REVIEW ON DEVELOPMENTS IN VARIOUS TECHNIQUES FOR FLATNESS TOLERANCE

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ABSTRACT: The enhanced development in manufacturing process is due to the use of Computerized Numerical Control (CNC) methods. It results in a high yield of manufactured products. Inspection and measurement system must be accurate enough to inspect the high-quality products given by manufacturing system. This increases the load on inspection system as they must validate the products. The development rate of the inspection and measurement system is low. Today, the measurement and inspection process takes more time for product inspection. Many researchers devoted themselves to improve the efficiency of measurement and inspection systems. This review comprises the research work done in various techniques for flatness tolerance evaluation. The concept of minimum zone method for flatness evaluation are discussed in the paper. The methods reviewed in this study were mainly applied in 3-axis point to point measurements so far and can be applicable for 5-axis measurements with some modification.

Keywords: CMM, Flatness evaluation, Minimum Zone solution, Sampling Method, Sample size

I. INTRODUCTION

To maximize product performance, inspection and measurement systems have recently been combined with CNC methods. These systems are now used to inspect products for geometric and dimensional tolerances. Measuring geometric tolerances is more difficult than dimensional tolerances and measured values are always approximate. The variation has occurred in two techniques, namely data acquisition and data fitting from an inspection and measurement system leading to approximate results. In recent years, researchers have focused on improving the performance of an inspection and measurement system. Parameters such as the sampling distance, the inspection plan, the dynamics of the inspection systems and the tolerance evaluation algorithms mainly affect the performance of the systems and reduce their efficiency.

In this article, the focus is on the development of various techniques to assess flatness tolerance. In many applications, Flatness tolerances are evaluated to verify the quality of the contact surfaces. The review contains several summarized techniques from the last two decades in flatness error evaluation and inspection strategy. Technologies are examined from the perspective of an inspection engineer. The rest of his works are organized like this. Developments in various techniques related to flatness tolerance assessment to improve the performance of measurement and inspection processes are discussed in Section 2. Section 3 contains conclusions drawn from the review conducted in this study on techniques for assessing tolerance to flatness. This section has also analyzed future research trends to further improve the performance of an inspection and measurement system.

DEVELOPMENTS IN FLATNESS TOLERANCE EVALUATION TECHNIQUES

Flatness is one of the most important and widely considered geometric tolerances in determining product quality. The flatness error is calculated by two general methods, namely the least squares method and the least area solution. Flatness tolerance assessment techniques play an important role in accurately assessing flatness tolerance. In recent years, many researchers have adapted new techniques to improve the assessment of tolerance to flatness. The results of these techniques are as follows:

Figure 2.1: One Point Plane Bundle Method (OPPBM) flowchart [1]

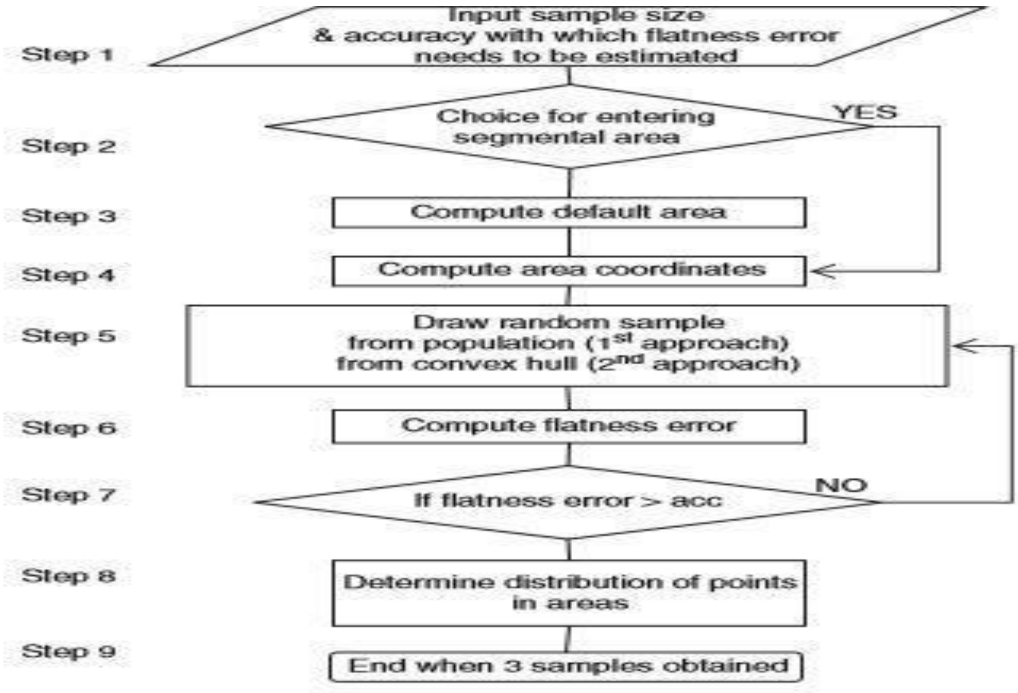
V. Radlovacki et al. [1] designed a new software model to evaluate the area-based minimum flatness error. The flatness error was calculated using reference planes passing through a point in a point cloud collected by CMM. The method is called One Point Flat Pack Method (OPPBM) and the flow chart is shown in Figure 2.1. The method is validated with data from the literature and experimental data measured by the CMM Carl Zeiss Contura G2 RDS equipped with the VAST XXT contact probe. The results show that the value of the flatness error estimated by OPPBM approaches the least squares method (LSM) and the minimum area (MZ) with an acceptable calculation time. The method can also be used to determine other shape errors, such as straightness, and can be used as an alternative to flatness error evaluation using CMM software.

