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surface geometric structure,
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EVALUATION OF CLASSIFICATION ABILITY OF THE PARAMETERS CHARACTERIZING STEREOMETRIC PROPERTIES OF TECHNICAL SURFACES

The analysis of classification ability of the parameters used for the description of surfaces formed during the processes of technological processing constitutes important issue in the surface layer metrology. To investigate the classification ability, variance and geometric mean of the ordered differences of the parameter value. The study compares behaviour of both indices for different distributions of ordered differences of the parameter value. Moreover, the relationship between both indices and influence of the number of minor differences of the parameter value on the value of variance and geometric mean.

1. INTRODUCTION

Evaluation of the quality of technical products and forecasting of their operating characteristics constitute the basic question of modern, highly specialized machine and device production. It stems from the increase of requirements on the precision and properties of produced elements and also the need to minimize material use, element weight and their dimensions and from the increase of loads, to which machine elements are subjected, which results in high requirements on durability. What is more, technology development results in the need to analyse and improve technical product quality.

Work on the above issues resulted in the elaboration of numerous measurement methods and devices for such measurements and a considerable increase of parameters to be used [1]. One of the elements of technical product evaluation is the analysis of surface topography, in particular stereometric properties of surfaces [1],[2],[3].

This type of analysis is difficult in the precision processing, due to limited height range of irregularities of the analysed surfaces, and other characteristics begin to play a significant role in its description [4]. Further difficulty is posed by selection of suitable

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parameters for description of surface topography [5],[6],[7]. Over three hundred normalized parameters, both in 2D as well as 3D system, are currently used in the evaluation of geometric structure of surfaces. These parameters evaluate different elements of a studied surface. Some of them are strongly correlated with one another, due to which the informative content is multiplied [5].

The number of parameters used for the evaluation of surface should not be too large and should be characterized by complementarity of the set. This would enable an easy and complex description of an analysed surface/ In practice, no more than five parameters are included in the description of analysis of any surface. In the industrial practice, only one selected parameter is often used for the surface topography, which is undoubtedly a mistake, especially, as its selection is often decided upon due to the ease of parameter interpretation, without taking into consideration its relationship with the intended use of the product.

Therefore, one of the key issues of technical product evaluation is selection of suitable, complementary set of parameters, ensuring easy interpretation of evaluations for given uses and surfaces and the ability for efficient differentiation of significantly different surfaces, which we call c parameter classification ability. The problem of parameter set selection with high classification ability, easy to read and useful for selection of parameters and conditions of processing is schematically shown in Fig. 1.

