



METHOD OF PLANNING CMM SAMPLING STRATEGY FOR FREE-FORM SURFACES

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Abstract: Effective surface measurements of free-form surfaces were planned locating the measurement points in the areas of greatest deviations. Repeatability of deterministic deviations on surfaces processed under the same conditions was applied. A CAD model of the actual surface, built on the measurement points, and including the form deviations was constructed. An essence of mechanical-geometric filtration, regression analysis, spatial statistics methods, and NURBS modelling were applied.

Key words: coordinate measurement, free-form surface, sampling strategy, geometric deviation, CAD model

1. INTRODUCTION

An effective measurement is one in which the probability of locating the maximum deviation is highest with the smallest possible number of measurement points. The most commonly assumed basis of planning are geometric features of the nominal surface, such as the mean curvature or the Gaussian curvature, because, according to the authors, these factors determine the distribution of processing errors [1, 3]. However, the experience of the author of the present paper shows that, in many cases, this assumption is only partially convergent with the actual results of surface processing.

Because curvature is spatially variable at each point of a surface, the distribution of machining forces and other phenomena occurring during processing are also spatially variable [1, 3]. As an effect of this, the distribution of geometric deviations is of the same character. Deviations of a systematic (deterministic) character, i.e. deviations which are repeated on subsequent surfaces processed under the same conditions, as well as deviations of a random character, are observed on a surface. Deterministic deviations are spatially correlated however a lack of spatial correlation indicates their spatial randomness [4, 5]. Spatial statistics methods, including the most popular Moran's statistics which measures spatial autocorrelation, are applied to research on dependency of spatial data [5, 6]. Identifying spatial autocorrelation in measurement data proves the existence of deterministic deviations. In such a case, advanced CAD software for surface modelling may be applied to fitting a surface regression model representing these deviations. The first step in model diagnosing is to

examine the model residuals for the probability distribution and the existence of spatial autocorrelation. The Moran's test is also used for this purpose [4, 5, 6].

The present paper proposes an approach to planning coordinate measurements of geometric deviations of mass-produced object with free-form surfaces, consisting in using a surface CAD model built on the observed geometric deviations. In order to do this, the random component must be removed from the geometric deviations, and a model of the surface, which represents the deterministic (form) deviations, must be determined. Such a model can represent, with a specified accuracy, the form deviations of subsequent surfaces processed under the same conditions.

2. REMOVING THE RANDOM COMPONENT

2.1. The nature of geometric deviations of free-form surfaces

The components of geometric deviations connected with the form deviations and waviness are most often deterministic in character. The component connected with random phenomena, including the surface roughness, is irregularity of high frequency [7]. The spatial coordinates assigned at each measurement point include two different in nature components. The component connected with the deterministic deviations is spatially correlated. The random component, on the other hand, is weakly correlated and is considered to be of a spatially random character [3, 4]. The different nature of geometric deviations may be the basis for removing the random component from measurement data [5, 6, 7]. With proper selection of measurement parameters, the ball tip diameter and sampling interval [7], the measurement data represent the form (deterministic) deviations and inherent random effects.

2.2. Modelling of the surface representing form deviations

In order to create the surface model representing form deviations, the NURBS method was applied [8]. The input data in surface interpolation is a set of points forming a spatial grid of points. In the case under concern, the data were obtained from coordinate measurements during which a two-direction grid of measurement points was obtained. In developing the geometric model, the method of global

surface approximation was used. After the approximation stage was completed, shape modification iteration of the created surface patch was applied in the subsequent stages [8]. These operations aimed at obtaining an adequate model of regression surface, which would represent form deviations. In this case, popular procedures were applied of changing the NURBS surface shape.

2.3. Models' adequacy verification

The method of surface adequate regression model (representing form deviations) designing consists in iterative modelling of the surface model and in testing the spatial randomness of the model residuals at the consecutive iteration stages (as in [4]). In the subsequently constructed models, the number of control points and the surface degrees in both directions are changed. The model residuals are examined each step, and the maximum and minimum values, arithmetic mean (should be ~ 0), probability distribution (the distribution normality was verified with the Kolmogorov-Smirnov test), and the spatial autocorrelation coefficient are determined. The model with the smallest number of control points and the lowest surface degrees in the U and V directions, for which the model residuals met the criteria of a normal distribution and of spatial randomness, is adopted as an adequate one.

3. EXPERIMENTAL RESEARCH

3.1. Scanning the surfaces and constructing deviation models

The experiments were performed on free-form surfaces of a workpieces made of aluminium alloy obtained in the milling process. The measurements were carried out on a Global Performance CMM.

The method was presented on ten nominally the same surfaces processed under the same conditions. In the first stage, measurements of all the surfaces along regular grid with the UV scanning option were made. Statistical parameters of the obtained sets of deviations were determined, and tests for randomness were performed. The tests showed spatial autocorrelation of the measurement data, which indicated the presence of form (deterministic) deviations on the surfaces under research.

In the second stage, surfaces representing form deviations were modelled on the obtained measurement data (Section 2). For all the tested samples the model with the smallest number of control points and the lowest surface degrees in the U and V directions, for which the model residuals met the criteria of a normal distribution and of spatial randomness, was adopted as an adequate one. In all the cases the criterion was met for the number of control points amounting to 15×15 , and the number of surface degrees being 3×3 . Earlier comparative studies have shown that the constructed models of form deviations are similar for all the tested samples with an accuracy of $\pm 4 \mu\text{m}$. The first determined model was adopted as a representation of the surfaces of form deviations.

3.2. Distribution of measurement points

For further tests, the first determined model was used to plan the distribution of measurement points on subsequent surfaces. A small number of points located in areas of greatest deviations along a regular grid is sufficient for this purpose (the effect of mechanical-geometric filtration were taken into account, 9 points were distributed).

3.3. Measurements

The model represents surface deviations and therefore it can be used for virtual fitting to the nominal CAD model in order to localization the object coordinate system for the process of measuring a simple form deviation of subsequent surfaces. The results of measurements made using proposed method were compared to the results of scanning the whole surfaces. Differences in the results of measurements were at the level of hardware uncertainty.

4. CONCLUSION

On the basis of the developed model, it is possible to predict the location of areas of maximum geometric deviations, generating measurement points and carrying out the measurement on subsequently produced objects. Applying the developed model in measurements significantly increases the effectiveness of the designation of form deviations of surfaces. A small number of points located along a regular grid in critical area is sufficient for the purpose of accuracy inspection.

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