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3D surface parameters (ISO 25178-2): Actual meaning of S_{pk} and its relationship to V_{mp}

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ABSTRACT

3D parameters are important in tribological studies and many of them show strong correlation with surface operational performance. Characterization of cylinder liner surfaces is a good example of the use of 3D roughness parameters. Standard ISO 25178-2:2012 defines new parameters retaining some of the old ones, even though presented as their equivalent 3D successors. That is the case for instance of the “*k*” series: S_{pk}, S_{vk} and S_k. This paper covers an analysis of the relationship between S_{pk} and the new volume parameter V_{mp} where it is shown that it is not correct to designate S_{pk} as the *average height of the protruding peaks above the core surface* as stated in the standard. It is also suggested that S_k should be maintained but that the new volume parameters, through their relationship to the “*k* series”, make it possible to discard S_{pk} and S_{vk}.

1. Introduction

Assessing surface characteristics for production control became available in the early years of the 1930-decade [1]. At that time equipment was mechanically complicated but able to generate surface profiles. Progressively mechanical solutions were substituted by electro-mechanical sensors that provided analogic signal from which not only the profile was extracted but also numeric parameters – R_a and R_t – that supplied the first elements for surface manufacturing process control. Nevertheless they were far from tackling the problem of surface adequacy to the end use. Engineers and designers devoted considerable efforts to overcome that limitation and tried to extract from the available 2D information – basically height and evaluation length – additional parameters that could meet the new demands. Different processes, different companies, different national standards, resulted in the adoption of a great number of parameters. The situation reached an extreme condition when, besides the widespread conviction that parameters should describe the future behavior of surfaces in terms of its functionalities, digital computers started to offer the possibility of playing with the data. Researchers and engineers were responsible for what has been called a “parameter rash” [2].

A new stage of surface characterization is quite recent and is the consequence of the possibility, now come true, of 3D assessment. This time the committees that undertook the arduous task of proposing a consistent parameter set that would satisfy most of the demands were concerned about limiting their number. The proposals of 1993 – “The Birmingham 14” – and 1999 – “The Huddersfield 17” – [3] were moderate when compared to the recently published ISO 25178 that finally came up with more than 40 parameters, well over the 14 and 17 previously considered.

Parameters defined in ISO 25178-2 have a prefix S or V the latter denoting volume parameters. The present work is mainly focused on the following 3D parameters:

Height parameters (measured from the reference plane):

- S_p: maximum peak height;
- S_v: maximum pit height (depth), lowest point of a dale/valley;

Functional parameters (based on a graphical construction):

- S_k: “thickness” of the central part of the surface, the core;
- S_{pk}: peak height above the core;
- S_{vk}: valley depth below the core;
- V_{mp}: material volume in the hill region;
- V_{vv}: void volume below the core;
- V_{mc}: material volume within the core;
- V_{vc}: void volume within the core.

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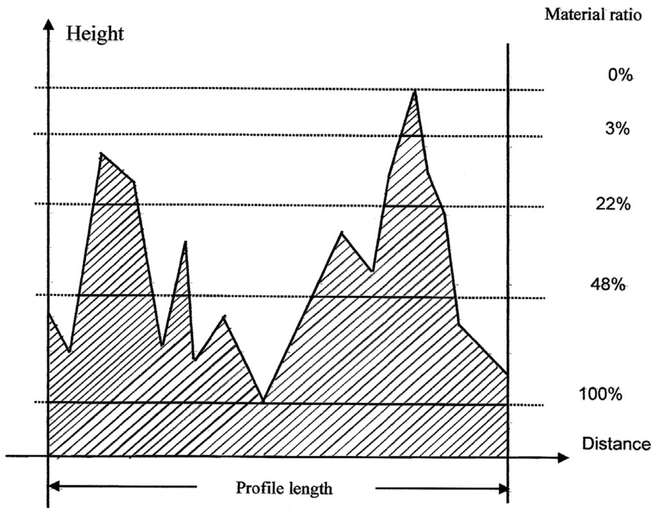

Fig. 1. Sketch of a surface profile – material ratio values for several heights of the cutting plane.

It should be noted that S_k, S_{pk} and S_{vk} (the "k series") are the successors, within the context of 3D parameters, of R_k, R_{pk} and R_{vk} previously defined by ISO 13565-2.

Volume parameters in the above list are closely related to the "k series" parameters and although the present work deals explicitly with the relationship between S_{pk} and V_{mp}, its development applies equally well to the relationship between S_{vk} and V_{vv}.

2. Parameter definition and calculation

The starting point to define the parameters considered in this work is the Abbott–Firestone curve. In 2D analysis a bearing ratio or material ratio represents the percentage of the total evaluation length of the surface profile that corresponds to regions where profile height exceeds a given value. Fig. 1 is a simplified representation of that concept that can be thought of as the result of cutting the surface by a plane parallel to the base line (zero height). The figure shows how that percentage changes with the height of the cutting plane.