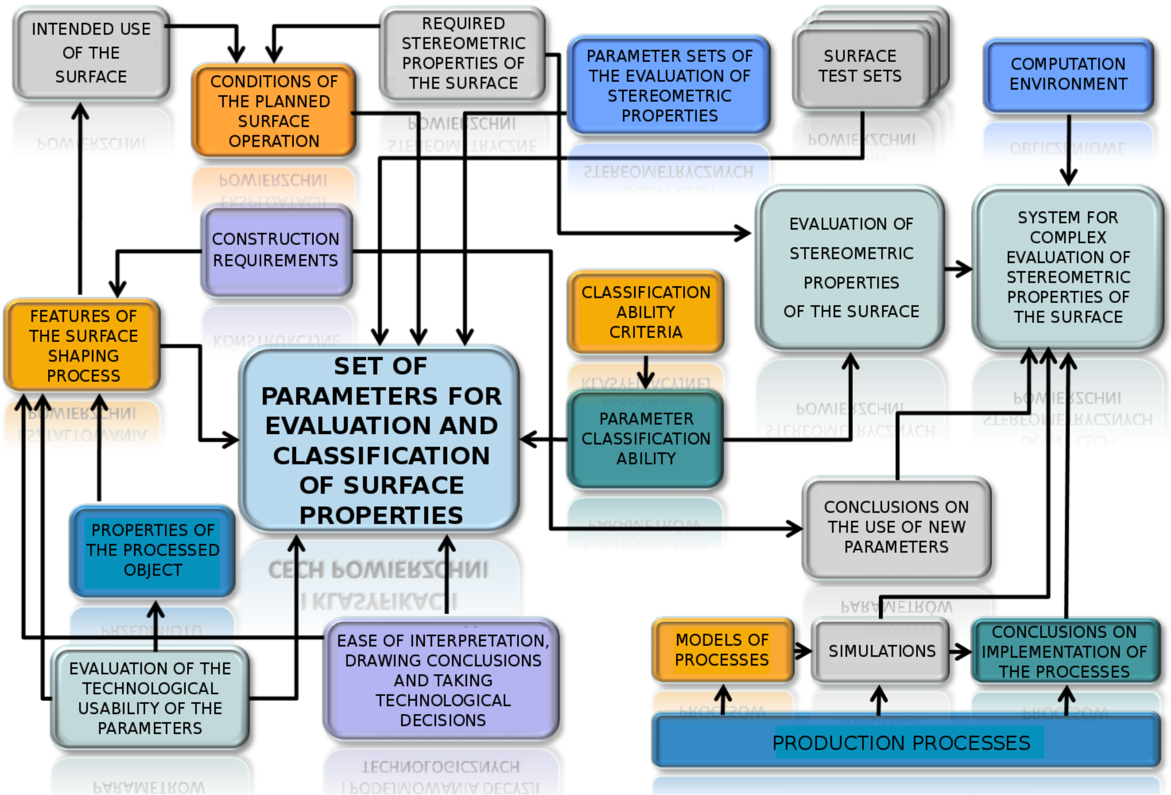

Fig. 1. Chart for methodology of the selection of parameter set with high classification ability [8]

The study investigated the variability of indices evaluating the classification ability of the parameters characterizing stereometric features of technical surfaces, depending on the type of parameter value distribution. Eight distribution types of the parameter value were taken into consideration. Variance and geometric mean of parameter value differences were assumed as classification ability indices. In particular, the existence, type and strength of relationships between the assumed parameter values for individual distributions and for all cases together were evaluated. Moreover, the effect of minor parameter value differences on variance and geometric mean of the differences was analysed.

2. PARAMETER CLASSIFICATION ABILITY

The classification issues are widely discussed in the literature, particularly in the technical and economic fields. Both general statistical tools, such as estimation, hypothesis verification and discriminant analysis [9],[10],[11], through methods directly related to technical object classification [12], to methods directly related to the quality analysis of technical products, including the method of classification ability of parameters evaluating topography characteristics of surfaces after processing [1],[6],[13],[14],[15].

For the evaluation of product surface quality, a variety of parameters are used, which are based on the results of measurements of certain surface features. The parameters proposed in the literature do not make it possible to compare different surface types unambiguously. Furthermore, numerous examples of completely different surfaces can be demonstrated, which are indistinguishable by the generally used parameters [2]. Thus, a question arises on the selection of such parameters or groups of parameters, which will enable the best technical object classification possible.

The use of the same parameters for evaluation of surfaces with different topographic structures may lead to incorrect conclusions on the real surface status. It is particularly visible for surfaces with low values of roughness parameters, in which e.g. surface waviness, motif features and others begin to play more significant role.

The technological importance of individual parameters depends on the correlation level of their values and parameters describing the forming process of the processed surface and parameters determining the tool properties and other processing characteristics Studies have shown, that in many cases the parameters with high classification ability also have high technological importance [16].

In order to enable the comparison of different parameters it is favourable to normalize these parameters. Certainly, this process has an effect on the distribution of each individual parameter, resulting in a loss of certain information on relationship between the dispersion measure and the position measure, which contribute a significant information on the classification ability of a parameter. In general, normalization can be performed using the following formula:

$$P_{j_i N} = \frac{f\left(P_{j_i}\right) - f(P_{j\,min})}{f(P_{j\,max})},$$

where f is a certain function, P_{j_i} is i-this value of parameter P_j, $P_{j_i N}$ the same value after normalization, whereas $P_{j\,min}$ and $P_{j\,max}$ are the respective lowest and highest values of the parameter P_j. After the normalization of the values of parameter P_j are without units and belong to the interval $\langle 0,1\rangle$. In the conducted analyses the identity function f was assumed, i.e. $f(P_{j_i}) = P_{j_i}$.

