M. HADŽISTEVIĆ, B. ŠTRBAC, V. SPASIĆ JOKIĆ, M. DELIĆ,
M. SEKULIĆ, J. HODOLIČ

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FACTORS OF ESTIMATING FLATNESS ERROR AS A SURFACE REQUIREMENT OF EXPLOITATION

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This study considers the impact of surface quality (surface roughness) on estimating flatness error when measurements are performed using coordinate measuring machine (CMM). Flatness error is estimated using various association methods and various sample sizes, while the distribution of sample points is done randomly on a flatness feature using the random number generator in Matlab. ANOVA is used for determining the significance of differences between the observed groups. It has been determined that the estimate of flatness error is affected by the processing method, the number of sample points and associative method used, but not by surface roughness.

Key words: roughness, surface, flatness, error, CMM

INTRODUCTION

Geometrical characteristics of a surface quality can be classified into four basic types. This classification is presented in a 2D coordinate system in Figure 1. The horizontal coordinate is the lateral resolution of an appropriate measuring technique used, while the vertical coordinate represents the metrological dimension. The considered characteristics have similarities and differences considering the lateral resolution and metrology dimension. For instance, 3D surface form error and flatness error measured by a CMM have different metrology dimensions, but their lateral resolution level is the same. Such analyses can be carried out on all four types of geometrical surface characteristics: 3D surface texture, 3D surface form error, 2D surface texture and flatness measured by a CMM.

FLAT SURFACE FITTING

One of the greatest demands set for the metallurgy by engineers is the development of constructive steel that meets a complex combination of exploitation requirements, and that is produced in a technologically reasonable manner. Strength, hardness and ductility (toughness) are the basic mechanical steel properties which are directly dependent on the carbon content [2].

Apart from these, workpiece exploitation requirements are affected by the deviations from the ideal form that appear as a result of processing a workpiece surface.

These deviations disable creating the ideal surface fittings. Thus various form and position tolerances are being widely used, depending on functional needs.

Standard ISO 1101 defines the flatness tolerance, but does not include information related to limitations of bandwidth (upper and lower wavelength cut-off), filters and associative methods. These parameters are included in GPS standards, while the proper parameters selection for particular measurement needs an experienced CMM operator. This very concept is aimed to eliminate the subjective influence of CMM operator on the accuracy of estimating form deviations. It significantly contributes to the importance of selecting sampling strategy as the research area.

An exact description of real geometry requires an infinite number of points in the measurement strategy. A real geometrical primitive is estimated by a finite set of measuring points. Selected locations of sample points

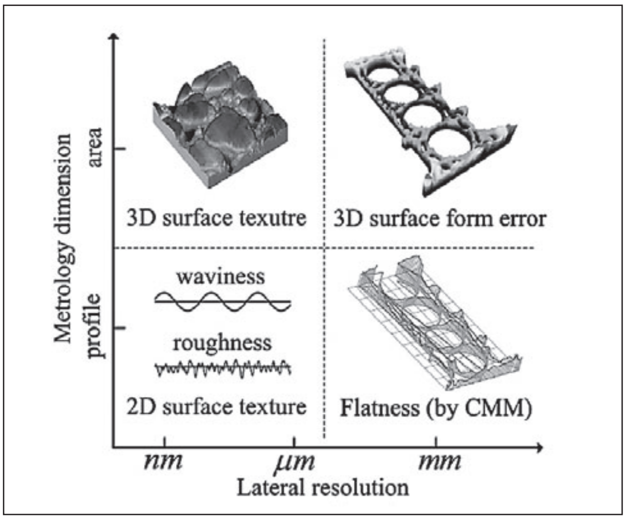

Figure 1 Classification of surface geometrical qualities [1]

M. Hadžistević, B. Štrbac, V. Spasić Jokić, M. Delić, M. Sekulić, J. Hodolič, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

should enable the necessary precision in terms of flatness error bound for a minimum cost [3]. Researchers use uniform, random and stratified allocation of sampling points (measuring strategies) [4]. Apart from these, some of the researchers use grid strategy which is adjusted to GPS, or adaptive strategies [5-7]. There are also strategies used mainly for estimating flatness, like Hammersley sequence and Halton-Zembra sequence [8]. Lee et al. showed that Hammersley's strategy is more successful than uniform or random strategy for measuring planes, cylinders, cones or spheres [3]. In studies [9,10] the authors suggested adaptive sample strategies based on the knowledge about the production process and its technological signature.

Many pairs of assembled workpieces can have at least one shared plane surface, while any significant deviation from the ideal plane out of tolerance can lead to distortion or asymmetric fitting. Thus, accuracy of flat surfaces fitting is often critical for the product quality.

