Automated algorithm for determining surface's oil capacity based on the analysis of the Abbot-Firestone diagram's parameters

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Abstract

A computer algorithm and software were developed for determining the oil capacity of machine parts' surface. The algorithm employs the parameters of the Abbot-Firestone diagram, which was constructed by segmenting the studied surface's profilogram. Based on the geometric approach, a technique is proposed that analyses the microrelief topography and determines the profilogram parameters. This made it possible to evaluate the oil capacity of machine parts' surface in accordance with the criteria presented in ISO 13565-2:1996.

Keywords

Algorithm, segmentation methods, computer program, Abbott-Firestone diagram, software, algorithm support, surface roughness, operational properties, surface oil capacity

1. Introduction

Profilometry methods have made significant strides in evaluating the parameters of damage caused by wear and tear, as well as controlling the quality of workmanship of machine parts' surfaces [1]. The main areas to be addressed in this regard include improvements to the surfaces analysed, providing for their versatility, reducing the manufacturing and operation costs. In addition, new automated algorithms and programs need to be developed to process significant amounts of data obtained.

The relationship between the surface performance and roughness parameters can be described by the Abbot-Firestone diagram, which is also referred to as the material ratio curve. The paper in [2] describes this relationship. Here, the surface performance is evaluated by the Abbot-Firestone curve's parameters rather than the surface roughness. According to the author, the surface ability to resist sliding friction can be characterised by the three main parameters determined from the diagram, in particular, R_{pk}, R_k and R_{vk}.

An automated software is required to process the Abbot–Firestone diagram and

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determine the above parameters. To this end, an algorithm was developed and software was written.

The paper in [3] describes the procedure for estimating the surface condition using the Abbott–Firestone diagram. According to the authors, the surface integrity can be defined by the relationship between the required surface's functional properties and variations in the new surface's properties. A surface can be evaluated using two basic properties, namely, the spatial arrangement (surface roughness) and physico-chemical properties of the surface layer.

The paper in [4] investigates the material ratio curve for the materials obtained by additive technologies. It suggests that the porous structure of the material obtained after 3D printing is reflected in the material ratio curve.

Also, the material ratio for the determination of is discussed with the consideration of three options to address the open surface pores. The secant scanning approach proposed by ISO 13565-2 and the manual set ratio at the first sharp drop of the material ratio curve were found to be able to achieve reasonable results for the AM open surface pore characterisation. The paper in [5] describes the relationship between the oil capacity and the material ratio curve's parameters. The authors have found the oil capacity to be a tribologically relevant parameter. As we know, ISO 13565-2 does not always determine oil capacity correctly. Therefore, methods for its correct calculation have been developed and proposed. The first method consists in obtaining a point in the maximum curvature of a normalised Abbott–Firestone curve. The second one consists in finding the maximum ordinate of a normalised material ratio curve rotated by an angle of 45°. The oil capacity is deemed to be estimated correctly if the transition point between the valley and plateau (core) parts is recognised. This point will aid in estimating the density of the textured surfaces' oil pockets. In addition, the deep-valley will also be recognised on a cylinder-liner surface.

The paper in [6] gives interesting examples of the automated processing of surface roughness profilograms. It considers a method for analysing surface roughness. On its basis, a wear diagram is constructed, which considers the surface processing technique. Thus, this method describes the surface condition and the microstructure resulting from the application of various processing techniques. This approach aids in increasing the accuracy of measurement results.

The paper in [7] summarises the findings of comparative studies dealing with the in-service properties of test specimens' flat surfaces with regular microrelief formed on top. Quantitative evaluation of the surface performance was conducted using the R_k group of parameters of the Abbott-Firestone diagram. The evaluation was supported by the profilogram analysis of flat surface's profile with a regular microrelief on top. Regularities were established in the variation patterns of in-service properties depending on the microrelief type and geometric parameters, as well as the conditions under which it was formed.