As shown by the study [16], the classification ability of the parameter P_j increases as the distribution of probability of its value approaches uniform distribution. Thus, an ideal situation can be assumed, in which differences between the successive values of the parameter P_j for individual surfaces are equal, i.e. for each $i = 0,1,\dots,n+1$ we have $\Delta P_{j_i} = P_{j_{i+1}} - P_{j_i} = \frac{1}{n+1}$, where n is the number of studied surfaces and $P_{j_{n+1}} = 1$.

A question arises, in what way classification abilities of individual parameters should be compared. Because the sum of all differences of values for the normalized parameter P_j is equal to 1, it is not possible to compare parameters following the Loewner order [17]. However, it is possible to compare them using one dimensional measures. Assuming, that the measure of classification ability of a parameter is the level of equalization of the differences between successive values of the parameter, it seems natural to recognize difference variances ΔP_{j_i} (determ. $Var(\Delta P_{j_i})$) as the natural index enabling comparison of normalized parameters. If values of the differences approach equalization, the variance will approach zero.

However, the use of variance is unfavourable due to the fact that it constitutes the mean value of square deviations, which is linked to all disadvantages of arithmetic mean. Another possible measure of classification ability is geometric mean of differences $Sg(\Delta P_{j_i})$. In the situation, where values of the differences are equalized, geometric mean approaches arithmetic mean, which in this case is equal to $\frac{1}{n+1}$. From the mathematic point of view, geometric mean seems to be better index of value equalization. A certain shortcoming of geometric mean is posed by the fact that it is equal to 0, when one of the elements is equal to 0, independent of the variability of the remaining values. A possible solution is adding a very low ε to each value. The assumed ε should be low enough to not influence the Sg value (e.g. $\varepsilon = \frac{1}{1000n}$). More on this topic can be found in the study [8].

The evaluation of classification ability of individual parameters can be carried out using the following methodology:

1. Selection of surface model set characteristic for a given processing type.
2. Determination of values of the considered parameters for all surfaces included in the test set.
3. Normalization of parameter values to the interval $\langle 0,1\rangle$.
4. Visualization of the normalized parameter values e.g. in a radar graph.
5. Sorting out values for each of the parameters Pj and determination of differences for the following values of individual parameters $\Delta P_{j_i} = P_{j_{i+1}} - P_{j_i}$.
6. Determination of $\varepsilon \ll \Delta P_{j_i}$ value for each i.
7. Determination of geometric mean for all corrected ΔP_{j_i}

   $Wsk_{klas} = \left(\prod_{i=1}^{n}(\Delta P_{j_i} + \varepsilon)\right)^{\frac{1}{n}}$, for all parameters P_j.
8. Value $0 < Wsk_{klas} < \frac{1}{n+1}$. is the index for classification ability of the parameter j. Classification ability increases with the value Wsk_{klas}.

3. OF GEOMETRIC MEAN AND VARIANCE AS INDICES OF PARAMETER CLASSIFICATION ABILITY EVALUATION

The objective of the study is examination of variance and geometric mean ΔP_{j_i} variability depending on different distribution types ΔP_{j_i} and finding the relationship between variance and geometric mean ΔP_{j_i}. Moreover, the study shows the influence of low ΔP_{j_i} values on the value of variance and geometric mean. For the number of values of the parameter P_j equal to n=20, eight distribution types ΔP_{j_i} were taken into consideration: type 1 - single, two and three point distribution, type 2 - few low and many high ΔP_{j_i}, type 3 - many low and few high ΔP_{j_i}, type 4 - many mean values ΔP_{j_i} and few extreme, type 5 - few mean values ΔP_{j_i} and equalization of extreme values, type 6 - few mean and low values ΔP_{j_i} and many high, type 7 - many low values ΔP_{j_i}, whereas few of the remaining values, type 8 - distribution ΔP_{j_i} uniform or almost uniform. For each distribution type six to eight examples were analysed. By way of simplification, without a loss of generality the possibility $\Delta P_{j_i} = 0$ was omitted, which allowed for analyse of the Sg value (ΔP_{j_i}) instead of Wsk_{klas}.

