Proposal of edge-area form removal of cylindrical surfaces containing wide dimples by application of various robust processing techniques

P Podulka
Rzeszow University of Technology, The Faculty of Mechanical Engineering and Aeronautics, 35-959 Rzeszów, al. Powstańców Warszawy 12, Poland
E-mail: p.podulka@prz.edu.pl

Abstract. Surface topography parameters of car engine elements (cylinder liners, piston skirts) are usually calculated after form removal. There are many algorithms dedicated for selection of reference plane in surface topography analysis. However, areal form removal of cylindrical surfaces containing deep or wide valleys (oil pockets, scratches) was not fully recognized when the dimples were edge-situated. Moreover, application of some robust techniques not always provided a reasonable results in areal form removal for surfaces with small (less than dimples diameter value) oil pocket distances. In this paper some digital filtering techniques were proposed for minimization of reference plane distortion when cylindrical elements contained deep and wide valleys with near-edge distribution. It was assumed, that application of commonly used robust techniques caused the distortion of deep or wide near-edge dimples; some of the proposed digital processing algorithms provided a better edge-filtering results.

1. Introduction
There are many disadvantages affecting the surface topography measurements and analysis. One of them are the errors committed while data processing. Usually the surface topography parameters are calculated after form removal. Many procedures were concerned with Gaussian mean line (plane) implementation [1-4] and its modification [5]. Improper selection of procedure for areal form removal can cause the increase of surface texture parameters inaccuracy [6].

For two-process surface filtering for waviness removal, the robust Gaussian regression filter was developed [7, 8]. The fine texture marks fall well within the accepted filter bandwidth for the sample length (cut-off) the scratches do not (they are too wide [9]). There was also grave problem with form removal by application of polynomials as a fitted reference plane; it was found that using a polynomials caused severe distortion of dimples [10].

Some of digital procedures for valley extraction was proposed in [11]; dimples were fulfilled by smooth shape. Surface topography containing dimples was studied in [12-15]. Edge-effect problem elimination by recursive implementation of Gaussian filters was proposed in [16]. However, areal form removal of cylindrical surfaces containing deep and wide oil pockets was not fully recognized when dimples were edge-situated. Moreover, the influence of selection of reference plane on surface topography parameters was not precisely defined with edge-located valley analysis.

2. Materials and methods
In this paper cylinder liners with burnished oil pockets were analysed. They were measured by stylus instrument Talyscan 150 or white light interferometer Talysurf CCI Lite. The average values of diameter and depth of oil pockets were around 1 mm and 50 µm correspondingly. More than 30 measured and 30 modelled surfaces were taken into consideration but only some examples were showed in details. The maximum size of analysed surfaces was 5 x 5 mm; the spacing was 15 µm.

For extraction of form and waviness directly from these surfaces commonly used regular Robust filter (RF) was applied. The effect of reference plane on surface views and parameters from ISO 25178 standard was studied. The influence of edge-area distributed dimples into selection of reference plane
was taken into account. For minimization of distortion of wide valleys the procedure with its digital excluding (Valley Digital Excluding Method – V DEM) was applied. Some of the aspects of digital fulfilling of extracted valleys were proposed by the following author in [11]. For edge-area form removal it was recommended to use the various digital filters – Gaussian (GF) and median (MF) as an example. Furthermore, the effect of distances (Ved) of dimples from the edge of analysed surface details on selection of reference plane was presented.

3. Results and discussions

According to isometric view analysis, application of commonly used Robust filtering methods (with cut-off equal to 0.8 mm) provided a reasonable results for both measured and modelled surfaces (figure 1-b and -f). However, when dimples were edge-situated or value of Ved coefficient was smaller than digital filtering cut-off value, the distortions of valleys had a tendency to increase (figure 1-d and -h). All edge-located oil pockets were flattened (examples of flattened dimple areas were indicated by the arrows in figure 1-b); the value of Svk parameter decreased. When the distance between dimple and edge of studied surface detail was smaller than cut-off value of digital filtering, the edge-to-dimple area was also falsely estimated; form was eliminated incorrectly (figure 1-f).

