these surfaces polynomials (from 2nd to 4th degree) and robust Gaussian filter with bandwidth value between 0.8 (RGF_0.8) and 1.6 (RGF_1.6) mm were used. The effect of reference plane on surface views and parameters from ISO 25178 standard were studied. The influence of distance between valleys (V_d) as well as digital filtering cut-off values (DF_{cutoff}) on areal form removal was also taken into account.
3. Results and discussions

From the isometric view (figure 2) analysis it was assumed that application of polynomials of 2nd, 3rd and 4th degrees did not allow to remove form correctly; the higher degree was proposed the higher distortions of Sk parameters (core roughness depth Sk, reduced valley depth Svk, reduced summit height Spk) were observed. When the degree of polynomial increased, the value of Sk and Spk parameters increased but the value of Svk decreased correspondingly. It was proposed to select the reference plane when the value of Sk parameter was minimalized (the errors and/or uncertainty of application of different degree of the polynomials were presented in [14]); for this type of surfaces the 2nd degree of polynomial was proposed. However, from the analysis of extracted profile details (figure 3-a) it was concluded, that form was not entirely eliminated. Therefore digital filtering was required.

![Fig. 1. Isometric views of examples of extracted details from measured a1 (a), a2 (b) and modelled a3 (c), a4 (d) surfaces and their material ratio curves (e, f, g and h) respectively](image)

![Fig. 2. Surface a3 after form removal by polynomial of: 2nd (a), 3rd (b) and 4th (c) degree and their material ratio curves (d, e and f) correspondingly](image)

![Fig. 3. Extracted profiles from surface a3 after form removal by application of polynomial of: 2nd (a), 3rd (b) and 4th (c) degree](image)
For the isometric view analysis it was found that application of RGF 0.8 allowed to remove form correctly (according to polynomial appliance). However, when the $V_{ds} < V_{di}$ then some distortions of dimples were occurred (figure 4-b). In figure 4 two types of oil pockets distribution was presented; $V_{ds}$ value for dimple no 1 and dimple no 2 (or no 3 and no 4 respectively) was less than 0.5 mm, while for dimples no 2 and no 3 was relatively bigger (more than 1.2 mm). When the $V_{ds} < DF_{cov}$, distortion of dimples was also particularly noticeable (figure 4-b and -d). The smaller value of $V_{ds}$ was obtained the bigger distortion of dimples was observed (surface areas most exposed to distortions were indicated by arrows in figure 4-a).

![Fig. 4. Detail from surface a3 after selection of reference plane by the RGF0.8 (a) and extracted profiles with the following dimples analysis: 1 and 2 (b), 2 and 3 (c), 3 and 4 (d)](image)

In figure 5 three enlarged details extracted from surface a3 (presented in figure 4) with different distribution areas of oil pockets were showed. When the value of $V_{ds} < DF_{cov}$ then values of $Sq$, $Sp$, $Sz$ and $Sa$ parameters were larger than the values of these parameters when the $V_{ds} > 0.8$ mm ($DF_{cov}$). The decrease of $V_{ds}$ caused the increase of height parameters such as $Sk$ and $Spk$ and decrease of $Svk$ parameter; the value of $Sv$ parameter also decreased. The accurate assessment of $Sk$ family parameters is of a great importance; false estimation of those parameters can cause classification of properly made parts as a defects and its rejection.

![Fig. 5. Extracted details from surface a3 (descriptions in figure 4-a) after application of RGF0.8 as a reference plane and their selected height parameters respectively](image)

Usually, areal form removal by RGF0.8 caused distortion of deep and wide valleys when $V_{ds} < DF_{cov}$ (figure 6-b). However, some distortions of oil pockets occurred while $V_{ds} > DF_{cov}$ (figure 6-a). Therefor RGF1.6 was proposed as a procedure for selection of reference plane. It was noticed than application of digital filter (RGF as an example) with bandwidth (cut-off) value higher that the value of distance
between the deepest areas of dimples (1.6 mm for surface profile in figure 6-b) provided better results; the distortion of wide valleys was smaller (figure 6-c and -d).

Fig. 6. Extracted profiles from surface after form removal by application of: RGF0.8 (a, b) and RGF1.6 (c, d)

4. Conclusions
Selection of reference plane in surface topography measurement was taken into consideration. It was found that application of polynomials of 2nd, 3rd and 4th degrees did not allow to remove form correctly when surface contained deep and wide valleys. Therefore for cylinder liner surfaces with deep and wide dimples created by burnishing techniques, usage of digital filtering (with robust approach for extraneous effects caused by measuring method and/or treatment process) was reasonably required.

Application of Robust Gaussian digital filtering (RGF) with bandwidth value equal to 0.8 mm was proposed. When Vds was smaller than DFcov then distortion of wide dimples had a tendency to increase. Moreover, when the Vds was smaller than the Vdi then DFcov should be greater than the distance between middle areas of oil pockets.

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