For the distribution type 1 ΔP_{j_i} a single point distribution was taken into consideration for ΔP_{j_i} =0.05, five two point distributions for $\Delta P_{j_i} \in \{0.045;0.055\}$, $\Delta P_{j_i} \in \{0.04;0.06\}$, $\Delta P_{j_i} \in \{0.02;0.06\}$, $\Delta P_{j_i} \in \{0.043;0.08\}$, $\Delta P_{j_i} \in \{0.038;0.1\}$ and five three point distributions for $\Delta P_{j_i} \in \{0.045;0.05;0.055\}$, $\Delta P_{j_i} \in \{0.04;0.05;0.06\}$, $\Delta P_{j_i} \in \{0.04;0.05;0.07\}$, $\Delta P_{j_i} \in \{0.04;0.045;0.08\}$, $\Delta P_{j_i} \in \{0.035;0.04;0.1\}$. For all the cases a minor variability of variance and geometric mean occurs, which is presented in Fig. 2.

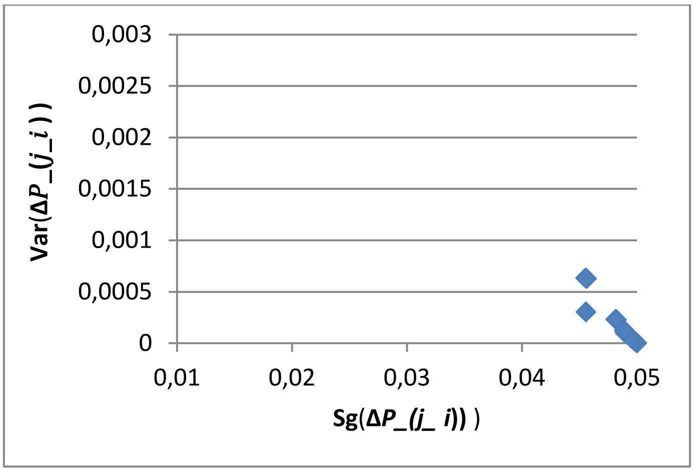

Fig. 2. Dependency of Var (ΔP_{j_i}) on Sg(ΔP_{j_i}) for type 1 distribution

Location of points on the graph suggests existence of relatively strong, inversely proportional linear relationship between geometric mean and variance. On the basis of the above sets ΔP_{j_i} it can be observed, that onlu in the fourth of the provided examples ΔP_{j_i} <0.02 occur. Then, the value of geometric mean is at its lowest in this group of distributions and amounts to 0.0456. Distributions ΔP_{j_i} in this class correspond to uniform or almost uniform distributions for the parameter value P_j. Following the earlier considerations, the geometric mean values are in this case highest among all the considered values and are close, or equal to, their theoretical maximum. At the same time, variance ΔP_{j_i} is at its lowest among all the considered cases. Therefore, the discussed distribution type ΔP_{j_i} corresponds to the parameter P_j with the highest classification ability.

Eight examples were analysed for type 2. Also in this group a minor variability of variance and geometric mean occurs, however, Var(ΔP_{j_i}) is higher, and Sg (ΔP_{j_i}) is considerably lower than for type 1. The below graph suggest existence of weak relationship between both indices (Fig. 3) Here, the number ΔP_{j_i} <0.02 is equalized and amounts to 3 or 4. In two cases, when this number is equal to 3, the Sg (ΔP_{j_i}) value is high, and in one of them is at its highest. Similar results were obtained for type 6.