Ensuring the reproducibility of control results is one of the crucial issues to be addressed as part of wear and tear investigations, since it reduces the probability of obtaining false results. In addition, the rate of determining diagnostic parameters, as well as ensuring their sensitivity to damage types analysed, remains topical.

Therefore, developing fast-acting engineering algorithms that allow for a high-accuracy evaluation of the oil content on the parts' surface after manufacturing and during operation is relevant.

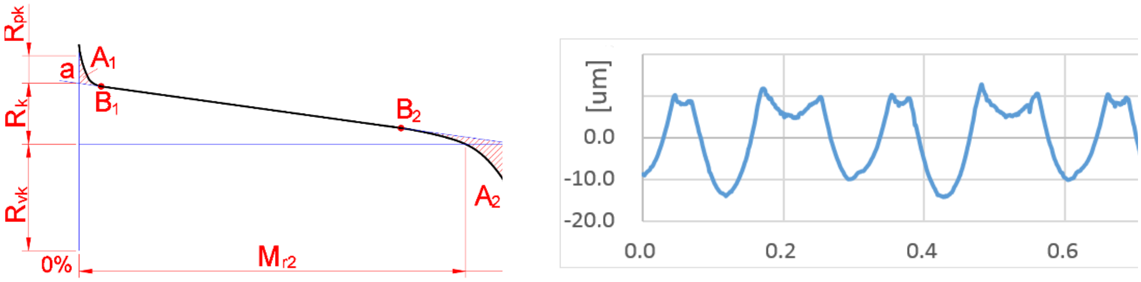
To achieve this goal, it is necessary:

- to develop a computer algorithm and software for the construction of the Abbot-Firestone diagram and determining its parameters;

- to investigate the algorithm using test profilograms and verify the obtained parameters.

2. Material and Methods

Automating the Abbott-Firestone diagram construction process, Fig. 1a, based on the surface roughness profilograms' analysis, Fig. 1b, and defining the main parameters of group R_v is essential for describing the in-service properties of the surface, in particular, its oil capacity. To develop an automated algorithm for its construction and further analysis, peaks and depressions of the specimen surface's profile were obtained. A modern device for measuring surface roughness, Surface Roughness Tester - Mitutoyo, SurfTest SJ-301, with a 0.05 mm step on the base length, was used, Fig. 1a.



(a) (b)

Figure 1: General view of the Abbott-Firestone diagram (a) and surface roughness profilogram (b)

Surface performance was evaluated using the formula given in ISO 13565-2:1996. It presents a dependence for determining the amount of oil that will be retained on the surface [4]:

$$V_0 = \frac{R_{vk}(100 - M_{r2})}{200}, \quad (1)$$

де V_o – the volume that contains the lubricant, mm³/cm².

The parameters in formula (1) can be obtained graphically from the Abbot-Firestone diagram. However, the graphical construction process is quite complex, inaccurate and lengthy. Therefore, automating the diagram construction process by state-of-the-art automation methods appears promising for evaluating the surface performance.

An algorithm was developed to automatically determine the main diagram parameters, Fig. 2. At the first stage, profilometric control data (profilograms, Fig. 1b) are loaded into the program. Next, the averaged profilogram values and the global maxima and minima are determined on the base length of the surface roughness. The papers in [8, 9] describe the approaches based on the signal segmentation methods that were used to identify depressions and peaks. The data obtained were key to determining the number of peaks and depressions, as well as their local maxima and minima. Along the ordinate axis, the Abbot-Firestone diagram displays the values ranging from the peak's maximum to the depression's minimum with a certain step. Given this, the algorithm provides for the opportunity of determining these values. Next, we cut the baseline length of the profile micro-roughness by segments with a preset step. As a result, a sum of segments was obtained, which is displayed by the Abbott-Firestone diagram along the abscissa axis. Here, the corresponding cross-section step value was present (0.15 mm in this research). The discretisation step (cross-section step) directly affects the accuracy of diagram construction and the accuracy of determining the parameter of interest. Its value is selected depending on the difference between profilogram's highest peak and deepest depression in the range of 0.05-0.2. The cut-off step also affects the number of points on the Abbott–Firestone diagram (see details of the Abbott–Firestone diagram). The lower its value, the more accurate the surface wear diagram.