Unfortunately, real surface is neither flat, nor smooth. It implies that flatness and roughness should be within the pre-defined tolerance limits. 2D profile of real processed surface is given in Figure 2.

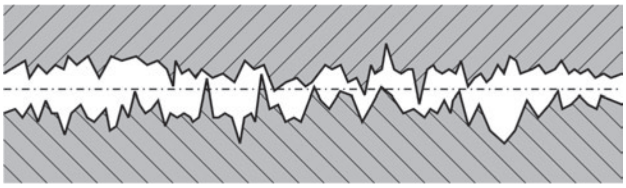

Figure 2 2D profile of two real processed surfaces in contact

The objective of this research was to determine the significance of various factors, like the processing method used for workpiece production and sample size, on measuring flatness result. The measurements were carried out on a small sample - only on five workpieces - for the purpose of getting the initial idea on the nature of the considered relations and defining the directions for further research, as described in the conclusions section of this paper.

EXPERIMENT

This research was based on evaluating the flatness errors using CMM and samples made of the same material - steel C55E. Out of five workpieces 90×90/ mm each, three had been processed by turning (using different machining parameters), one was milled, while one was subject to grinding. All of the workpieces had different surface quality levels, as shown in Figure 3.

Table 1 contains the machining parameters used and the surface quality of the panels used in the research.

The measurement of standard surface roughness parameter (Arithmetic average deviation from the mean line Ra) was carried out using surface roughness tester model Mahr Perthometer (MarSurf PS1, Mahr GMbH, Germany). Surface roughness was measured nine times

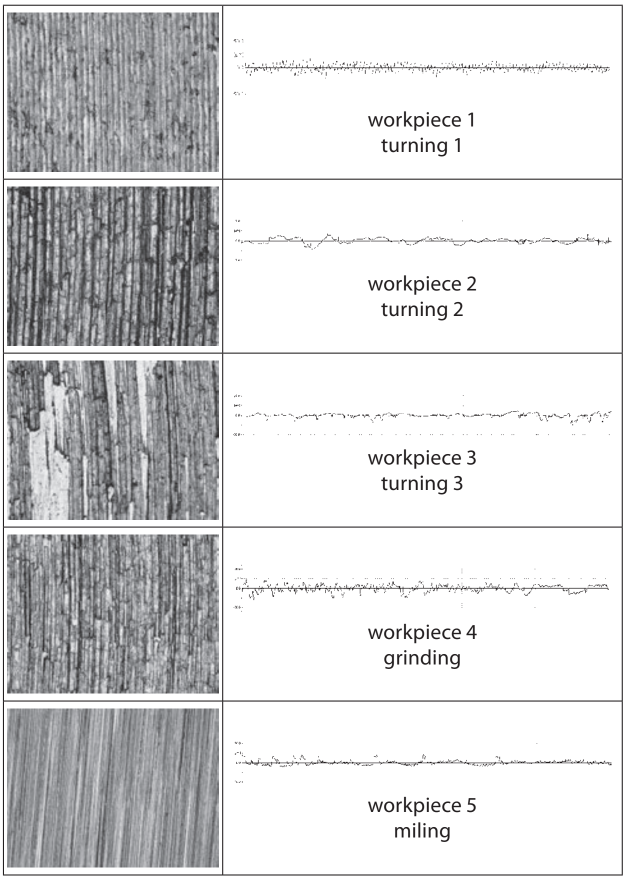

Figure 3 Surface photos and 2D profiles of workpieces used in the research and processing method used

Table 1 **Processing type and machining parameters**

	w.p. 1	w.p. 2	w.p. 3	w.p. 4	w.p. 5
Machining process	Tur. 1	Tur. 2	Tur. 3	Gri	Mil
Number of rev./ r/min	424	424	424	250	450
Feed/ r/min	0,25	0,10	0,06	-	-
Feed/mm/min	-	-	-	50	40
Depth of cut/ mm	1	1	1	1	1
Roug-hness Ra/ μm	4,12	2,89	1,58	0,53	4,14

and all the measured test values were averaged for each test.

Flatness error evaluation was carried out in accordance with the experiment plan, using CMM Carl Zeiss Contura G2 with a probe tip r=1,5 mm. The influence of the CMM errors was minimized by placing the workpieces in the same position during the tests. The positions of the measuring points on flatness features were determined using a random number generator and Matlab software package. Every point location was determined by a pair of independent x and y coordinates, while the third coordinate was determined by carrying out the measuring process. Each workpiece was measured five times, using plans with 10, 20, 40, 80, 160, 320, 640, 1280 and 2000 points respectively.