X. Wen et al. [2] presented a method to evaluate the minimum area of flatness error and detect the uncertainty. An Enhanced Genetic Algorithm (IGA) is used for the evaluation of the minimum flatness error zone. The Guide to the Expression of Uncertainty in Measurement (GUM) and the Monte Carlo Method (MCM) were used to assess the uncertainty of the flatness error. The results of the presented method compared with conventional methods. The method gives more efficiency and precision with a simple algorithm presented.

P.V. Rao and. Al. [3] proposed a sampling strategy to evaluate the flatness error using the minimum area method, as well as to demonstrate that surface roughness has an impact on the sampling strategy. The Hammersley sequence is used for the sampling strategy and the measurement area is assumed to be a unit square; The sample points are then calculated using the sequence formula. The experiment consists of three different parts with different roughness values inspected with CARL ZEISS CMM. The data is then transferred to MATLAB to find the minimum flatness error area solution. The result shows that the sample size increases with increasing surface roughness value.

P.V. Rao et al. [4] proposed an algorithm as shown in figure 2.2 to find the optimal sample size for an accurate evaluation of the flatness error value. The method used for the sampling plan is the Hammersley sequence. The experiment consists of a measurement on two identical specimens machined under the same working conditions by CARL ZEISS CMM. The flatness value is calculated using the minimum area solution that is based on the QHULL computational geometry algorithm in MATLAB. The result shows that the flatness value can be estimated in a small sample size with reasonable precision. This study allows determining the process capacity of the manufacturing systems.

Figure 2.2: Algorithm to find optimal sample size [4]



J. Huang [5] developed an algorithm using three theorems to obtain the error of straightness and flatness without generating a complete convex envelope. The algorithm eliminates redundant data points and generates an optimal solution using a small number of data points. The algorithm is validated by two examples for each straightness and flatness error. For a problem with a large number of data points; the algorithm works efficiently using theorems.

H. Ding et al. [6] proposed an algorithm for the evaluation of the flatness error in which the minimum area is formulated as a linear programming problem. The algorithm calculates the flatness error in time O (n). The algorithm is compared with existing methods, such as the least squares and convex envelope methods from the literature. The proposed algorithm is efficient and easy to implement and produces an approximate minimum area solution with desirable precision.

S. Raman et al. [7] carried out an experiment of statistical analysis of the sampling strategy to evaluate the flatness error. The two-factor ANOVA is used as a statistical analysis method with two factors, sampling methods and sample size. The four sampling methods and the five different sample sizes are considered factors in the design of the thirty-replica plate experiment. The sampling methods are Hammersley sequence, Halton-Zaremba sequence, aligned systematic sampling, and systematic random sampling. The precision and length of the probe path give a priority factor in deciding the sampling method and sample size. Analysis shows that the Halton- the Zaremba sequence or systematic random sampling gives a high precision of the flatness error.

MS. Shunmugam et al. [8] presented an algorithm for the minimum area and the evaluation of the function-oriented straightness and flatness. The algorithm is based on computational geometry techniques. The algorithm is validated with the results of the literature. The algorithm offers a unique solution in less time and less complexity.

J. Mou et al. [9] proposed a feature detection-based method that uses the Hammersley sequence and a stratified sampling method to generate a sampling plan based on specific data points. Case studies are used to compare the results of the proposed method. The results show that reducing the number of samples derived from the proposed method reduces time and cost, while maintaining the desired level of precision.

Q. Liu et al. [10] studied the effects of CMM measurement error in estimating geometric tolerance. Least squares and Min-Max uncertainty algorithms were used to estimate geometric tolerances. The study indicates that the performance of the algorithm is based on the effect of CMM measurement error on the processing of CMM data.

CONCLUSIONS

The review indicates that the researchers focused on techniques related to sampling strategies and evaluation of the minimum area solution. Methods like OPPBM, IGA and QHULL give a minimum area solution with the desired precision.

These methods take sufficient time to provide a solution and can be applied with less complexity. In determining the sampling plan, factors such as the manufacturing process, cutting tool, part material, and surface roughness must be considered. An ANOVA was performed for two factors, namely the sampling method and the sample size. This method shows the effects of these two factors on the flatness error. In the analysis results, two sampling strategies considered as solutions give a precise flatness error. The number of sampling points is directly proportional to the roughness of the measurement surface. The methods presented in the review were applied for the point-to-point measurement process. 3-axis measurement systems were used to measure the area and generate a point cloud. The the accuracy of the flatness error also depends on the measurement system. The 5-axis measurement system is new and more accurate than the 3-axis measurement system. No significant research work was found on the evaluation of flatness tolerance using a 5-axis measurement system. The method given in the review can be modified and applied to assess flatness tolerance using 5-axis measurement techniques, such as point-to-point and sweep measurement process.

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