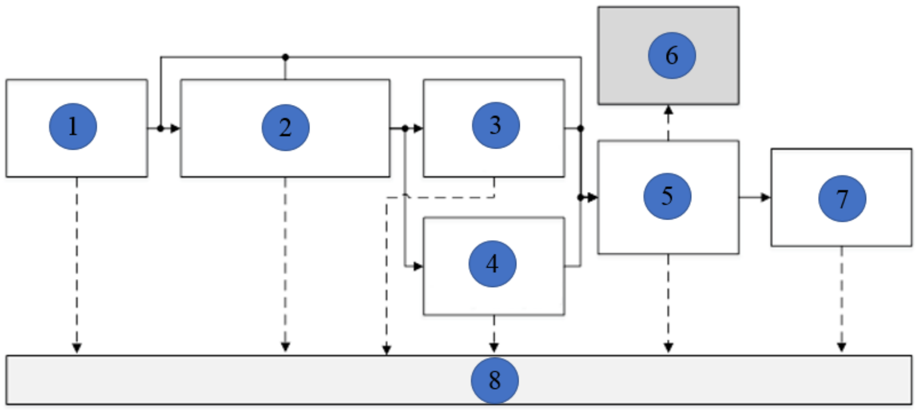


Figure 2: Block diagram of the developed computer algorithm for determining the parameters of the Abbot–Firestone diagram: 1 - data downloading; 2 - determining profilogram's global maximum $H_{\max H}$ and $H_{\min H}$; 3 - determination of largest minimum H_{maxmin}; 4 - determination of local minimum $H_{\min J}$; 5 - determination of Abbot–Firestone diagram values and readings; 6 - saving the obtained values of the parameters R_{pk}, R_k and R_{vk}; 7 - calculation of parameter V_o; 8 - data visualization.

The main stage of the algorithm for determining the surface's oil capacity consists in finding the R_k, parameter based on the graphical analysis of the diagram profile. Here, a straight tangent to the curved section' profile of the Abbot–Firestone diagram needs to be constructed. The algorithm allows setting two points B_1, B_2 on the diagram. Parameters of the a-a line tangent to the inclined plane of the Abbot–Firestone diagram will be automatically determined in the interval between these points.

After obtaining the values and readings of the Abbott–Firestone curve, the parameters R_{pk}, R_k and R_{vk} are determined in accordance with method [4], and parameter V_o is determined using formula (1). At each stage of its operation, the developed program can display an intermediate result by visualising it. In addition, the data generated by the Abbot–Firestone diagram can be saved as a text file for further processing.

3. Result and Discussion

We consider the proposed algorithm step by step:

1. The initial stage consists in determining profilogram's global maximum $H_{\max H}$ and minimum $H_{\min H}$ among the loaded values H_k along its entire length (L) $L = \Delta t \cdot K$, where Δt is the discretisation step, K is the number of readings $k = \overline{1, K}$. Figure 3 schematically shows the profilogram and defines the maxima for two segments of the surface micro-roughness' peaks.

In this example, the local maximum of the first peak is equal to the global maximum, that is, $H_{\max 1} = H_{\max H}$, and the local minimum of the second depression is equal to the global minimum, $H_{\min 1} = H_{\min H}$.

We determine the average value of the profilogram peak H_{aver}. It will help us find and detect local maxima $H_{\max I}$, $i = \overline{1, I}$ and minima $H_{\min J}$, $j = \overline{1, J}$, as well as divide the profilogram into peak segments. This example is illustrated in Fig. 3 $I = 2$, $J = 2$.

$$H_{aver} = \frac{1}{K} \sum_{k=1}^{K} H_k \quad (2)$$

де H_k – the value of the profile.