For minimization of distortions of deep and wide edge-situated valleys, the increase of digital filtering cut-off value was proposed. Application of Robust filter with 1.6 mm cut-off value caused decrease of oil pocket deformations (figure 2-a and -d); the degree of dimples flattering decrease (the value of Svk parameter increased). However, the value of Sk parameter increased twice (according to the variation of cut-off value) as well as Spk parameter value (figure 2-b and -e). The higher value of cut-off was applied the higher growth of parameters describing plateau part of surface was observed.

For minimization of distortions of deep and wide edge-situated valleys, the increase of digital filtering cut-off value was proposed. Application of Robust filter with 1.6 mm cut-off value caused decrease of oil pocket deformations (figure 2-a and -d); the degree of dimples flattering decrease (the value of Svk parameter increased). However, the value of Sk parameter increased twice (according to the variation of cut-off value) as well as Spk parameter value (figure 2-b and -e). The higher value of cut-off was applied the higher growth of parameters describing plateau part of surface was observed.

![Fig. 1. Isometric views of examples of extracted details from measured (a) and modelled (e) surface and after form removal by Robust Filtering (b, f), their reference planes (c, g) and profile detail (d, h) respectively; cut-off = 0.8 mm](image1)

![Fig. 2. Isometric views (a, d) of extracted details from surface presented in figure 1 after application of Robust Filter with cut-off equal to 0.8 mm (a) and 1.6 mm (d), their material ratio curves (b, e) and extracted profiles (c, f) correspondingly](image2)
When the value of \( V_{ed} \) coefficient decreased, the distortion (flattening) of deep and wide valleys has a tendency to increased (the value of \( S_{vk} \) parameter was smaller). When the \( V_{ed} \) was bigger than digital filter bandwidth then deformation of oil pockets was minimalized (figure 3-c). However, when the \( V_{ed} \) was bigger (and the distance between dimples was smaller than filter bandwidth) the distortion of valleys tended to increase.

(a) (b) (c) (d)
Fig. 3. Extracted profile detail from surface containing deep and wide dimples after selection of reference plane with application of Robust filter (cut-off = 0.8 mm): profiles with edge-situated oil pockets (a, b), profile with dimple located in the center (c) and profile containing two adjacent valleys (d)

Application of digital fulfilling of extracted valleys and further application of various filtering techniques was proposed for minimization of dimple distortion. For surface detail presented in figure 4 areal form removal was obtained by commonly (Gaussian) and often (Median) used filters with bandwidth value of 0.8 mm. From the analysis of extracted profiles (figure 4-c, -f and -i) it was assumed that application of \( V_{DEM} \) allowed to reduce the dimple deformation (compared to RF); there were only slight differences between profiles when GF and MF were applied (the values of total height of profile \( P_t \) were very similar).

Proposal of using the \( V_{DEM} \) with digital filtering resulted in significant adjustment of height parameters specification (their values decreased). Compared to the RF, application of \( V_{DEM} \) with digital filtering (GF or MF) gave better results in edge-area form removal when dimples were near-edge located (the value of \( V_{ed} \) was smaller than the bandwidth value of digital filtering). The value of maximum height of surface detail (Sz) decreased; height parameters (root mean square \( S_q \), maximum peak \( S_p \) and arithmetic mean heights \( S_a \)) also decreased. Moreover, the maximum valley depth \( S_v \) increased when \( V_{DEM} \) was applied. The minimum (maximum) value of \( S_q, S_p, S_z \) and \( S_a (S_v) \) parameters were obtained when reference plane was determined by GF with valley excluding method.

(a) (b) (c) (d) (e) (f) (g) (h) (i)
Sq 0.888 \( \mu m \) 0.809 \( \mu m \) 0.853 \( \mu m \)
Sp 4.42 \( \mu m \) 2.99 \( \mu m \) 3.44 \( \mu m \)
Sv 3.63 \( \mu m \) 7.08 \( \mu m \) 4.04 \( \mu m \)
Sz 8.05 \( \mu m \) 0.631 \( \mu m \) 7.48 \( \mu m \)
Sa 0.646 \( \mu m \) 0.631 \( \mu m \) 0.639 \( \mu m \)

Fig. 4. Extracted details (a, d, g), their height parameters (b, e, h) and profiles (c, f, i) from surface after form removal by: RF (a, b, c) and \( V_{DEM} \) with application of GF (d, e, f) and MF (g, h, i); cut-off = 0.8 mm
4. Conclusions
Areal form removal of cylindrical surfaces containing deep and wide dimples were taken into account. It was assumed that Robust digital filtration was useful for two-process surfaces, especially with oil pocket applications. However distortion of dimples was particularly noticeable when valleys were edge-situated; improper selection of reference plane caused glaring errors in surface topography parameter calculations. Increase of the bandwidth value of digital filtering allowed for minimization of deep valley deformation. However, the features of plateau part of the surface were not quite recognizable; the values of height parameters were falsely estimated.