Filtering was carried out after the described measurements. The use of Gauss low-pass filter (cut-off =

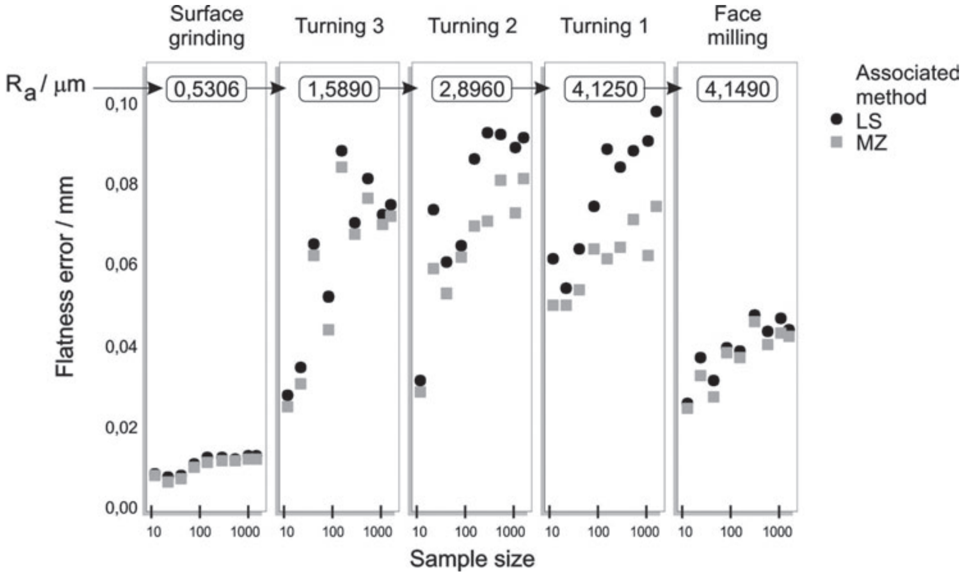

Figure 4 The impact of roughness, number of sample points and associative and processing methods used, on mean flatness errors, measured by CMM

2,5 mm) did not affect any of the flatness error measurement results.

RESULTS AND DISCUSSION

Figure 4 shows the interdependences of mean flatness errors, numbers of sample points, associated methods used and various roughness values of the measured surfaces.

Figure 4 shows that the flatness values estimated by the least square method are significantly higher than the values determined by the minimum zone method.

Further, it is notable that increasing the number of sample points increases deviations from flatness to some extent. Study [2] shows that, for a certain surface quality, it is possible to possible to determine a number of sample points sufficient to estimate flatness for a surface of certain dimensions. This study points to a different conclusion. Its results suggest that the estimate of deviation from flatness is affected by the number of sample points, but the surface quality does not seem to be another influential factor. It is also noted that the machining process has some influence on the estimate of deviation from flatness. Figure 2 also shows that the surface roughness of the milled part is significantly higher than with the parts processed by turning, but it is indicative that the flatness error values are quite smaller with the milled parts.

Carrying out a two factor ANOVA with the results of measuring three workpieces processed by turning showed no significant differences between the estimates of flatness errors ($p = 0,8$). It was also determined, as expected, that the number of sampling points is a source of variation ($p < 0,05$). The analysis was made for the results gained by MZ associative method and for the LS as well (the results are presented separately in Figure 2). The analysis shows that, in the described experimental conditions, various turning machining parameters are not a source of significant variation as far as flatness error is concerned.

Finally, it seems that the processing method is a significant source of variations when estimating flatness errors. This conclusion can be drawn just by observing figure 2. It is obvious that flatness errors estimated on the ground workpiece are significantly smaller than the ones estimated on workpieces processed by turning and milling. On the other hand, flatness error estimates of the turned surfaces are higher than the ones gained on the milled surfaces. The first are higher even when roughness values are nearly the same. ANOVA cannot be applied to support these conclusions because groups do not have the same variations.

CONCLUSION

The results of this research point to a conclusion that the quality of a surface processed by turning has no significant impact on estimating flatness error when measured with a CMM. However, it is recommended to carry out a series of more thorough research, using much larger samples and different machining parameters. Also, some research could be undertaken involving more processing methods, materials, and different measuring strategies. Finally, further research may have determining functional dependencies between surface roughness and estimating form errors as its goal.

This research revealed some clear indications that the quality of surface of a machined workpiece is not of significance when measuring form errors (flatness errors in this case).

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Note: The responsible translator for English language is V. Radlovački from University of Novi Sad, Serbia