Eight examples were analysed for type 3 distribution. Here, the highest variance and geometric mean variability occurs, and Var(ΔP_{j_i}) values are high and Sg(ΔP_{j_i}) average or low. It is difficult to determine the existence of relationship between both studied indices on the basis of Fig. 4. The number ΔP_{j_i}<0.02 amounts here from 7 to 10. When the number is at its lowest, Sg(ΔP_{j_i}) value is highest, and Var(ΔP_{j_i}i) lowest. When the population number ΔP_{j_i}<0.02 amounts to 10, Sg(ΔP_{j_i}) value is lowest, whereas Var (ΔP_{j_i}) attains one of the highest values. In the discussed case, values of both studied indices deviate from the values obtained in the remaining example groups to a greatest extent.

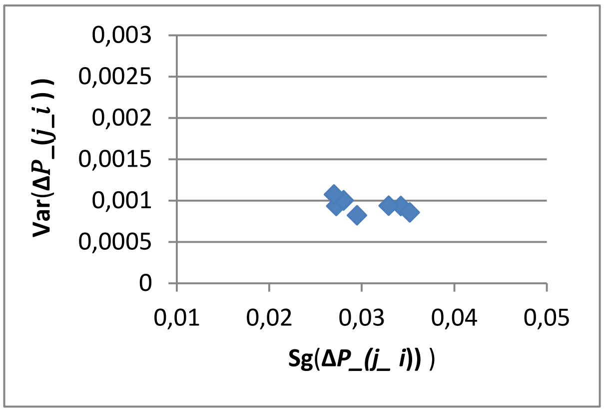

Fig. 3. Dependency of Var (ΔP_{j_i}) on Sg(ΔP_{j_i}) for type 2 distribution

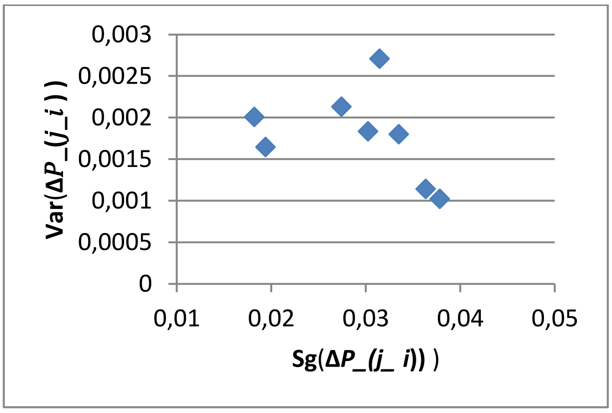

Fig. 4. Dependency of Var (ΔP_{j_i}) on Sg(ΔP_{j_i}) for type 3 distribution

Type 4 was analysed in the following group of six examples. As can be seen in Fig. 5, variability of the analysed indices was low, which can be related to i.a. identical number ΔP_{j_i}<0.02. In this case, a certain inversely proportional, linear relationship can be observed between Var(ΔP_{j_i}) and Sg(ΔP_{j_i}). The discussed distribution type ΔP_{j_i} is close to the uniform distribution of the parameter P_j value, which is followed by low Var(ΔP_{j_i}) value, high Sg(ΔP_{j_i}) value and high classification ability of the P_j parameter.

Seven examples were analysed for type 5 distribution. Fig. 6 can be interpreted by determining existence of strong linear, inversely proportional relationship between Var(ΔP_{j_i}) and Sg(ΔP_{j_i}). In the example, where number ΔP_{j_i}<0.02 is lowest and amounts to 6, Sg(ΔP_{j_i}) attains highest value, whereas when this value is highest and equal to 8, Sg(ΔP_{j_i}) has lowest value. An inverse relationship occurs for the population number ΔP_{j_i}<0.02 and Var(ΔP_{j_i}). Similar conclusions were obtained for type 7 distribution.