It was proposed to use the procedure of dimples excluding (VDEM) and further application of digital filtering; two (Gaussian and Median) filters were proposed, as an example. Suggested method allowed to minimalize the distortion of reference plane with detailed consideration of near-edge distributed oil pockets. Application of VDEM processing proved a better results even the bandwidth of digital filter was smaller than size (diameter) of the dimples. Moreover, when the distance between valleys was smaller than digital filter cut-off value, the distortion of oil pockets was also reduced (compared with robust filtration).

Areal form removal by digital filtration with processing by VDEM scheme might be useful for stratified surfaces containing deep and wide dimples. The distortion of edge-to-dimple area of reference plane was also minimized when VDEM was used. Proposal of separation of form with valley exclusion and then digital filtration (ordinary Gaussian filter), provided a better results than application of robust techniques (Robust filters), commonly used in surface topography assessments.

5. Acknowledgments
This paper was prepared with financial support from the project no. 2013/09/N/ST8/04333 from National Science Center.

References
[1] Deriche R.: Recursively implementing the Gaussian and its derivatives. In: Proceedings of the 2nd International Conference in Image Processing, 1992, 263–267 
[2] Janecki D.: Gaussian filters with profile extrapolation. Precision Engineering 4, 2011, 602–606.
[3] Raja J., Muralikrishnan B., Fu S.: Recent advances in separation of roughness, waviness and form. Precision Engineering 26, 2002, 222–235
[4] Seewig J.: Linear and robust Gaussian regression filters. Journal of Physics: Conference Series 13, 2005, 254–257
[5] Crisan D., Li K.: Generalised particle filters with Gaussian mixtures. Stochastic Processes and their Applications 125, 2015, 2643–2673
[6] Podulka P.: Selection of reference plane by the least squares fitting methods. Adv. Sci. Technol. Res. J. 2016; 10(30):164–175
[7] Bodschwinna S. H., Lemke H.-W.: Development of a robust Gaussian regression filter for three-dimensional surface analysis. X International Colloquium on Surfaces. Chemnitz, Germany, 2000, 122–131
[8] Li H., Jiang X., Li Z.: Robust estimation in gaussian filtering for engineering surface characterization. Precision Engineering 28, 2004, 186-193
[9] Whitehouse D.J.: Some theoretical aspects of a practical measurement problem in plateau honing. Int. J. Prod. Res. 21, 1983, 215-221
[10] Podulka P., Dobrzański P., Pawlus P., Lenart A.: The effect of reference plane on values of areal surface topography parameters from cylindrical elements. Metrology and Measurement Systems 2, 2014, 247–256
[11] Podulka P., Pawlus P., Dobrzański P.: Extraction of valleys on the cylindrical surfaces. Mechanik 11, 2016, 1700–1701 [in Polish]
[12] Godi A., Kuhle A., De Chiffre L.: A new procedure for characterizing textured surfaces with a deterministic pattern of valley features. Measurement Science and Technology 24, 2013, 085009
[13] Godi A., Kuhle A., De Chiffre L.: A plateau-valley separation method for textured surfaces with a deterministic pattern. Precision Engineering 38, 2014, 190–196
[14] Grabon W., Pawlus P.: Distinguishing the plateau and valley components of profiles from various types of two-process textures. Metrology and Measurement Systems 4, 2016, 593–602
[15] Grabon W., Pawlus P., Galda L., Dzierwa A., Podulka P.: Problem of surface topography with oil pockets analysis. 2011 J. Phys.: Conf. Ser. 311 012023
[16] Janecki D.: Edge effect elimination in the recursive implementation of Gaussian filters. Precision Engineering 36, 2012, 128–136