Fig. 2 shows the Abbott–Firestone curve of a surface with a Gaussian height distribution. The three regions are associated (top – down) to the parameters S_{pk}, S_k and S_{vk}.

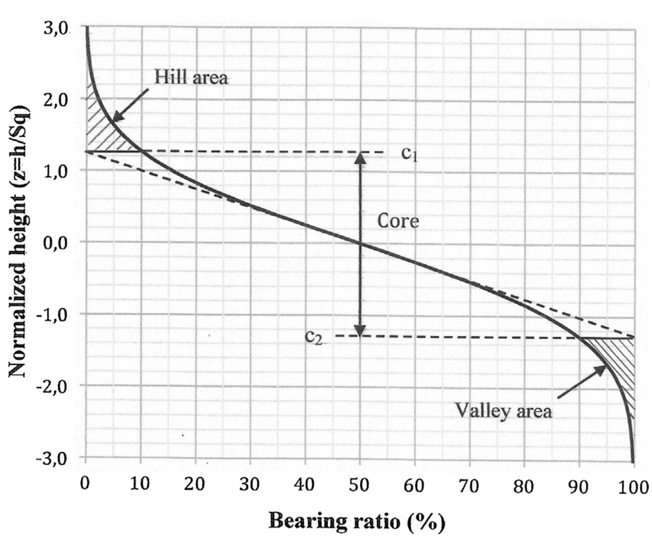

Fig. 2. Abbott–Firestone curve – Gaussian surface height distribution.

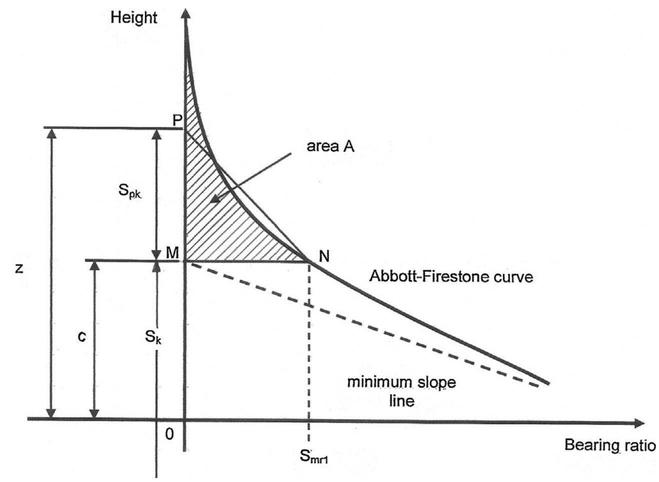

Fig. 3. Calculation of S_{pk}.

The vertical axis of Fig. 2 represents heights (positive values) and depths (negative values) as related to a reference plane (base line). The vertical axis scale is graduated in dimensionless values by dividing real heights by S_q, root mean square value of the height distribution. The horizontal axis, graduated from 0% to 100%, represents the areal material ratio, but this is no longer a ratio between segments of the profile as in Fig. 1; in 3D the material ratio is obtained as the ratio of the sum of the cross sections of the hills cut by a plane at a given height to the total area being subject to analysis. For that reason the expression bearing area ratio (or bearing ratio for short) will be used subsequently. Thus in Fig. 2a bearing ratio value of approximately 10% corresponds to a height $c_1 = 1.25$.

Physically one may think of the parameters as follows: S_{pk} corresponds to the surface material that may be worn out in the initial contact with another surface – peaks above the core – and S_{vk} represents valleys/pits whose depth goes down beyond the core and that might be filled with debris coming from the peaks. The core, characterized by its "thickness" S_k, would be that part of the surface responsible for providing at the same time a bearing area as well as oil reservoirs, at least in the cases of lubricated sliding contact.

2.1. Calculation of S_{pk}

According to ISO 25178 [4] (as previously defined by ISO 13565 [5]) the S_{pk} definition is tied to S_k. As indicated in Fig. 2 the straight line best fit to the central portion of the Abbott–Firestone curve (minimum slope) must be stretched until it touches the vertical lines at 0% and 100% bearing ratios. The horizontal segments traced from those points to the curve divide it into three regions: hill, core and valley regions.

As per the instructions stated in the standard, S_{pk} shall be the height of the rectangle triangle MNP of Fig. 3 such that the triangle area equals the area above MN and limited by the Abbott–Firestone curve and the vertical axis.

As a consequence of that definition one can write:

$$A = \frac{1}{2} S_{pk} \cdot S_{mr1} \qquad (1)$$

where S_{mr1} is the bearing ratio corresponding to point N, obtained by tracing a horizontal segment from the point M (intersection of the line of minimum slope with the vertical axis) to the Abbott–Firestone curve.

It should be noted that S_{pk} has a dimension of length and its effective value for practical applications requires multiplication by S_q if a normalized height is at its origin.