The last analysed case is type 8. In five examples the number ΔP_{j_i}<0.02 amounts to 4 and in one 5, for which Sg(ΔP_{j_i}) is lowest and Var(ΔP_{j_i}) is highest. Similarly to the previous distribution types, Fig. 7 allows determination of existence of strong inversely proportional relationship between Var(ΔP_{j_i}) and Sg(ΔP_{j_i}).

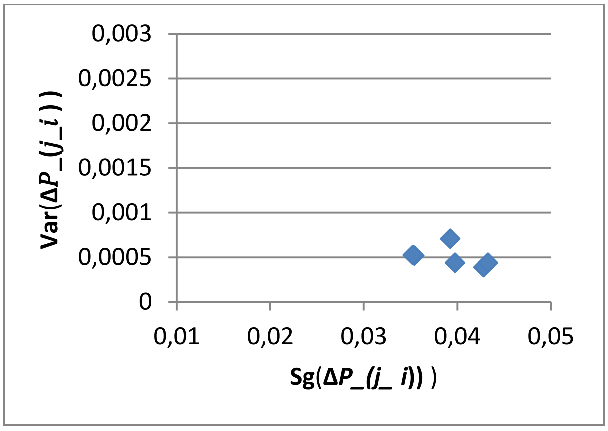

Fig. 5. Dependency of Var(ΔP_{j_i}) on Sg(ΔP_{j_i}) for type 4 distribution

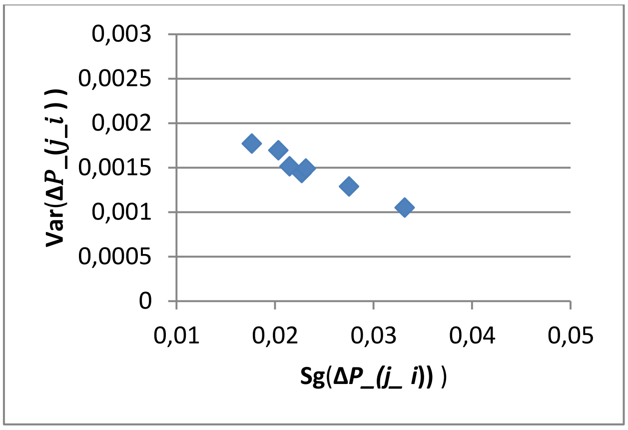

Fig. 6. Dependency of Var(ΔP_{j_i}) on Sg(ΔP_{j_i}) for type 5 distribution

The above conclusions regard considerations of all examples at the same time. This is illustrated by Fig. 8.