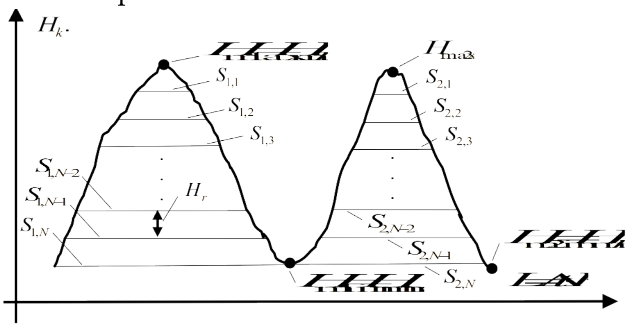


Figure 3: Schematic representation of the surface roughness profilogram's element

2. Using the average peak of profilogram H_{aver} (red line, Fig. 4), as well as the global minima $H_{\min H}$ and maxima $H_{\max H}$, we define the local maxima $H_{\max I}$ and minima $H_{\min J}$. For this purpose, we used the threshold levels set in the program. Figure 4 shows an example of the program interface and the results obtained at the intermediate stage of processing.

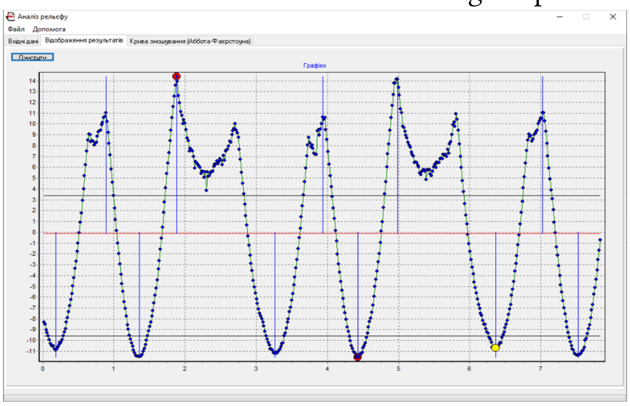


Figure 4: Input data of the surface roughness profilogram and segmentation of its peaks and depressions

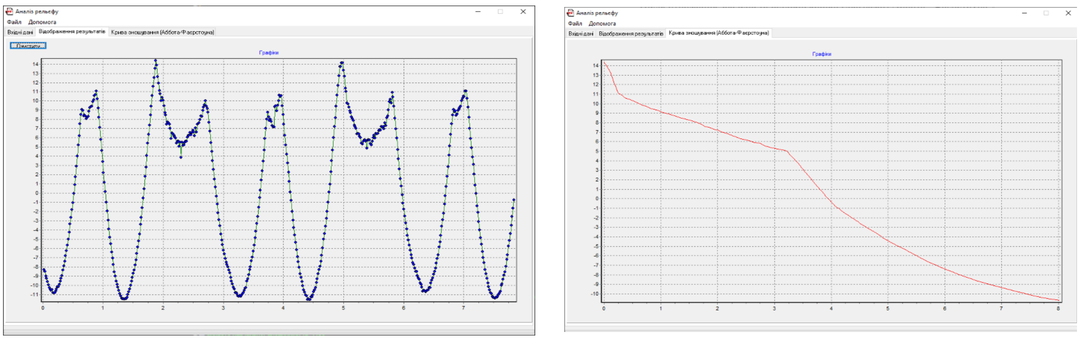
The global maximum and minimum are indicated in red. A maximum determined among local minima is indicated in yellow. The black lines represent threshold levels, while the blue lines represent peaks and depressions identified in the profilogram.

3. To construct the Abbot–Firestone diagram, the cross-section step H_r is set. Then, moving from $H_{\max H}$ to $H_{\min H}$, we define values $S_{C,N}$, which correspond to the cross-section lengths of profilogram peaks.

where $c=\overline{1,C}$ is the number of segmented peaks $n=\overline{1,N}$ is the number of peak' cross-sections.