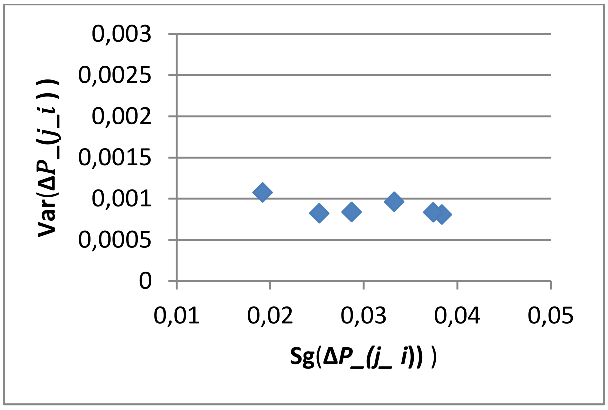

Fig. 7. Dependency of Var(ΔP_{j_i}) on Sg(ΔP_{j_i}) for type 8 distribution

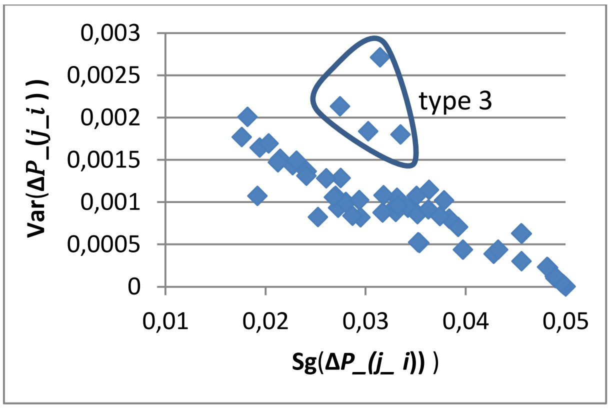

Fig. 8. Dependency of Var(ΔP_{j_i}) on Sg(ΔP_{j_i}) for all distribution types

Thus, it can be determined, that a strong, inversely proportional relationship exists between Var(ΔP_{j_i}) and Sg(ΔP_{j_i}) . As was mentioned earlier, picture of this relationship is distorted by the data from type 3 distribution, in which high number ΔP_{j_i}<0.02 occurs as indicated in Fig. 8. Moreover, it can be concluded on the basis of ranges attained by Var(ΔP_{j_i}) and Sg(ΔP_{j_i}), that geometric mean is more sensitive measure of parameter classification ability.

4. INFLUENCE OF LOW ΔP_{j_i} ON THE PARAMETER CLASSIFICATION ABILITY EVALUATION

Fig. 9 and 10 present relationship between the number ΔP_{j_i}<0.02 and Var(ΔP_{j_i}) and Sg(ΔP_{j_i}), respectively. They demonstrate existence of a strong relationship between these characteristics. If the relationship between the population number ΔP_{j_i}<0.01 and Var(ΔP_{j_i}) and Sg(ΔP_{j_i}) is analysed, even stronger relationship can be observed.

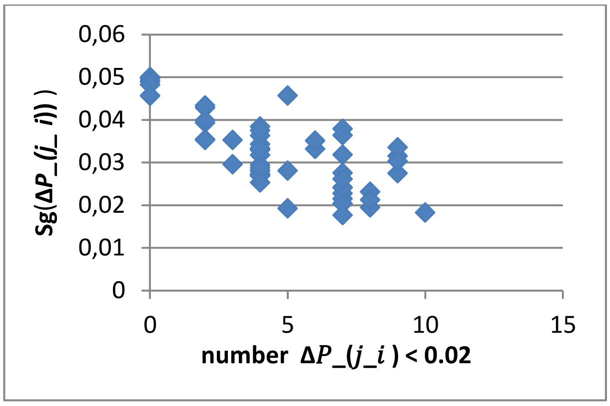

Fig. 9. Dependency of Sg(ΔP_{j_i}) on the population number ΔP_{j_i}<0.02 for all distribution types

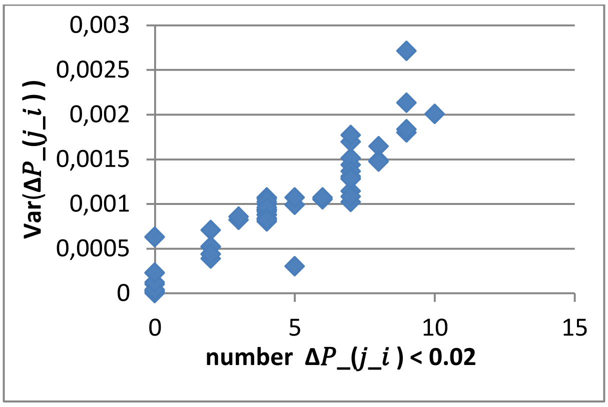

Fig. 10. Dependency of Var(ΔP_{j_i}) on the population number ΔP_{j_i}<0.02 for all distribution types

5. CONCLUSIONS

In summary, it can be determined that both Var(ΔP_{j_i}) as well as Sg(ΔP_{j_i}) are good indices determining parameter classification ability. However, the above presented analyses allow to conclude, that geometric mean constitutes better index due to higher sensitivity to different distributions of ΔP_{j_i} value. Furthermore, parameter classification ability is negatively influenced by the existence of high number of low or very low ΔP_{j_i} values. In particular, this refers to the evaluation using geometric mean. Thus, to evaluate classification ability of a selected parameter using variance and geometric mean, the population number of low ΔP_{j_i} should be also analyzed.

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