4. Therefore, the Abbott–Firestone diagram's parameters were determined on the segment between the global maximum $H_{\max H}$ and minimum $H_{\min H}$ with a given step H_r, and its values are the sums of durations $S_{C,N}$ for the segmented peaks. Since the profilogram's global minimum corresponds to its deepest depression, the sums of each peak cannot be calculated correctly, since the neighboring segments of peaks may not have such values. Thus, for the calculation and construction of the Abbott-Firestone diagram, the largest minimum H_{maxmin} of the local minimum $H_{\min J}$ was determined, and the curve was constructed from the global maximum $H_{\max H}$ to the largest minimum H_{maxmin}.

Figures 5,6 show examples of the developed program's interface.



(a) (b)

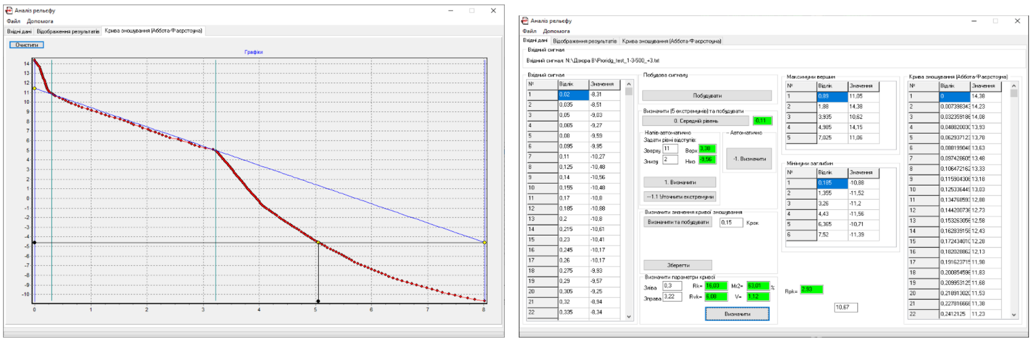
Figure 5: Interfaces of the developed program: initial data of the surface profilogram (a) and visualisation of the constructed Abbot–Firestone diagram (b)

Noteworthy, determining the Abbot–Firestone diagram's parameters may be complex. This depends, to a certain extent, on the profilogram type of the surface analysed, discreteness of its recording, and tuning parameters of the proposed algorithm, Fig. 6b.

5. After constructing the Abbot–Firestone diagram, we calculate its parameters. To this end, we set two levels, within which we define the Abbot–Firestone diagram's section, to which the a-a tangent line is plotted (Fig. 1a).

6. A tangent is plotted by points B_1 and B_2 (fig. 1A) within the selected section.

7. At the point where the tangent and the Abbot–Firestone diagram's section intersect, we determine parameters R_{pk}, R_k, R_{vk} and coefficient M_{r2}. Next, we calculate V_o by formula (1).



(a) (b)

Figure 6: Visualisation of the defined parameters of the Abbott–Firestone diagram: a) Abbott–Firestone diagram; b) software interface with input data of the Abbott-Firestone diagram and defined parameters (R_{pk}, R_k, R_{vk} and V_o)

The proposed computer algorithm made it possible to develop software that automates the calculation of the Abbot–Firestone diagram's parameters based on the surface roughness profilograms. Further research should focus on investigating the Abbot–Firestone diagram's parameters obtained for surfaces treated with different plastic deformation methods. This will allow us to obtain more information about the impact of technological methods and processing conditions on the in-service properties of surfaces [10, 11].

4. Conclusions

Based on the research findings, the following scientific and practical results were obtained:

-an algorithm for constructing the Abbott-Firestone diagram and calculating its parameters has been developed. It is based on the automated analysis of surface roughness profilograms. In addition, it determines the quantitative characteristics of the oil capacity of parts' surfaces after manufacturing or during operation.

- a method for cutting surface profilograms and segmenting their peaks and depressions is proposed. It provides for a high accuracy of the parameters determined and physical correctness of the results obtained.

- an approach to approximating arrays of points with local scattering over the relief's depressions is proposed, which avoids approximation errors. Its efficacy was confirmed by the results of numerous calculations.

-the algorithm for calculating the Abbot-Firestone diagram's parameters was verified, and its validity was confirmed.

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